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PUBLIC UTILITIES  
COMMISSION

The Honorable Chair and Members of the  
Hawai'i Public Utilities Commission  
465 South King Street  
Kekuanaoa Building, 1st Floor  
Honolulu, Hawai'i 96813

Dear Commissioners:

Subject: Docket No. 2011-0092 – Maui Electric 2012 Test Year Rate Case  
Maui Electric Power Supply Improvement Plan

Today, the Hawaiian Electric Companies<sup>1</sup> are filing separate Power Supply Improvement Plans (“PSIPs”) in designated dockets.<sup>2</sup> Attached hereto is Maui Electric Company, Limited’s Power Supply Improvement Plan (“PSIP”).

The PSIPs present the results of extensive planning in accordance with direction and guidance from the Hawai'i Public Utilities Commission (“Commission”) and provide a basis for Hawai'i to continue to attain a clean, secure and affordable energy future. Collaboration with our customers, stakeholders, regulators, and policy makers is essential to achieving a shared vision for Hawai'i's energy future.

The PSIPs each include a tactical plan (the “Preferred Plan”) to transform how electric utility services will be offered to meet customer needs and produce higher levels of renewable energy. The Preferred Plan is based on sound physics, engineering, and utility operating principles. Each is a diversified mix of technologies including significant distributed and utility-scale renewable resources that will result on a consolidated basis in over 65% of the Companies’ energy being produced from renewable resources by 2030 – the highest Renewable Portfolio Standard goal in the nation.

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<sup>1</sup> The “Hawaiian Electric Companies” or “Companies” are Hawaiian Electric Company, Inc., Hawai'i Electric Light Company, Inc., and Maui Electric Company, Limited.

<sup>2</sup> In Order No. 32053, Ruling on RSWG Work Product, filed April 28, 2014 in Docket No. 2011-0206, the Commission ordered Hawaiian Electric to file a PSIP within 120 days of the date of the Order. In Decision and Order No. 32055, filed April 28, 2014 in Docket No. 2011-0092, the Commission ordered Maui Electric to file a PSIP within 120 days of the date of the Order. See Order No. 32053 at pages 91-105 and Decision and Order No. 32055 at pages 86-94. Hawai'i Electric Light is filing an update to its PSIP filed on April 21, 2014, pursuant to Decision and Order No. 31758, filed December 20, 2013 in Docket No. 2012-0212. See page 2 of June 4, 2014 letter from Hawai'i Electric Light to the Commission, filed in Docket No. 2012-0092. On August 7, 2014, the Commission filed Order No. 32257, which opened a new proceeding (Docket No. 2014-0183) for the purpose of reviewing the Hawaiian Electric Companies’ PSIPs. The PSIPs filed in the individual dockets will be transferred to this new docket.

## April 28, 2014 Decisions and Orders

The PSIP is one of a series of plans and reports ordered by the Commission on April 28, 2014.<sup>3</sup> On that date, the Commission issued four important orders that collectively address key policy, resource planning and operations issues for the Hawaiian Electric Companies (“April 28 D&Os”) and included a white paper titled the “Commission’s Inclinations on the Future of Hawaii’s Electric Utilities.” In its Inclinations, the Commission emphasized the need for the Companies to “leap ahead” of other states in creating a 21st century generation system, and modern transmission and distribution grids. The Commission stated that it “views the objectives of lower, more stable electric bills and expanding customer energy options, while maintaining reliable energy service in a rapidly changing system operating environment, as essential principles that are the foundation for the future strategic business direction of the HECO Companies.”<sup>4</sup>

### The Results

The PSIPs align with the Commission’s guidance. The PSIPs establish a path to electric systems that will:

- Lower full service residential customer bills more than 20% by 2030;
- Result in more than 65% of the Companies’ energy being provided by renewable resources;
- Nearly triple the amount of distributed generation (“DG”), such as rooftop solar, that can be installed across our service territories in the future;
- Accommodate a large portfolio of lower-cost utility-scale renewable energy resources;
- Result in retirement of higher-cost, less efficient existing oil-based steam generators;
- Utilize energy storage and demand response to minimize the amount of “must-run” fossil-fueled generation needed to provide essential grid services;
- Increase the operational flexibility of generation resources;
- Utilize liquefied natural gas (“LNG”) to substantially reduce fuel costs and meet environmental regulations; and
- Create a state-of-the-art energy delivery system (the grid) as the platform for the new energy portfolio and customer options.

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<sup>3</sup> In addition to the PSIPs, the April 28 D&Os required the Companies to file several other plans and reports, including a Distributed Generation Interconnection Plan (also filed today); a Plan to implement an on-going distribution circuit monitoring program; an Action Plan for improving efficiencies in the interconnection requirements studies; a Proposal to implement an integrated interconnection queue for each distribution circuit for each island grid; an integrated Demand Response Portfolio Plan that will enhance system operations and reduce costs to customers.

<sup>4</sup> Inclinations at page 3.

## **The Approach**

The PSIPs are the product of the rigorous evaluation of complex and interrelated objectives. First, the Companies utilized a clean-slate approach to identify what an optimal generation portfolio would be in 2030. This involved considering several different possible options, including a least-cost option (“least cost approach”), an option balancing cost and increased renewable generation (“balanced portfolio”), and an option in which 100% renewable generation would be achieved (“100% renewable”). Each option involves choices and tradeoffs. The options were measured against various criteria, including the core objectives of lowering costs, increasing interconnection of a diverse portfolio of renewable energy resources, ensuring safety and reliability and increasing customer choices. While each of the options considered is achievable, the Companies believe the balanced portfolio – that is, the Preferred Plan – represents the optimal energy mix.

Second, the Companies defined and validated a detailed year-by-year path to transform the current system into a system to achieve the balanced portfolio. This involved applying industry accepted planning methods that take into account existing system conditions, reliability and cost considerations.

The approach and models considered the potential tradeoffs involved. The Companies considered numerous assumptions and forecasts critical to the analyses, and utilized comprehensive computer production models to analyze alternatives. As with any planning process of this magnitude, these forecasts and assumptions may or may not be borne out. But, uncertainty about the future cannot paralyze our planning. Therefore, the Companies made supportable assumptions in order to develop the plans. The Preferred Plans are flexible and can be adjusted based on changing conditions. The Preferred Plans can be immediately implemented using technologies available today. However, they are flexible and the mix of resources can be changed in response to future system conditions that differ from those assumed today.

The Companies further acknowledge that selecting the path forward is heavily dependent on policy and societal considerations, and those are not the Companies' alone to decide.

## **The Physical Design**

The physical design of the Companies' proposed electric systems in 2030 will reflect the growth of renewable and distributed generation, supported by a switch from oil to LNG, and enabled by a modern, highly functional, “smart” transmission and distribution grid. This is designed to lower generating costs, making customer bills more affordable.

## **Transformation to a high-renewable, lower-cost generation mix**

A critical part of the Companies' generation transformation involves increasing our use of low-cost renewable energy on the islands to become a national leader with more than 65%

renewable generation. Today, Hawai'i generates more than 85% of its electricity with fossil fuel. The Companies envision a more balanced energy resource portfolio in 2030 that will include an approximate tripling of distributed photovoltaic solar ("DG PV") and a significant level of both utility-scale intermittent and firm renewable sources. The Companies plan to leverage the unique resource characteristics of the different islands and integrate optimal levels of wind, solar, geothermal and other renewables sources to reduce generation costs. Energy storage and demand response will play integral roles in the grid of the future, while the role of fossil fuels will continue to diminish. LNG-fired generation will still be required to cover residual demand in times when renewable generation is not available or cannot be supplied through cost-effective storage technologies. As a result, this new generation mix will be more environmentally sustainable and less expensive compared with the conventional resource mix.

The new generation mix should help mitigate risks across several dimensions. In developing the Preferred Plans, conscious choices were made to blend resources that move the generation mix away from fossil-fueled resources. This was done, in part, to provide a financial hedge against fuel price volatility. The diversification of asset geography and technology increases system resiliency.

### **Preparation for LNG and optimizing generation retirement plans**

To stabilize and lower customer bills, the Companies will develop and implement plans to reduce fuel costs in the generation portfolio. A critical step in this strategy is replacing high-cost oil-based fuel with cleaner, lower-cost LNG. Renewable energy, while increasingly cost-effective in Hawai'i, can replace much, but not all, of the fossil fuel-based generation because of its intermittent nature. LNG, however, is a firm generation fuel source that is cheaper, cleaner, and potentially more stable in price than the current fuel mix. LNG will also present the opportunity to optimize the existing thermal generation fleet for the benefit of customers. Plans include converting existing units to burn LNG (hence postponing the capital investment required for a new unit), retiring existing units on more aggressive schedules, and establishing new, highly-efficient and fast-ramping LNG-related generation technologies. The Companies will pursue a cost-effective retirement plan for current oil-based thermal assets.

### **Ensuring a reliable and resilient generation portfolio**

The Companies will maintain a safe, reliable and resilient electric power system during this generation transformation. A balanced portfolio of firm, intermittent, utility scale and distributed generation and storage will mitigate system risks related to reliability and resiliency. The Companies will continue to ensure a high level of system reliability under the new, higher-renewable regime, using as ancillary services both generation units and grid services tools, such as energy storage technologies and demand response. The high use of intermittent generation requires more reserves and increased frequency control. The Companies will continue to explore ways in which renewables can provide these system reliability reserves and further reduce dependency on thermal resources.

### **Exploring opportunities provided by new technologies**

To deliver the most value to our customers, the Companies must continue innovating, exploring, and evaluating new technologies for a cleaner generation system with competitive and affordable costs for our customers and Hawai'i. The Companies acknowledge that the development and integration of new technologies requires flexibility in our planning and we will adapt the future generation mix and grid design as new technologies become commercially available and cost-effective.

### **Ensuring grid reliability and enhanced functionality**

The Companies foresee a fundamental change in how the grid operates. A comprehensive modernization of the grid is required to ensure the Companies can maintain and improve the reliability and resiliency of the system while integrating new sources of generation and customer products.

The first critical component of the Companies' grid investment plan is energy storage. To support the significantly increased amount of clean, intermittent renewable generation, the Companies plan to utilize a number of storage options, including using storage to provide ancillary services.

The second component of the Companies' grid investment plan is deploying new technology across the grid. The increased variability and greater geographic dispersion of generation requires increased levels of grid operation controls, based on real time visibility of grid conditions such as voltage, generator performance, and localized faults. The Companies will install a communications network to monitor and control the grid – including transmission lines, distributed generation, and storage sources – which will increase visibility and enhance outage management. This technology backbone will also encourage the addition of new technologies to the grid.

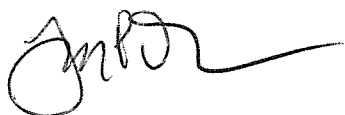
### **PSIPs are Part of Interrelated Plans and Vision**

The PSIPs and the other plans and reports filed in response to the April 28 D&Os are part of an overall strategy to continue the transition of Hawai'i and the Hawaiian Electric Companies into a clean energy future. The Companies' vision for the future is to deliver cost-effective, clean, reliable, and innovative energy services to our customers, creating meaningful benefits for Hawai'i's economy and environment. Achieving this vision will require an innovative and transformative utility whose business, regulatory and operating models are all aligned. In this dynamic environment, no single party can realize this future for Hawai'i or determine the utility

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August 26, 2014  
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model that best serves customers. For this reason, the Companies seek a shared vision for Hawai'i's energy future with our customers, stakeholders, regulators, and policy makers.

Very truly yours,



Joseph P. Viola  
Vice President  
Regulatory Affairs  
Hawaiian Electric Company, Inc.

Vice President  
Hawai'i Electric Light Company, Inc.  
Maui Electric Company, Limited

Enclosure

cc: Division of Consumer Advocacy

# Maui Electric Power Supply Improvement Plan

August 2014



Hawaiian Electric  
Maui Electric  
Hawai'i Electric Light

Maui Electric submits this Power Supply Improvement Plan to comply with the Decision and Order issued by the Hawai'i Public Utilities Commission on April 28, 2014 in Docket No. 2011-0092, Order No. 32055. The Companies retained Black & Veatch, Boston Consulting Group, Electric Power Systems, HD Baker and Company, PA Consulting Group, and Solari Communication to assist in the creation of this plan.

The Hawaiian Electric Companies created this PSIP based, in parts, on a realization of the current state of the electric systems in Hawai'i, forecast conditions, and reasonable assumptions regarding technology readiness, availability, performance, applicability, and costs. As a result, this plan presents a reasonable and viable path into the future for the evolution of our power systems. We have attempted to document and be fully transparent about the assumptions and methodologies utilized to develop this plan. We recognize, however, that over time these forecasts and assumptions may or may not prove to be accurate or representative, and that the plan would need to be updated to reflect changes. As we move forward, we will continually evaluate the impacts of any changes to our material assumptions, seek to improve the planning methodologies, and evaluate and revise the plan to best meet the needs of our customers.



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# Executive Summary

This Power Supply Improvement Plan (PSIP) defines Maui Electric’s vision for transforming the electric system to meet customer needs, implement the State of Hawai’i’s policy goals, and secure a clean and affordable energy future. Based on the Company’s ongoing strategic planning efforts, the PSIP includes a realistic, flexible and operable tactical plan (the “Preferred Plan”) that recognizes our collective goals and the realities of our situation. For Maui County, the PSIP increases renewable content of electricity to approximately 72% by 2030, and reduces full service residential customer bills, on average, by 28% in real terms. For the Hawaiian Electric Companies the consolidated renewable content of electricity increases to approximately 67% by 2030.

We take our obligations to our customers seriously. This report represents enormous amounts of thoughtful and thorough analysis to provide the most credible plan possible for our customers.

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## OUR SHARED VISION

Our vision is to deliver cost-effective, clean, reliable, and innovative energy services to our customers, creating meaningful benefits for Hawai’i’s economy and environment and making Hawai’i a leader in the nation’s energy transformation. Hawai’i has the potential to become a national model for clean energy by not only achieving the highest Renewable Portfolio Standard (RPS) goal in the nation by 2030, but also by leading the way to define the utility model of the future.

To achieve this, we believe the Hawaiian Electric Companies have a responsibility and a unique opportunity to evolve in Hawai’i’s complex and rapidly changing energy ecosystem. In this dynamic environment, no single party can realize this future for

## Executive Summary

The PSIP Achieves Unprecedented Levels of Renewable Energy

Hawai'i. For this reason, we seek a shared vision with our customers, regulators, policy makers and other stakeholders in order to achieve shared success for all of Hawai'i.

## THE PSIP ACHIEVES UNPRECEDENTED LEVELS OF RENEWABLE ENERGY

The Hawaiian Electric Companies will not only meet the mandated RPS of 40%, but will achieve an unprecedented level of 67% by 2030. As illustrated in Figure ES-1 and Figure ES-2 below, for Maui County, the Maui Electric Preferred Plan increases the already aggressive RPS from 45% in 2015 to 72% in 2030. A significant amount of market-based, distributed solar photovoltaics (PV) is included in the Preferred Plan and accounts for about one-third of this total.

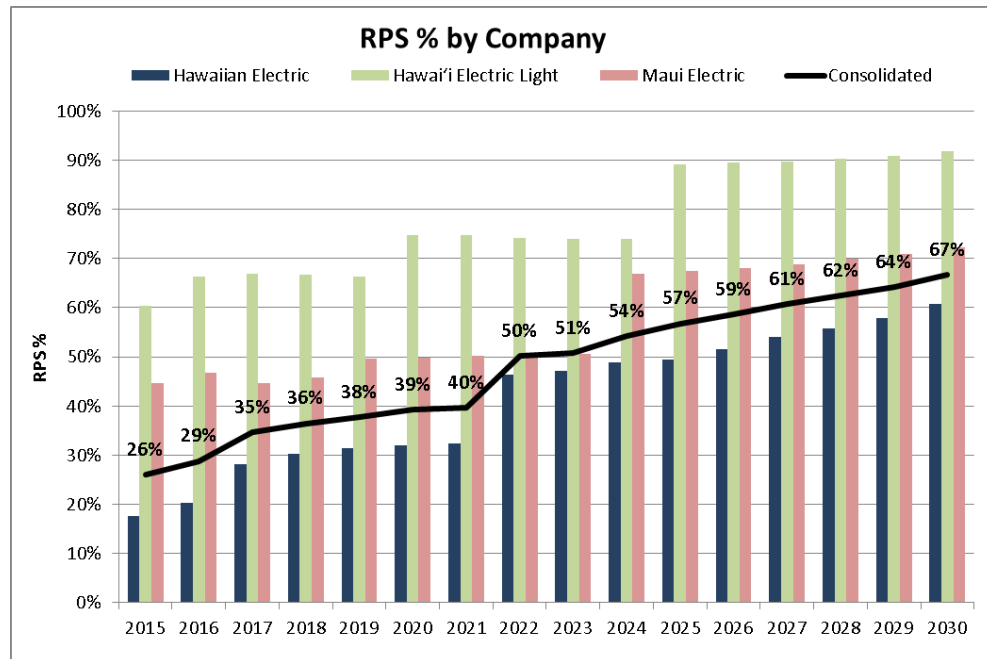


Figure ES-1. Renewable Portfolio Standard (RPS) for the Hawaiian Electric, Maui Electric, Hawai'i Electric Light, and the Consolidated Companies, 2015-2030.

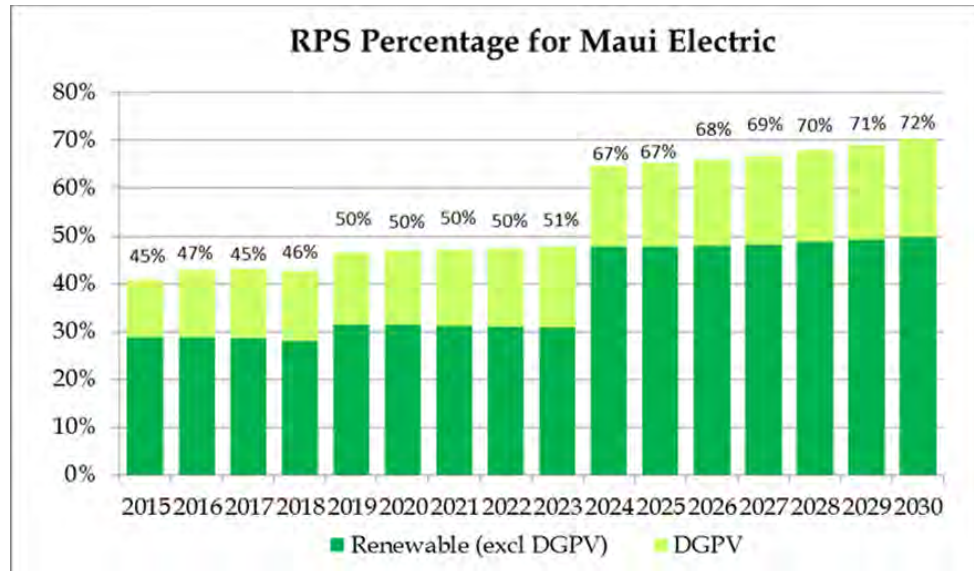


Figure ES-2. Renewable Portfolio Standard (RPS) for Maui Electric on Maui, Lana'i, and Moloka'i, 2015-2030, showing the relative contribution from distributed generation (DG-PV)

### Maximizes Utilization of Renewable Energy

From 2015 through 2030, 95.8% to 99.2% of the estimated energy produced from all renewable resources would be utilized (not curtailed) each year, as shown in Figure ES-3. This is accomplished by:

- Installing energy storage to provide regulating and contingency reserves;
- Using demand response as a tool for better managing system dispatch;
- Selecting future thermal generation resources that have a high degree of operational flexibility;
- Increasing the operational flexibility of existing thermal generation not slated for retirement during the study period; and
- Reducing the “must-run” requirements of thermal generators.

## Executive Summary

The PSIP Achieves Unprecedented Levels of Renewable Energy

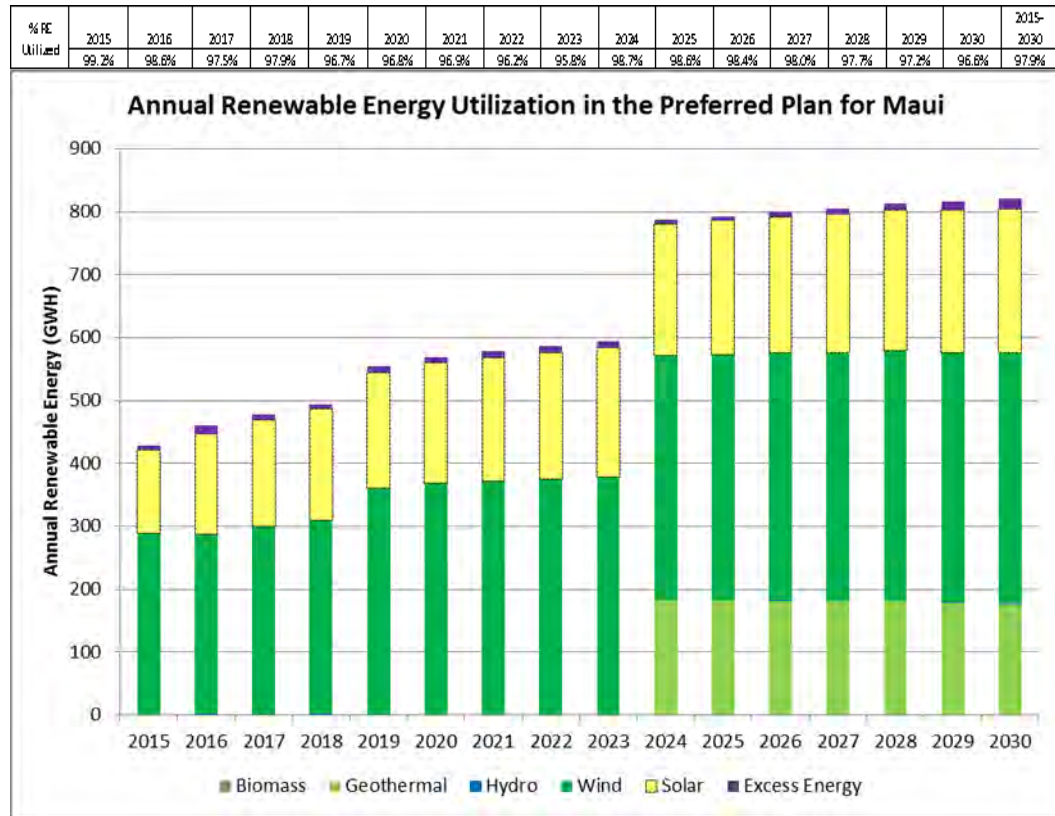


Figure ES-3. Total System Renewable Energy Utilized by Maui Electric (Maui)

## The Preferred Plan Provides a Hedge Against Fuel Price Volatility

In developing the Preferred Plan, conscious choices were made to blend resources that move the generation mix away from fossil-fuel resources. This was done, in part, to provide a financial hedge against fuel price volatility and future uncertainty with respect to fuel availability.

Generally, when the analysis result showed a “close call” between a renewable and non-renewable option, the renewable option was chosen. The respective effects of fuel price volatility were a determining factor for some resource selections. Accordingly, renewable resources that consume no fuel were selected for the PSIP in some cases where they were not the obvious low-cost option. The selections of new generation resources for inclusion in the Preferred Plan were based on economics, planning flexibility, and operational flexibility.

Full consideration was also given to the portfolio value that demand response<sup>1</sup> and energy storage technologies, both non-fuel consuming options, can provide; both were found to make valuable contributions.

## OVERVIEW OF THE PREFERRED PLAN

### Energy Mix

The energy mix for Maui from 2015 to 2030 is illustrated in Figure ES-4 below. Renewable energy from distributed PV continues to grow over time and new utility-scale wind is also added to the system. As firm generating units are deactivated and decommissioned, new flexible firm generation is added in its place. Oil is replaced by liquefied natural gas (LNG), and a portion of the coal is replaced by biomass.

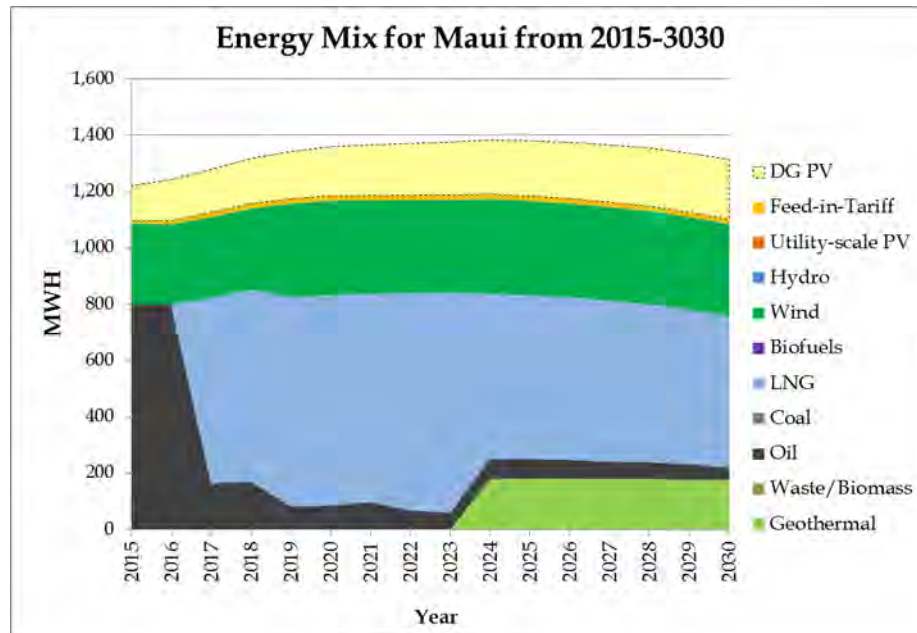


Figure ES-4. Annual Energy Mix of Maui Electric Preferred Plan

The Preferred Plan for Maui Island for 2015–2030 can generally be summarized as follows:

- Increases distributed generation three-fold.
- Switches fuel at certain units to meet new environmental regulations.

<sup>1</sup> As defined in the *Integrated Demand Response Portfolio Plan (IDRPP)*, filed by the Companies on July 28, 2014, in Docket No. 2007-0341.

## Executive Summary

### Overview of the Preferred Plan

- Procures lower cost LNG, and modifies certain generating units to utilize LNG as a fuel.
- Retires existing thermal generation through the 2019–2030 time period.
- Installs new Internal Combustion Engine (ICE) generators in South Maui fired with Ultra Low Sulfur Diesel (ULSD) fuel (a Non-Transmission Alternative, avoiding a new south Maui overhead transmission line), and at the Waena site, fired with LNG.
- Adds wind generation early in the plan.
- Installs energy storage for regulation and contingency reserves.
- Relocates, at a later time, the ICE generators from South Maui to Waena and converts those ICE generators to LNG.
- Adds a geothermal plant in 2024.
- Upgrades the Central Maui transmission line in 2018.
- Aggressively expands demand response programs.
- Modernizes the grid with smart technologies.

The Preferred Plans for Lana‘i and Moloka‘i for 2015–2030 can generally be summarized as follows:

- Switches to 50% LNG fuel in 2017.
- Switches to 50% biodiesel fuel decreasing cost below that of ULSD.
- Installs utility scale solar in 2018.
- Installs large-scale energy storage in 2018.

## Timelines for the Preferred Plan

The timelines for the Preferred Plans for the Maui Electric power system on Maui for 2015–2030 are illustrated in Figure ES-5, which shows when new resources would be added (“above the date line”) and existing resources would be retired (“below the date line”). Similarly, Figure ES-6 shows the Preferred Plan for Maui Electric’s Moloka‘i system for 2015–2030. Figure ES-7 shows the Preferred Plan for Maui Electric’s Lana‘i system for 2015–2030.

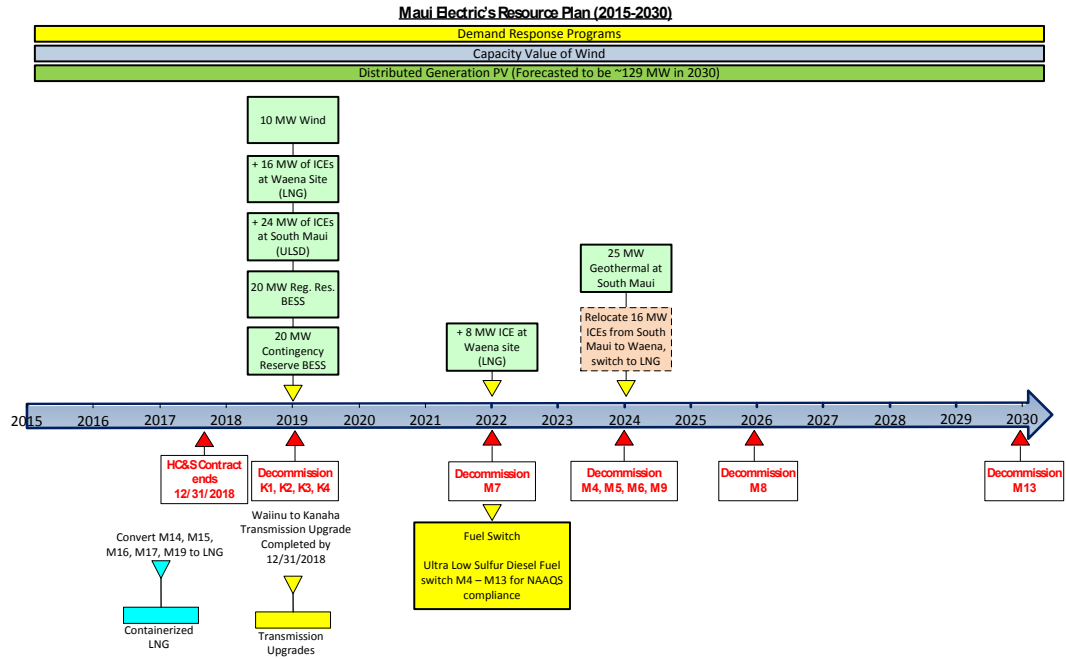


Figure ES-5. Maui Electric Preferred Plan 2015-2030 (Maui Island)

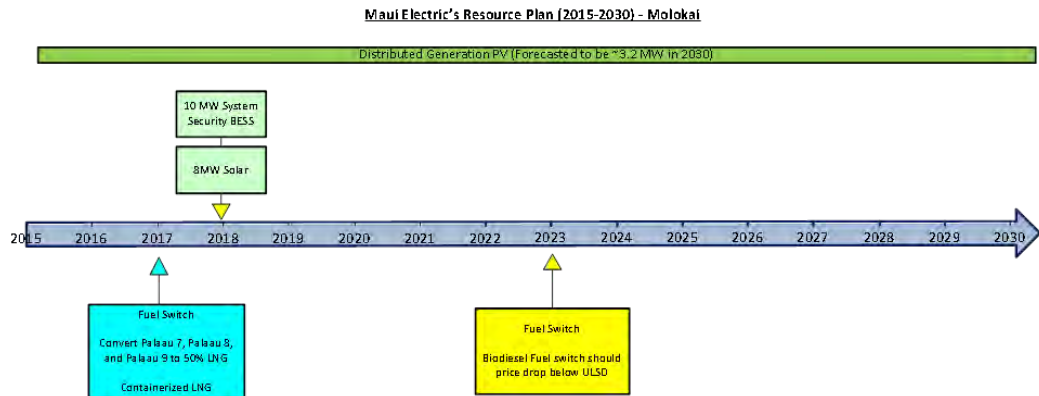


Figure ES-6. Maui Electric Preferred Plan 2015-2030 (Moloka'i)

## Executive Summary

### Overview of the Preferred Plan

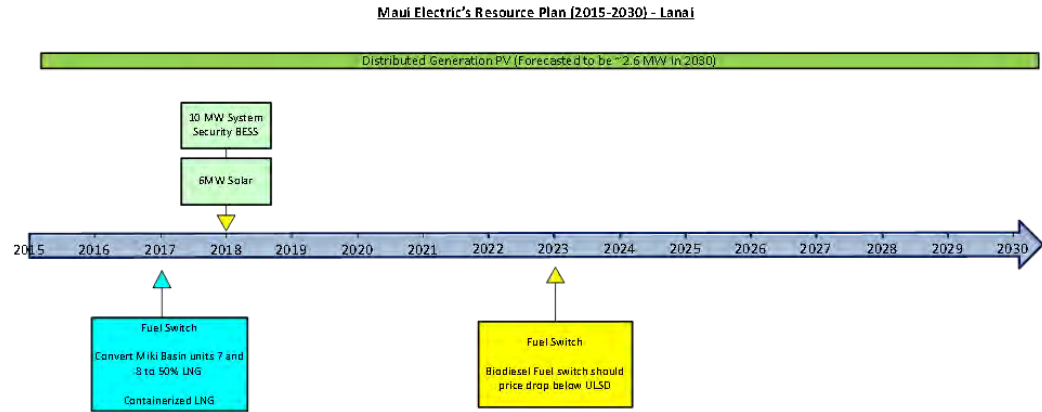


Figure ES-7. Maui Electric Preferred Plan 2015-2030 (Lana'i)

## The Preferred Plan is Realistic

The Preferred Plan accomplishes our strategic vision of the 2030 power system, and importantly, it does so in a way that is both realistic and achievable.

The Preferred Plan relies only on technologies that are commercially ready today and that can be successfully developed in Hawai'i's unique political and social environment.

Recognizing that the investment to implement the Preferred Plan will be substantial, and perhaps beyond the ability of a single entity to make, the plan assumes a mix of utility and third-party investment in new infrastructure. The Preferred Plan does not rely on a single large capital project to achieve success and thus, portfolio risk is well diversified within the plan.

Finally, the Preferred Plan is "operable." In other words, the plan is based on sound physics, engineering, and utility operating principles.

## The Preferred Plan Reduces Customer Bills

The Preferred Plan identifies those transformational and foundational investments needed to reliably serve customers on Maui, Moloka'i and Lana'i with flexible, smart and renewable energy resources.

The Preferred Plan coupled with changes in rate design that more fairly allocates fixed grid costs across all customers (assumed effective in 2017) is expected to reduce monthly bills for average residential customers by 28% from 2014 to 2030. See Figure ES-8.



### Average Monthly Bill for Average Full Service Residential Customer (real 2014 \$) - DG 2.0

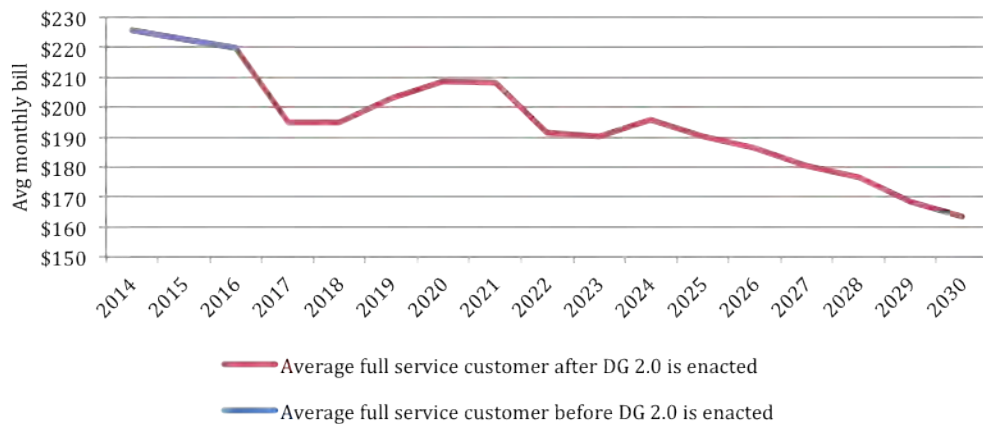


Figure ES-8. Average Full Service Residential Customer Bill Impact

The customer bill reductions are driven by projected changes in the underlying cost structures.

Fuel expense declines significantly over the period, driven by the continued shift toward renewable generation and the cost savings from the introduction of LNG, beginning in 2017.

Purchased power costs increase over the period, reflecting both the expanding purchases of renewable energy and the capacity costs for replacement dispatchable generation.

O&M expenses are expected to decline in real terms across the period, driven by the reductions in costs associated with Smart Grid and information technology investments.

## The Preferred Plan is Flexible

The Preferred Plan is flexible and can be adjusted based on changing conditions as we move towards 2030.

**Planning Flexibility:** The ability to make adjustments regarding capital intensive resource decisions was accomplished through a combination of retirements of less efficient power plants, and selection of new resources from a menu of generation, demand response programs, and energy storage options that can be developed in relatively short time frames.

**Operational Flexibility:** The selected thermal generation resources exhibit a high degree of operational flexibility across a wide range of duty-cycles and system conditions.

**Technological Flexibility:** The Preferred Plan can be immediately implemented using proven technologies that are available today. However, it retains the ability to change the mix of future resources in response to system conditions that differ from those assumed today. The plan also allows incorporation of emerging technologies that may achieve commercial readiness or produce cost savings in the future.

**Financial Flexibility:** The plan is agnostic with respect to ownership of incremental resource additions.

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## TRANSPARENCY

The planning approach we have taken provides our customers and other stakeholders with a transparent view of the options considered and the potential tradeoffs assessed as part of the planning analyses. To this end, we assembled numerous assumptions and forecasts critical to the analyses, and utilized sophisticated and comprehensive production simulation models to analyze alternatives. These models employed a variety of modeling techniques, and all were based on utility planning and operating methods with worldwide utility-industry acceptance.

Achieving the aggressive goals in this plan requires that all stakeholders be aligned in moving forward expeditiously. As with any planning process of this magnitude, the forecasts and assumptions incorporated in this PSIP may or may not be borne out. However, we made what we believed were logical, fair and supportable assumptions that support near term actions.

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## EXECUTION OF THE PREFERRED PLAN

The Preferred Plan clearly identifies the strategic initiatives that we believe must be implemented in order to continue the journey towards a more sustainable energy future.

The Preferred Plan identifies near term actions that must be initiated on the path towards realization of shared vision. We are committed to do our part. We will continue to transform and collaborate to make this a reality. The Commission has already opened a docket to review our PSIPs. We look forward to the additional insight and any required approvals to keep moving toward our shared goals.

# I. Introduction

We operate in an environment that is defined by geography, changing technology, and policies intended to promote clean energy. These conditions create opportunities, as well as challenges, as we move into the future. We intend to adapt to changes in market and technological conditions to meet the challenges along the way. Accordingly, we have initiated a comprehensive strategic planning effort to position the Hawaiian Electric Companies to provide high value energy services to our customers, and promote the economic well being of Hawai‘i. Our plan is based on extensive analysis of the current situation and of future opportunities. We have integrated our findings into a Preferred Plan that increases renewable content of electricity in Hawai‘i to 67% by 2030 and reduces full service customer bills by 23 to 28%.

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## THE POWER SUPPLY IMPROVEMENT PLAN

The Hawaiian Electric Companies were ordered to create Power Supply Improvement Plans (PSIPs) for each operating utility. The resultant PSIPs are tactical, executable plans based on well-reasoned strategies that can be implemented expeditiously. They are supported by comprehensive analyses in resource planning, and focus on customer needs.

## I. Introduction

Overview of the PSIP

### Goals of the PSIP

Utilizing a strategic “clean slate” view of 2030, we created a balanced portfolio of the optimal mix of generation, both thermal and renewable, demand response, and energy storage to:

- Successfully and economically integrate substantial amounts of renewable energy.
- Maximize the utilization of renewable energy that is produced.
- Maintain system reliability.
- Systematically retire older, less-efficient fossil generation.
- Reduce “must-run” generation.
- Increase generation operational flexibility.
- Utilize new technologies for grid services.

The result of our effort is a tactical *Preferred Plan* for each operating utility – that can be confidently and expeditiously implemented.

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## OVERVIEW OF THE PSIP

This document is organized as follows:

**Chapter 1. Introduction:** An introduction to and an overview of the contents of the PSIP.

**Chapter 2. Strategic Direction:** A high-level vision of our power grid in 2030.

**Chapter 3. Generation Resources:** The current state of our power grids.

**Chapter 4. Major Planning Assumptions:** A discussion of the major assumptions upon which we based our modeling analysis to develop the preferred plans.

**Chapter 5. Preferred Plan:** A presentation of our Preferred Plan to attain the goals of the PSIP.

**Chapter 6. Financial Implications:** An analysis of the financial impacts of implementing the Preferred Plan.

**Chapter 7. Conclusions & Recommendations:** A summary of the conclusions derived from our analyses and recommendations moving forward

**Appendices A–O:** A series of appendices that provide supporting information and more detailed discussions regarding the creation of the PSIP.

## HAWAIIAN ELECTRIC SYSTEM LOAD PROFILES

System loads throughout the day on our electric power grids have changed dramatically over the past eight years. As an example of this change, Figure 1-9 shows this trend on the O'ahu grid using data from the first week of June during the period from 2006 to 2014. This is not only an accurate representation for every week of a year on O'ahu, but is also relevant for the Maui Electric and Hawai'i Electric Light power systems.

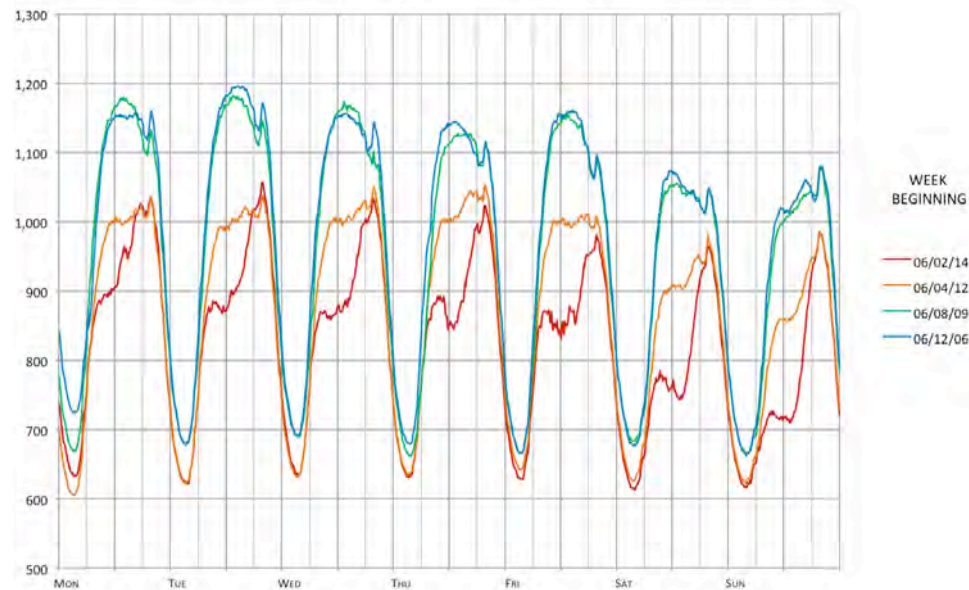


Figure I-9. O'ahu System Load Profiles, 2006–2014

A review of load profiles from recent years yields the following observations:

- Daytime peak loads on the O'ahu grid in 2006 and 2009 regularly reached 1,200 MW; in 2014, daytime peak loads only reach approximately 850 MW: a drop of about 30%.
- Over the past four years, the summertime system load has shifted from a daytime peak to an early nighttime peak, due mainly to distributed solar generation.
- System minimum loads have also lowered, due mostly to energy efficiency measures.

This trend suggests that sales and peaks have declined which, coupled with the growth in distributed generation photovoltaics (DG-PV), is a harbinger for greater challenges operating a stable and reliable grid.

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# RENEWABLE ENERGY INTEGRATION AND DIVERSITY

The generation portfolio of the future will be comprised of greater amounts of variable renewable resources, complemented by firm thermal generation that will be both renewable and fossil fueled. The renewable energy will be derived from solar (both distributed generation and utility-scale generation), wind, hydroelectric, biomass (including waste) and geothermal resources. Energy storage and demand response will play integral roles in the grid of the future, while the role of fossil fuels will continue to diminish.

## A Portfolio of Diverse Renewable Generation

The state of Hawai‘i is blessed with abundant sunshine, generous winds, and geothermal resources that can be harnessed for energy production, but no indigenous fossil fuels. Recognizing this, we have the most aggressive Renewable Portfolio Standard (RPS) in the nation. The Hawaiian Electric Companies are already on course to exceed the mandated RPS of 40% in 2030. Our PSIP further exploits Hawai‘i’s natural resources creating plans to significantly exceed the RPS requirements.

## The Role of Thermal Generation

Even with an abundance of renewable energy resources, the power system must have a complement of firm, dispatchable thermal resources. Historically, these types of generators provided bulk power for transmission and distribution throughout the electric grid. In the future, they will be called upon to generate power during periods when variable renewable generation is unavailable (that is, periods of darkness, extended storms, or no wind), and to provide valuable grid services to sustain grid reliability. These thermal resources will be fueled by liquefied natural gas (LNG), which is lower cost and environmentally cleaner than petroleum-based fuels.

## Energy Storage

Continued advancements in energy storage technology harbors increased opportunities for employing additional amounts of variable renewable resources onto the electricity grid at reasonable costs. Our PSIP analyzes and develops a plan for using energy storage systems (ESS) to maximize renewable energy utilization (minimize curtailment) and sustain frequency regulation and dynamic stability requirements.

## Demand Response (DR)

Demand response can enable grid operations, save costs, and provide customers more options to manage their bills and be active contributors to the electric system. Power systems have historically controlled the supply of power to match the uncontrolled demand for power. Demand response programs empower customers and system operators to work collaboratively to balance load supply and demand through innovative technology and programs. Toward that end, we have designed and will implement DR programs<sup>2</sup> across the entire state, and have incorporated the utilization of DR in our Preferred Plans.

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## FINANCIAL IMPLICATIONS

The transformation of the power system will require significant investments by the company and third parties to build the necessary flexible, smart, and renewable energy infrastructure needed to reliably serve customers across the state. We have developed estimates of foundational and transformational investments that will need to be made during the planning period. And, through detailed hourly and sub-hourly production simulation modeling have estimated the fuel, power purchase, operating, and maintenance expenses resulting from implementation of the Preferred Plans. A financial model was utilized to examine the financial implications of the PSIPs for customers.

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## OVERVIEW OF OUR PREFERRED PLAN

For each operating utility, we have developed a Preferred Plan for transforming the system's current state to a future vision of the utility in 2030 consistent with the Strategic Direction we set forth to achieve long-term benefits for our customers and our state (and is presented in Chapter 2).

Implementation of these Preferred Plans will transform the electric systems on O'ahu, Maui, Lana'i, Moloka'i, and Hawai'i and will substantially decrease our reliance on imported fossil fuels and reduce customer bills while integrating tremendously high levels of renewable energy. More than 65% of our energy will be provided by renewable energy resources in 2030, significantly surpassing our state's renewable energy target and securing Hawai'i's place as a national leader in clean energy.

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<sup>2</sup> The Companies filed its *Integrated Demand Response Portfolio Plan (IDRPP)* with the Commission on July 28, 2014.

## I. Introduction

Overview of Our Preferred Plan

### Our Shared Vision

Our vision is to deliver cost-effective, clean, reliable, and innovative energy services to our customers, creating meaningful benefits for Hawai'i's economy and environment, and making Hawai'i a leader in the nation's energy transformation. Hawai'i has the potential to become a national model for clean energy by not only achieving the highest Renewable Portfolio Standard (RPS) goal in the nation in 2030, but also by leading the way to define the utility model of the future.

To achieve this, we believe the Hawaiian Electric Companies have a responsibility and a unique opportunity to evolve in Hawai'i's complex and rapidly changing energy ecosystem. In this dynamic environment, no single party can realize this future for Hawai'i. For this reason, we seek a shared vision with our customers, regulators, policy makers and other stakeholders in order to achieve shared success for all of Hawai'i.

### Stakeholder Engagement

Our approach towards achieving heightened visibility is to boldly and vigorously engage with our customers and the community we serve. In order to increase our awareness of and ability to meet the expectations of our customers and our community, Maui Electric recently sought input from key stakeholders representing County government, community organizations, environmental interest groups, and employees on their perspectives on what energy could look like for Maui. These outreach efforts provided us with valuable insight on the preferences, concerns, and economic and social values of our customers, creating a tremendous opportunity to better align our operational and educational efforts with stakeholders.



## 2. Strategic Direction

A healthy, resilient and cost effective power supply and electric power delivery system is vital to the well being of the people of Hawai‘i. The Hawaiian Electric Companies provide service to over 450,000 customers across five of the Hawaiian Islands, and because our customers expect and depend on reliable electric service, we are in contact with them every second of every day. We believe that a healthy, viable and progressive utility is imperative for managing, producing and delivering the electric energy that is essential to our economy.

We operate in an environment that is defined by geography, changing technology, and policies intended to promote clean energy. These conditions create opportunities, as well as challenges, as we move into the future. We intend to adapt to changes in market and technology conditions and to meet the challenges along the way. Accordingly, we have initiated a comprehensive strategic planning effort to position the Hawaiian Electric Companies to provide high value energy services to our customers, and promote the economic well being of Hawai‘i.

While our strategic planning is an ongoing effort, the work that has been accomplished to date has defined Power Supply Improvement Plans (PSIPs) that cover the desired end states, and the path to progress from the current state to the desired end state by 2030.

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### SHARED VISION

Our vision is to deliver affordable, clean, reliable, and innovative energy services to our customers, creating meaningful benefits for Hawai‘i’s economy and environment, and making Hawai‘i a leader in the nation’s energy transformation. Hawai‘i has the potential to become a national model for clean energy by not only achieving the highest

## 2. Strategic Direction

### Common Objectives

Renewable Portfolio Standard (RPS) goal in the nation in 2030, but also by leading the way to define the utility model of the future.

To achieve this, we believe the Hawaiian Electric Companies have a responsibility and a unique opportunity to evolve in Hawai‘i’s complex and rapidly changing energy ecosystem. In this dynamic environment, no single party can realize this future for Hawai‘i. For this reason, we seek a shared vision with our customers, regulators, policy makers and other stakeholders in order to achieve shared success for all of Hawai‘i.

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## COMMON OBJECTIVES

*Common objectives across stakeholders drive the energy landscape of the future.*

We share the Hawai‘i Public Utilities Commission’s commitment to lower, more stable electric bills; increased customer options; and reliable electric service in a rapidly changing environment.<sup>3</sup> In order to drive the transformation for Hawai‘i, we have anchored our strategies in a set of common objectives.

These common objectives include:

- 1. Affordable costs, reflecting the value provided to, and by, customers.** We will create sustainable value for our customers by providing affordable, stable and transparent costs. We will fairly compensate customers for the benefits they provide to the grid, while also fairly pricing the benefits customers derive from the grid.
- 2. A clean energy future that protects our environment and reduces our reliance on imported fossil fuels.** Hawai‘i is uniquely positioned to embrace the development of local renewable energy resources and increase our energy security. We will achieve a renewable portfolio that significantly exceeds the minimum standard of 40% by 2030.
- 3. Expanded and diversified customer energy options.** We will serve all connected to the grid, including those with and without distributed generation (DG), through customized levels of grid services, electric power delivery and value-added products and service offerings.
- 4. A safe, reliable and resilient electric system.** We will provide a level of reliability that supports our customers’ quality of life. We are unwavering in our commitment to safety and reliability; these principles are the bedrock of any electrical system. Recognizing Hawai‘i’s remoteness and lack of interconnections, we must have an

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<sup>3</sup> See “Commission’s Inclinations on the Future of Hawai‘i’s Electric Utilities”, Exhibit A attached to Decision and Order No 32052, filed on April 28, 2014, in Docket No. 2012-0036, at 3.

electric system resilient enough to support the continuous flow of energy to our communities through a wide variety of conditions and circumstances.

- 5. A healthy Hawai'i economy.** We will contribute to the health and diversity of Hawai'i's economy for the benefit of all stakeholders.
- 6. Innovation in energy technologies.** We will actively pursue new clean energy technologies in partnership with others to bring energy solutions to our customers.

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## APPROACH FOR THE PHYSICAL DESIGN OF THE ELECTRIC SYSTEM IN 2030

A transformation of the physical components of the grid (for example, generators, transmission and distribution infrastructure, non-traditional alternatives) is vital for the Companies to deliver on this vision. It requires both a clear understanding of the goals as well the ability to identify and implement a path from the current state to the desired end state.

**The Companies recognize that the environment in which they operate is constantly changing. Continuous monitoring of market trends and changing circumstances are critical for fact-based planning. This will require adjustment of our strategic and tactical plans within the planning horizon.**

To cope with the changing market trends, to support this transformation, to set goals and to set the path forward, the Companies have developed the Power Supply Improvement Plans in two steps:

**A. Step A: Define the desired end state for the physical design of the power system in 2030**

This step was accomplished by developing a series of "clean sheet" hypothetical end states for 2030 that allowed the Companies to understand the broad ramifications associated with different futures, and choosing an end state that is in our view the best balance of objectives over the long term. The end state chosen is consistent with the underlying principles, recognizes the uniqueness of island grids, and promotes the State's clean energy policies.

**B. Step B: Define and validate a path to transform from the current state to the desired end state in 2030**

This step was accomplished through application of utility industry accepted planning methods that take into account existing system conditions, technology commercial readiness, reliability and cost considerations. Chapters 3 through 7 and

## 2. Strategic Direction

Approach for the Physical Design of the Electric System in 2030

the appendices of this report provide the details of how this analysis was accomplished and the results of that analysis.

This approach enables our customers and other stakeholders to have a transparent view of the options considered and the potential tradeoffs<sup>4</sup> assessed during these analyses.

### Step A: Clean-sheet analysis to define a desired end state and provide strategic direction

The goal of ‘Step A’<sup>5</sup> was to provide high-level guidance for the physical design of the electric system in 2030, the end of the planning horizon considered in this PSIP. In order to ensure an un-biased and clean-sheet approach in defining the future physical design, the following guidelines were used in this step of the analysis:

- Forward-looking optimization focusing on 2030 as the single year.
- Using a fact-based and industry accepted set of assumptions and forecasts.
- Avoiding any pre-conceptions and not favoring any particular technology.
- Taking an ownership-agnostic view.
- Applying a spectrum of end state options to assess trade-offs.
- Applying a clean-sheet approach to define service reliability requirements.
- Evaluating the cost of the physical design options from an “all-in” societal perspective to consider the impact to Hawai‘i versus any particular customer class (in this definition all-in societal costs included the total costs of DG-PV installation and maintenance in addition to all the utility-scale generation costs and T&D costs).<sup>6</sup>
- Using common objectives stated above to select the desired end state in 2030.

**The goals of the approach were to assess the impact of various end states and to select one that the Companies should pursue as the desired target for the physical design in 2030.**

### Step B: Detailed and tactical production analytics to define and validate the path

In Step B., the focus shifted from goal setting to developing a detailed tactical and executable plan from today to the final vision in 2030, considering the feasibility, costs, risks, and activities required to support the transition. The operability of the system

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<sup>4</sup> For instance one tradeoff might be low cost and another low cost volatility. Choosing the absolute lowest cost might result in high cost volatility. In a case like this we chose a path that resulted in a balance between low cost and low cost volatility.

<sup>5</sup> The strategic exercise under Step A has been performed on O‘ahu, Maui and Hawai‘i Island; Lana‘i and Moloka‘i were assessed separately within the detailed and tactical production analytics.

<sup>6</sup> Note that the evaluation under Step A was performed only for the clean-sheet analysis. The Preferred Plan and Financial analyses presented later in this report do not include customer-incurred costs related to installation and maintenance of customer-installed generation.

under various physical designs, as well as both normal and likely off-normal<sup>7</sup> circumstances, was tested and validated within an integrated planning and production simulation environment. Given the importance and complexity of this analysis, the Companies elected to create a unique, collaborative, and iterative modeling process powered by different models and participants. This process proved to be invaluable both in terms of validating key tactical and transitional solutions as well as providing a forum to test and refine concepts.

The detailed production simulations define the following annually from 2015 to 2030: existing generation portfolio, timing and characteristics of individual projects, retirements, implications of new tariffs (for example, DG 2.0)<sup>8</sup> and customer offerings (for example, Demand Response), system reliability, and operational requirements. This provides the ability to assemble and optimize the power system portfolio and grid design across time, consistent with our overall objectives to be cost-effective, to exceed the Renewable Portfolio Standard (RPS) goal, to reduce dependency on high-priced fossil fuels, to diversify and “green” the energy portfolio, and to establish a basis for implementing advanced technologies such as energy storage. **The analytical product is the Preferred Plan that is presented in Chapter 5 of this report.**

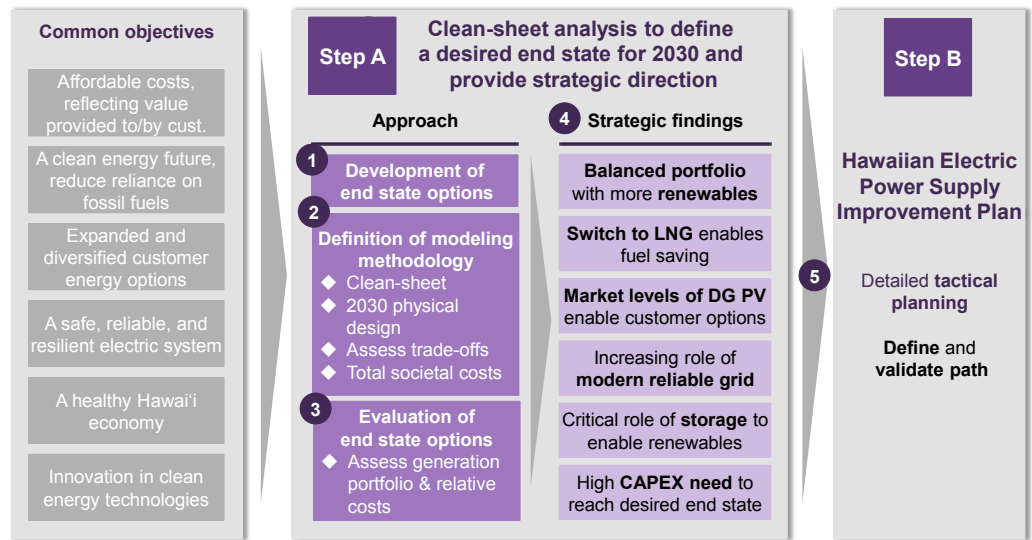


Figure 2-1. Approach to Define Desired Physical System Design 2030 End-State

The remainder of this chapter will focus on describing Step A in more detail.

<sup>7</sup> Off-normal circumstances include likely events like trip of a large generating unit, trip of a heavily loaded transmission line, etc.

<sup>8</sup> A generic term used to describe revised tariff structures governing export and non-export models, based on fair allocation of costs among distributed generation (DG) customers and traditional retail customers, and fair compensation of DG customers for energy provided to the grid.

## 2. Strategic Direction

Approach for the Physical Design of the Electric System in 2030

### Step A: Clean-Sheet Evaluation and Selection of the Desired End State

#### Development of End State Options

Five high-level physical design end state options were developed for the evaluation, reflecting a set of alternative futures with key trade-offs and differentiating factors, and fulfilling the necessary condition of achieving RPS targets and maintaining an operable system at affordable costs<sup>9</sup>. Five end state options were defined.

**‘Benchmark’ end state:** Describes the Companies’ current liquid fuel-based portfolio trajectory with increasing DG-PV integration under the existing regulatory tariff and new utility-scale renewable projects that have already been submitted for approval to the PUC. It assumes LNG is not an accessible option for the islands.

**‘Least cost’ end state:** Describes the physical design assuming only the existing level of DG-PV integration, a cost-optimization of utility-scale renewable technologies firmed by LNG. This end state option optimizes the generation mix that results in the lowest overall societal cost level. As the levelized cost of DG-PV is expected to be higher than most other generation sources, DG-PV would not grow from today under the ‘Least cost’ end state option.

**‘Balanced portfolio–DG 2.0’ end state:** Describes a generation portfolio that is a balance of system costs with increased renewables assuming a market driven DG-PV integration under a hypothetical “DG 2.0” rate structure (described in Chapter 6.), combined with an optimized utility-scale renewables portfolio firmed by LNG.

**‘Balanced portfolio–DG heavy’ end state:** Like ‘Balanced portfolio–DG 2.0’, this option seeks a balance of costs and renewables but allows for a much higher DG-PV integration compared with ‘Balanced portfolio–DG 2.0’. It assumes market driven DG-PV integration under the existing regulatory tariff, combined with an optimized, utility-scale renewable-portfolio firmed by LNG.

**‘100% Renewable’ end state:** Describes a generation portfolio to achieve 100% renewable share by 2030. It assumes market driven DG-PV integration under the existing tariff structure, maximum required utilization of other renewable resources on the islands, and the use of biofuel and biomass to fuel the necessary thermal generating resources for operability.

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<sup>9</sup> “Affordable” includes both cost and cost volatility thereby including considerations such as fuel diversity.

## Definition of Modeling Methodology for Step A

To quickly evaluate and have the flexibility to test each end state option at a high-level—the Companies developed a simplified hourly-based production model for 2030<sup>10</sup>. The model was ownership agnostic regarding generation resources and sought to calculate the total ‘all-in societal’ costs for the physical design (including generation costs and cost of the DG-PV paid by customers and through tax credits) and T&D costs.

### High-Level Modeling Logic for Step A

The high level model for Step A is characterized by the following attributes:

- Hourly supply-demand model was built for 2030 for O’ahu, Maui and Hawai’i Island; Lana’i and Moloka’i were not in the scope of the analysis performed under Step A.
- Levelized cost of energy and technology attributes assessed for over 15 technologies (DG-PV, utility-scale PV, onshore-wind, offshore-wind, ocean thermal, ocean wave, run-of-river hydro, geothermal, waste-to-energy, biomass, coal, various LNG technologies, oil-based steam, biofuel, energy storage).
- DG-PV installed capacities for 2030 were taken as an input into the model, developed by the Companies and used in the DGIP and PSIP process.
- High level estimates for reliability requirements were linked to capacities for DG-PV, utility-scale PV and wind for day-time and also linked to wind only for night-time. (Detailed tactical planning in Step B calculates with more precision system security requirements that differ by hour based on the generation portfolio output.)
- Demand was covered for every hour of the year starting with DG-PV considering its hourly load shape, followed by the various technologies based on their cost economics and resource constraints.
- Optimization minimizes aggregated costs across renewable generation, conventional generation, storage costs, curtailment and ancillary services.
- Overall installed firm capacities required were 30% above annual system peak-load
- The assessment did not consider most existing configurations, except that all existing contracts were honored until their expiration.
- The model assumed any and all configurations were operable and reliable.
- All the assumptions used in the model were aligned and consistent with subsequent, more detailed modeling efforts described in Chapters 3 through 7.
- Estimates on Transmission & Distribution (T&D) costs have also been added to each of the end state options. The T&D costs encompassed transmission, distribution, smart

<sup>10</sup> This model considered high-level estimates on reliability constraints, did not consider most existing configurations, except that all existing contracts were honored until their expiration and assumed any and all configurations were operable and reliable.

## 2. Strategic Direction

Approach for the Physical Design of the Electric System in 2030

grid and system operations investments. These costs were derived for each resulting end state option by assessing the expected location of generation assets on the system.

**Key input parameters that were included** in the strategic model to assess tradeoffs:

- **Demand parameters:** All relevant demand information for 2030, such as hourly demand curves for 2030, including the impact of gross demand and energy efficiency measures, hourly demand response adjustment factors, network losses, and DG-PV integration rates.
- **Supply parameters:** All relevant supply information for 2030, such as technology readiness, levelized cost of energy capital and operating costs per technology for 2030 based on National Renewable Energy Laboratories (NREL) forecasts<sup>11</sup> and Energy Information Administration (EIA) adjustment factors<sup>12</sup>, fuel price forecasts, resource constraints per technology, hourly capacity factors per renewable technologies, assumed lifetime of assets, grid integration costs, forecast on DG-PV installed capacities.
- **System security requirements:** Annual reserve margin requirement, day-time and night-time regulating and contingency reserves.
- **Other:** Inflation, cost of capital.

**Parameters that were not included** in the strategic model (Step A) but were included in the detailed tactical PSIP analytics and modeling (Step B):

- **Demand parameters:** All relevant demand information from 2015 to 2030, sub-hourly information.
- **Supply parameters:** All relevant supply information from 2015 to 2030, unit level technology information, maintenance schedules per unit, existing generation fleet, existing contractual capital cost and energy cost conditions, contractual dispatch requirements and contract duration, differentiation of costs depending on the year of building assets, retirements, minimum load requirement per unit, various type of storage technologies, retirement schedules.
- **System security requirements:** Regulating and contingency reserves on hourly basis; full range of system security requirements in line with the Companies written policies, use of demand response programs for ancillary services.
- **Other:** Avoided cost calculation for Hawai'i Island PPAs.

<sup>11</sup> National Renewable Energy Laboratories: Cost and performance data for power generation technologies (2012).

<sup>12</sup> Energy Information Administration: Updated capital cost estimates for utility-scale electricity generating plants (2013).



Key inputs of the model were the following:

- The expected levelized cost of various generation technologies assuming the generation mix is built by 2030
- Resource constraints and technological attributes of alternative technologies
- Service reliability requirements like contingency reserve requirement, regulating reserve requirement, and reserve margins
- Estimated T&D costs to enable interconnection and ensure safe and reliable service

The results of the assessment for Step A were optimized physical design portfolios by each end state option and island considering the costs and attributes of the different end states. In addition, transmission and distribution upgrade costs to integrate additional generation units were estimated and included to result in a total cost by end state option.

The same assumptions were used in Step A and Step B. The assumptions are summarized in Appendix F, and the major assumptions are presented and discussed in Chapter 4.

## Evaluation of end state options across common objectives and selection of desired end state

**The evaluation of the five high-level physical design end state options across the common objectives resulted in the selection of *'Balanced portfolio-DG 2.0'* as the desired 2030 physical design.**

This option would provide for a robust and diversified renewable portfolio mix that will significantly exceed the 2030 RPS, reduce Hawai'i's dependence on oil, and support a clean energy economy. Market driven DG-PV provides options for our customers. While 'all-in societal costs' were higher than the least cost option, DG 2.0's revised tariff structure would create an equitable rate structure to mitigate the DG cost impact to full service customers who are expected to be the majority of our customer base through 2030.

While the other four end state options were optimized to certain objectives, they were not selected due to other tradeoffs:

- **'Benchmark'**: Oil-based fuels make this option costly and is the least favorable for a clean energy future due to highest level of emissions and continued dependence on imported fossil fuels.
- **'Least cost'**: This option proves that switching from oil to LNG and higher levels of renewables is favorable for reducing costs; however, due to the limitations on the option for customers to install DG-PV, it is not supportive of expanding and diversified customer energy options.
- **'Balanced Portfolio-DG heavy'**: Driven by higher DG-PV prevalence, the end state all-in societal generation and T&D costs are higher than *'Least cost'* and *'Balanced*

## 2. Strategic Direction

Approach for the Physical Design of the Electric System in 2030

*portfolio-DG 2.0*. It also puts pressure on the reliability of the system given the high level of variable renewables.

- **‘100% renewable’**: This is achievable but it also has the highest cost, driven by potential resource constraints on lower cost resources, the required energy storage systems to integrate renewables and maintain an operable system and high cost of biofuels compared to other resources that are required to achieve 100% renewable generation. It also puts pressure on the reliability of the system given the high level of variable renewables.

### Strategic findings from the selected desired end state (‘Balanced portfolio-DG 2.0’)

The above described exercise resulted in the following overall strategic findings related to the desired ‘Balanced portfolio-DG 2.0’ physical design of the electric system in 2030:

- The aggregated Renewable Portfolio Standard (RPS) will substantially exceed the RPS mandate of 40% by 2030.
- A balanced portfolio of variable and dispatchable renewables in concert with thermal units offers the most value to customers.
- Converted and new LNG fired thermal units provide critical, efficient and flexible energy resources, ensure the operability and reliability of the grid, enable unit retirements, and can work in combination with variable renewable resources.
- LNG will enable significant fuel saving versus other liquid fuels.
- A combination of distributed and utility-scale resources contribute to the portfolio.
- Under the hypothetical new DG 2.0 tariff structure, aggregated DG-PV capacities across all Companies expected to grow rapidly from the current ~330 MW up to ~910 MW corresponding to ~15% of the total generation (HECO ~650 MW, MECO ~135 MW, and HELCO ~115 MW).
- Energy storage will be a key enabling technology for higher renewables while ensuring reliability and resiliency of the system.

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## STRATEGIC DIRECTION FOR THE DEVELOPMENT OF COMPREHENSIVE TACTICAL MODELS AND PLANS IN STEP B

The objective in Step A was to define the target clean-sheet end state for the physical design in 2030 for the Companies and derive strategic findings and strategic initiatives for future development. In order to realize the desired end state the Companies see the following major strategic initiatives:

- Increase the integration of utility-scale and DG renewable energy resources to exceed the 2030 RPS goal and provide customers with options;
- Diversify the fuel mix to provide lower-cost fuel options and energy service reliability;
- Prepare for LNG and pursue an optimized retirement plan for older oil-fired generation;
- Utilize energy storage to manage increasing integration of variable renewables;
- Expand demand response programs to allow increasing integration of renewables and broadening customer participation;
- Modernize the electric grid to provide greater reliability, minimize costs associated with operating the grid, and enable more renewables and customer energy-management options.

Guided by the strategic findings and directions outlined above, the next step was to translate the selection of 'Balanced Portfolio-DG 2.0' into a detailed tactical plan for each island to transform the existing physical design into the desired end state.

The remainder of this PSIP will further explain Step B and Preferred Plan to achieve the desired physical design, consistent with the above findings.

## 2. Strategic Direction

Strategic Direction for the Development of Comprehensive Tactical Models and Plans in Step B

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## 3. Current Generation Resources

The Hawaiian Electric Companies provide generation on five islands – O‘ahu, Maui, Moloka‘i, Lana‘i, and Hawai‘i Island – with three utilities and five grids. This accounts for about 90% of all the generation requirements for the entire state of Hawai‘i.

Maui Electric serves 69,000 customers combined on Maui, Moloka‘i, and Lana‘i with 262 MW (net) generation on Maui, 12 MW (gross) generation on Moloka‘i, and 10.4 MW (gross) generation on Lana‘i.

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### RENEWABLE RESOURCES

Within the three utilities, the renewable generation varies widely. As of December 31, 2013, Table 3-1 demonstrates that the Hawaiian Electric Companies are far exceeding the Renewable Portfolio Standards (RPS) requirement of 15% by 2015.

| Utility                | Renewable Portfolio Standard |
|------------------------|------------------------------|
| Hawaiian Electric      | 28.6%                        |
| Maui Electric          | 44.4%                        |
| Hawai‘i Electric Light | 60.7%                        |
| Consolidated           | 34.4%                        |

Table 3-1. 2013 Renewable Portfolio Standard Percentages

### 3. Current Generation Resources

Renewable Resources

#### Renewable Generation

The Companies have a number of clean energy generation units across the service area. Figure 3-1 points out these units and the island where they are sited.

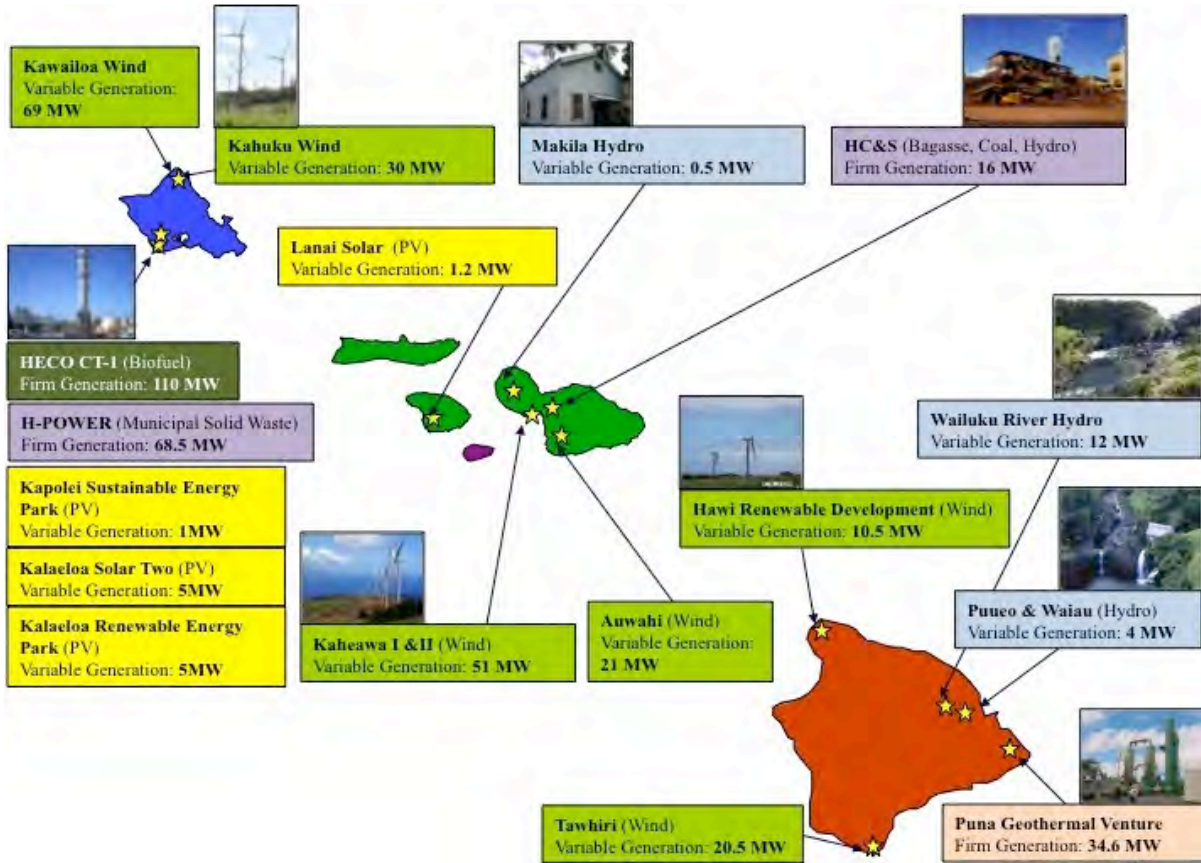


Figure 3-1. Current Clean Energy Resources

In total, the Companies have 131.2 MW of variable clean generation and 210 MW of firm clean generation.

### Renewable Generation Resources

The renewable energy generated by all three operating utilities is comprised of a number of resources. In total, we have attained an RPS of 34.4%.

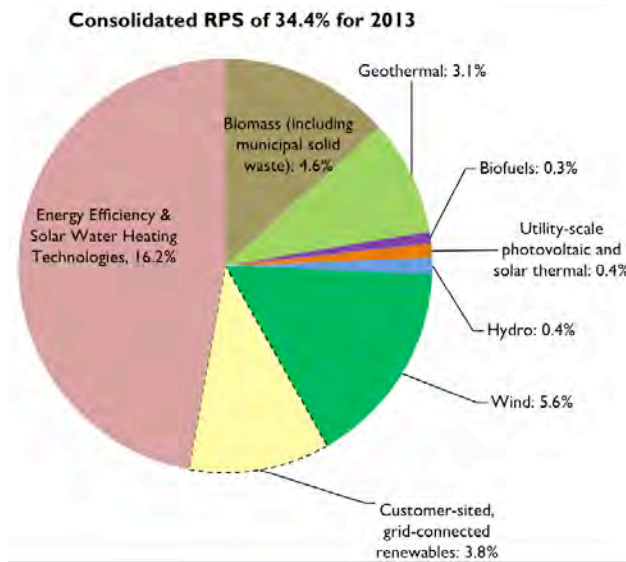


Figure 3-2. Consolidated RPS of 34.4% for 2013

### Photovoltaic Installations

The last ten years have witnessed an explosion in PV generation, mostly from individual distributed generation. By the last quarter of 2013, the amount of megawatts generated has grown almost 170 times greater as compared to only seven years earlier (in 2005).

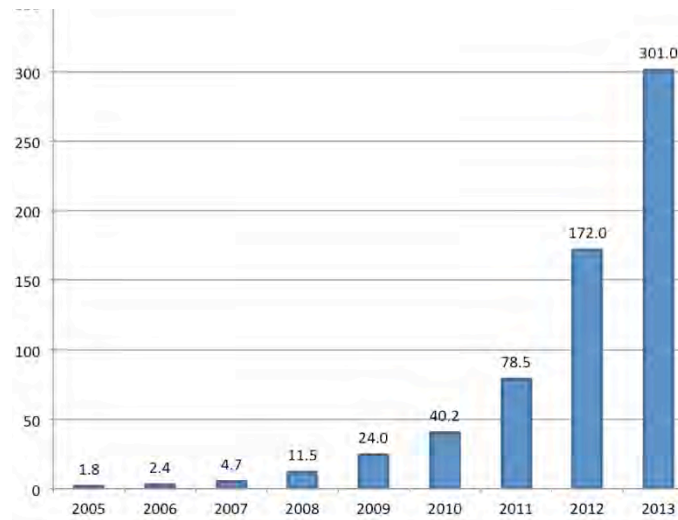


Figure 3-3. Photovoltaic Generation Growth: 2005 through 2013

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## MAUI ELECTRIC GENERATION

### Maui Electric Generation Mix

Maui Electric Company owns and operates three island electric grids on the islands of Maui, Moloka'i, and Lana'i. Each island has its own unique physical grid design based on system load, demand, and customer needs.

Maui Electric generates the majority of its power from combined cycle and internal combustion engine units, as well as a growing portfolio of renewable energy. Maui's total firm capacity is 262.28 MW (net). Lana'i's total firm capacity is 10.40 MW (gross). Moloka'i's total firm capacity is 12.01 MW (gross).

Maui Electric's generation portfolio is composed of a mix of renewable and firm resources. Our current generation mix allows us to integrate significant amounts of renewable energy when available, while ensuring reliability for our customers.

### Maui Island Grid

The Maui grid includes a growing portfolio of variable renewable energy that includes wind, solar photovoltaic, and hydropower. Our firm generation resources include centralized generating stations comprised of combined cycle and internal combustion engine units, oil-fired steam units, and biomass.

Energy delivery on the Maui System from the generation stations is through a 69kV transmission and 23kV sub-transmission lines. Maui has 65 distribution substations, situated near large customer load centers (towns, industrial centers, subdivisions) to allow power to be extracted from the transmission network and lowered to voltages that can be safely and efficiently distributed to customers.

### Maui Utility-Owned Generation

Maui Electric owns and operates two generating stations and one distributed generation site on Maui.

Our Kahului Power Plant has four steam units totaling 35.92 MW (net) of firm capacity. Two of the four units were deactivated in accordance with our Curtailment Reduction Plan, but can be reactivated in the event of a shortfall.

Our Hana Substation No. 41 has two diesel units totaling 1.94 MW (net) of firm capacity.



Our Ma'alaea Power Plant has 15 diesel units, a combined cycle gas turbine, and two combined/simple cycle gas turbines totaling 208.42 MW (net) of firm capacity.

Hawaiian Commercial & Sugar is an independent power producer that uses a mix of biomass, coal, and hydroelectric resources to provide firm and supplemental generation to the Maui system.

| Unit                       | Fuel        | Type                                   | Net-Reserve MW | Net-Normal Top Load MW |
|----------------------------|-------------|--|----------------|------------------------|
| <b>Kahului</b>             |             |  |                |                        |
| K1                         | Fuel Oil #6 | Steam                                  | 5.62           | 4.71                   |
| K2                         | Fuel Oil #6 | Steam                                  | 5.77           | 4.76                   |
| K3                         | Fuel Oil #6 | Steam                                  | 12.15          | 10.98                  |
| K4                         | Fuel Oil #6 | Steam                                  | 12.38          | 11.88                  |
| <i>Total KPP</i>           |             |  | 35.92          | 32.33                  |
| <b>Hana</b>                |             |  |                |                        |
| H1                         | Diesel      | Diesel                                 | 0.97           | 0.97                   |
| H2                         | Diesel      | Diesel                                 | 0.97           | 0.97                   |
| <b>Ma'alaea</b>            |             |  |                |                        |
| M1                         | Diesel      | Diesel                                 | 2.50           | 2.50                   |
| M2                         | Diesel      | Diesel                                 | 2.50           | 2.50                   |
| M3                         | Diesel      | Diesel                                 | 2.50           | 2.50                   |
| M4                         | Diesel      | Diesel                                 | 5.51           | 5.51                   |
| M5                         | Diesel      | Diesel                                 | 5.51           | 5.51                   |
| M6                         | Diesel      | Diesel                                 | 5.51           | 5.51                   |
| M7                         | Diesel      | Diesel                                 | 5.51           | 5.51                   |
| M8                         | Diesel      | Diesel                                 | 5.48           | 5.48                   |
| M9                         | Diesel      | Diesel                                 | 5.48           | 5.48                   |
| M10                        | Diesel      | Diesel                                 | 12.34          | 12.34                  |
| M11                        | Diesel      | Diesel                                 | 12.34          | 12.34                  |
| M12                        | Diesel      | Diesel                                 | 12.34          | 12.34                  |
| M13                        | Diesel      | Diesel                                 | 12.34          | 12.34                  |
| M14, M15, M16              | Diesel      | Combined Cycle Gas Turbine             | 56.78          | 56.78                  |
| M17, M18, M19              | Diesel      | Two Combined/Simple Cycle Gas Turbines | 56.78          | 56.78                  |
| X1                         | Diesel      | Diesel                                 | 2.50           | 2.50                   |
| X2                         | Diesel      | Diesel                                 | 2.50           | 2.50                   |
| <i>Total MPP</i>           |             |  | 208.42         | 208.42                 |
| <i>Total Utility Owned</i> | —           | —                                      | 246.28         | 242.69                 |

Table 3-2. Maui Utility-Owned Generation Units

### 3. Current Generation Resources

#### Maui Electric Generation

#### Lana'i Utility-Owned Generation

The Lana'i grid includes a centralized generating station with nine (9) diesel units with 10.4 MW of capacity. In addition the La Ola photovoltaic farm, owned by Lana'i Sustainability Research, contributes 1.2-MW.

Miki Basin Units LL-1 to LL-6 (six 1,000 kW diesel engine-generator units totaling 6,000 kW) were converted to peaking status at the end of 2006, and as such, can be relied on for 5,000 kW of capacity to the Lana'i system. Lana'i's distribution system is operated at 12.47 kV, 6.6 kV, and 2.4 kV. Lana'i does not currently have any transmission lines in place.

| Unit           | Fuel   | Type          | Gross-Reserve MW | Gross-Normal Top Load MW |
|----------------|--------|---------------|------------------|--------------------------|
| LL1            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL2            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL3            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL4            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL5            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL6            | Diesel | Peaking       | 1.00             | 1.00                     |
| LL7            | Diesel | Firm Capacity | 2.20             | 2.20                     |
| LL8            | Diesel | Firm Capacity | 2.20             | 2.20                     |
| Manele Bay CHP | Diesel | Firm Capacity | 1.00             | 0.83                     |
| <i>Total</i>   | —      | —             | <i>10.40</i>     | <i>10.23</i>             |

Table 3-3. Lana'i Utility-Owned Generation Units

### Moloka'i Utility-Owned Generation

Moloka'i has capacity to generate 12.0 MW (gross) of power at the Pala'au Power Plant.

The Moloka'i grid includes a centralized generating station with nine (9) diesel internal combustion units and one (1) diesel combustion turbine. It includes an overhead transmission line from Pala'au Generation Plant to Pu'unana Substation. Moloka'i's transmission and distribution systems are operated at 34.5 kV, 12.47 kV, 4.16 kV, and 2.4 kV respectively.

| Unit         | Fuel   | Type          | Gross-Reserve MW | Gross-Normal Top Load MW |
|--------------|--------|---------------|------------------|--------------------------|
| Pala'au #7   | Diesel | Firm Capacity | 2.2              | 2.20                     |
| Pala'au #8   | Diesel | Firm Capacity | 2.2              | 2.20                     |
| Pala'au #9   | Diesel | Firm Capacity | 2.2              | 2.20                     |
| Pala'au #10  | Diesel | Firm Capacity | 2.2              | 2.20                     |
| Pala'au #1   | Diesel | Peaking       | 1.25             | 1.25                     |
| Pala'au #2   | Diesel | Peaking       | 1.25             | 1.25                     |
| Pala'au #3   | Diesel | Peaking       | 0.97             | 0.97                     |
| Pala'au #4   | Diesel | Peaking       | 0.97             | 0.97                     |
| Pala'au #5   | Diesel | Peaking       | 0.97             | 0.97                     |
| Pala'au #6   | Diesel | Peaking       | 0.97             | 0.97                     |
| <i>Total</i> | —      | —             | <i>12.01</i>     | <i>12.01</i>             |

Table 3-4. Moloka'i Existing Generation Units

Pala'au units 1 and 2 (two 1,250 kW Caterpillar units), and Pala'au Units 3, 4, 5, and 6 (four 970 kW Cummins units) operate in peaking service. Because of the age and operating history of these units, Maui Electric includes one Caterpillar unit and two Cummins units (1,250 + 970 + 970 = 3,190 kW) towards firm capacity for the Moloka'i system.

### 3. Current Generation Resources

Maui Electric Generation

#### Maui Electric Renewable Generation

Compared to a 15.3% RPS attainment in 2010, Maui Electric has almost doubled the amount of renewable energy on the system to 29.1% in 2013.

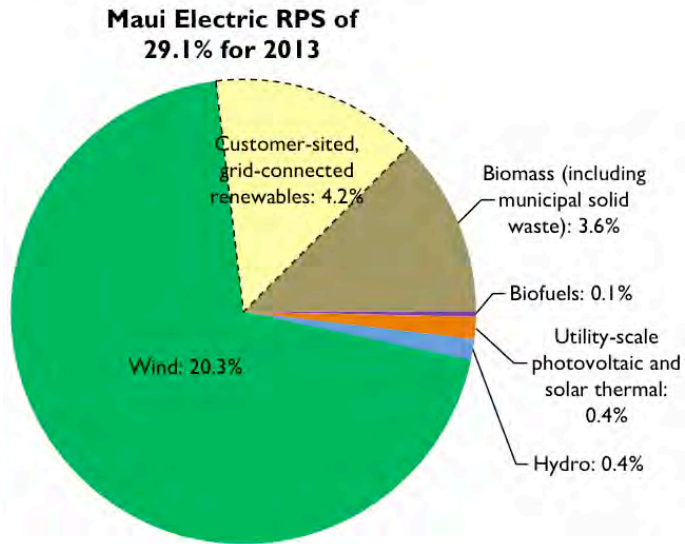


Figure 3-4. 2013 Maui Electric RPS Percent

## Variable Resources

As of December 31, 2013, there was also 126.6 MW of capacity from renewable sources on Maui, Lana'i, and Moloka'i.

Maui Electric's system incorporates wind energy from three wind farms totaling 72 MW of variable renewable generation on Maui island via power purchase agreements.

Kaheawa I consists of 20 wind turbines that provide us with 30 MW of variable capacity.

Kaheawa II consists of 14 wind turbines that provide us with 21 MW of variable capacity.

Auwahi consists of 8 wind turbines that provide us with 21 MW of variable capacity.

Makila hydroelectric unit provides Maui Electric with 0.5 MW of variable capacity.

| Unit                                 | Energy               | Rating MW    | Type                 |
|--------------------------------------|----------------------|--------------|----------------------|
| Hawaiian Commercial & Sugar (Maui)   | Bagasse, Coal, Hydro | 12.0<br>4.0  | Firm<br>Supplemental |
| Kaheawa I (Maui)                     | Wind                 | 30.0         | Variable             |
| Kaheawa II (Maui)                    | Wind                 | 21.0         | Variable             |
| Makila Hydro (Maui)                  | Hydro                | 0.5          | Variable             |
| Auwahi (Maui)                        | Wind                 | 21.0         | Variable             |
| La Ola Solar (Lana'i)                | Solar PV             | 1.2          | Variable             |
| NEM and FIT (Maui, Lana'i, Moloka'i) | Mostly Solar PV      | 41.7         | Variable             |
| <i>Total</i>                         | —                    | <i>131.4</i> | —                    |

Table 3-5. Renewable Generation on Maui, Lana'i, and Moloka'i (December 31, 2013)

### 3. Current Generation Resources

#### Maui Electric Distributed Generation

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## MAUI ELECTRIC DISTRIBUTED GENERATION

Distributed generation, mostly photovoltaics, are being installed by our customers on many of our distribution feeders. The growth of PV systems has been exponential on all of our major islands. All three operating utilities are in the Solar Electric Power Association's top 10 PV per capita. The accompanying maps show just how "distributed" the distributed generation on the island are, and the transmission and distribution challenges this presents.

### Maui Distributed Generation

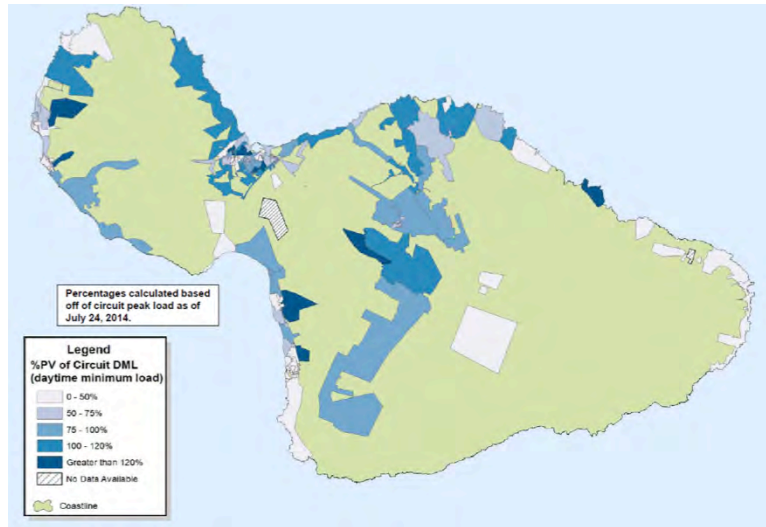


Figure 3-5. Maui Distributed Generation Map

### Lana'i Distributed Generation

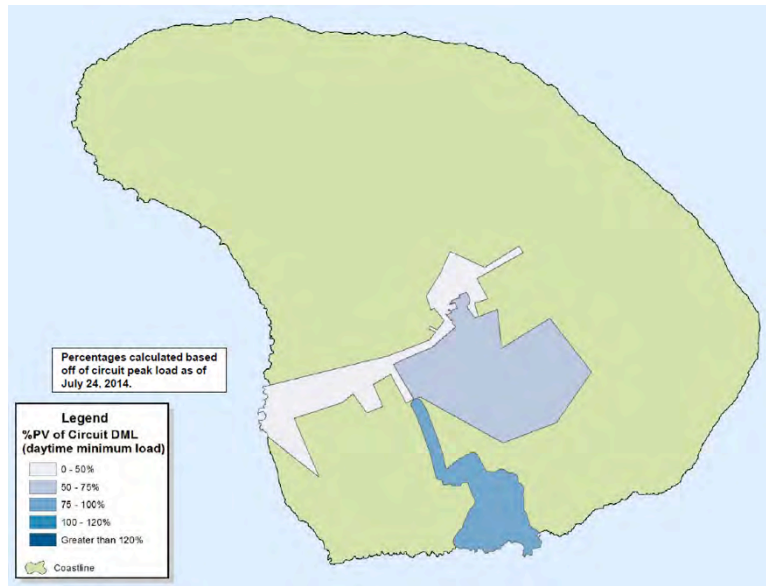


Figure 3-6. Lana'i Distributed Generation Map

### Moloka'i Distributed Generation

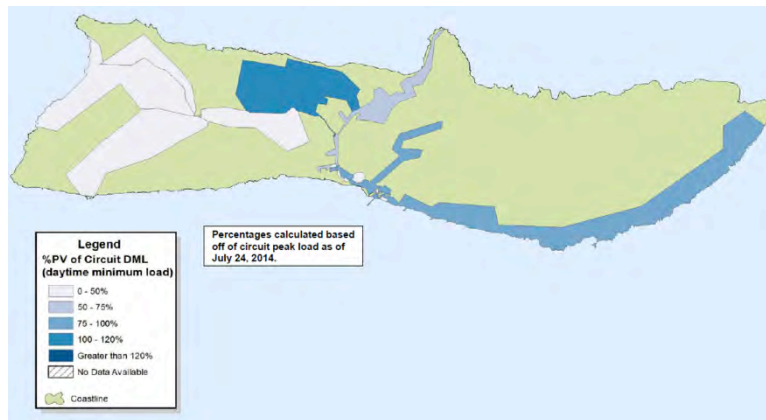


Figure 3-7. Moloka'i Distributed Generation Map

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## O'AHU–MAUI GRID INTERCONNECTION

For several years, the idea of inter-island cables between O'ahu and the neighbor islands have been discussed. An interisland cable would involve developing a High Voltage Direct Current (HVDC) submarine cable interconnection between islands. Submarine HVDC systems utilize a mature technology with very high service reliability. There are many such systems in operation around the world.

There are two fundamental purposes for such interconnections:

- Increase renewable energy penetration for O'ahu: One of the state of Hawai'i's major goals is to increase renewable generation. The majority of the state's population, and thus the majority of the Hawaiian Electric Companies' system load, is on O'ahu. Conversely, much of the best renewable resource potential is on the neighbor islands, particularly Maui County and Hawai'i Island.
- Increase the overall operating efficiencies of the O'ahu and Maui power systems: It may be possible to improve the efficiencies of the O'ahu and Maui systems by jointly dispatching the two systems utilizing an interconnection.

The use of a submarine cable to interconnect remote renewable generators to O'ahu makes sense only if sufficient renewable resources cannot be sourced on O'ahu. In the preferred plan, it appears that the 40% RPS goal by 2030 can be met with a combination of additional wind, utility scale solar and biofuels, without the need to import renewable generation from other islands. Therefore, for purposes of this PSIP, the Companies have not considered HVDC submarine cables to access additional renewable resources. If in the future, this key planning assumption proves to be incorrect, an inter-island cable could become feasible for this purpose. This planning assumption does not preclude proposals for neighbor island-sited renewable generation to serve O'ahu through a submarine cable, provided that such proposals are cost effective and reliable, relative to other options available to Hawaiian Electric.

With respect to the benefits of using interisland cables to achieve joint dispatch benefits between the Hawaiian Electric and Maui Electric systems, the PSIP analyses did include an evaluation of an interconnection between O'ahu and Maui.

### O'ahu–Maui Interconnection Specifications

The assumed O'ahu–Maui interconnection configuration for purposes of the PSIP's is two (HVDC) cables, each with a load carrying capacity of 100 MW. The 100 MW maximum size for each circuit was assumed in order to keep the single largest generating



contingency at 100 MW, or roughly the same size as the largest unit in the O'ahu system. The cable is assumed to be bi-directional: power can flow in either direction. Such a cable system would consist of:

- Two submarine HVDC cables installed between O'ahu and Maui, with separate landfall and interconnection points on either end of the cable.
- Four 100 MW each AC/DC converter stations (one for each end of each HVDC circuit); and AC interconnection facilities and system upgrades as necessary in the Hawaiian Electric and Maui Electric systems to interconnect the HVDC interisland cable system.
- All overheads necessary to site, permit, design, construct and operate the HVDC interisland cable system.

### Interisland Cable Feasibility Analysis Approach

The feasibility of utilizing an interisland cable for joint dispatch of the Hawaiian Electric and Maui Electric systems was evaluated by comparing:

- The net present value of system production costs with the Hawaiian Electric and Maui Electric systems assumed to be interconnected in a manner that allows economic dispatch of generation on both islands; to
- The sum of the present value of system production costs for each of the Hawaiian Electric and Maui Electric systems.

The difference between these two cases provides the gross benefit that could be provided by an interisland cable system that enables joint dispatch. This represents the higher bound of what an interisland cable could cost and still be economically feasible. This value was then compared to known cost estimates for an O'ahu–Maui interisland HVDC cable system<sup>13</sup>.

Using this methodology, it is not necessary to estimate the cost of this particular cable configuration. Instead, the differential computed above can be compared to known cost estimated for this proposed project. If the benefits are substantially less than the lowest interisland cable cost estimate known to date, then a cable is not economically feasible at this time. If on the other hand, the difference approaches the known cost estimate levels, then further analysis must be performed. This is a conservative approach since the existing cost estimates are for a single 200 MW HVDC system; a system with two 100 MW HVDC circuits is likely to be substantially more expensive (and complicated in terms of permitting) given the need for two routes, and two cable installations.

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<sup>13</sup> The lowest known cost estimate for an interconnection between the Maui and O'ahu systems is \$600,000,000, provided by NextEra Energy Hawai'i LLC on September 9, 2013 in Docket No. 2013-0169.

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## EMERGING RENEWABLE GENERATION TECHNOLOGIES

The Hawaiian Electric Companies considered many different renewable energy resources in our analyses for creating the PSIPs. Some of these renewable resources are currently commercially available, while others are emerging. Rather than consider the best available projections for these emerging technologies, we have based our PSIPs on readily available renewable energy resources. These include:

- Utility-scale simple-cycle combustion turbines
- Utility-scale combined-cycle combustion turbine and steam generator combinations
- Biomass and waste-fueled steam generation
- Internal combustion engine generation
- Geothermal generation
- Onshore utility-scale wind generation
- Utility-scale and small-scale solar photovoltaic generation
- Run-of-river hydroelectric
- Pumped storage hydroelectric

Several other commercially available generation technologies were also not considered appropriate for inclusion in our PSIPs (such as nuclear energy and storage hydroelectric).

### Determining Commercial Readiness

The Australian Renewable Energy Agency (ARENA) developed a Commercial Readiness Index (CRI) and released it in February 2014. We used the CRI to evaluate emerging generation options for the PSIPs because we found the CRI provided practical, objective and actionable guidance.

The CRI rates the commercial readiness level of a particular technology on a scale from 1-lowest level of readiness to 6-bankable. (See Appendix H: Emerging Renewable Technologies for more details on the rating scale.) In general, the CRI finds technologies commercially ready when:

- The technology has been implemented in a commercial setting and meets its intended need.
- The technology has been sited, permitted, built, and operated at full scale; and these challenges are well understood.

- The electricity industry, in general, accepts the performance and cost characteristics of the technology.
- Well capitalized engineering procurement construction vendors willingly provide cost and performance guarantees around an asset that uses the technology.
- A service, repair and parts system exists to support the technology.
- Financial institutions willingly accept the performance risk when underwriting technology projects.

We only considered commercially ready technologies (CRI level 5 or 6) in our PSIP modeling analyses.

### Technologies Not Commercially Ready

A number of emerging – although not commercially ready – generation technologies have been proposed for our Hawai'i power grids, including ocean wave, tidal power, ocean thermal energy storage (OTEC), and concentrated solar thermal power (CSP). See Appendix H: Emerging Renewable Technologies for details on these technologies.)

Two of these technologies hold much promise.

**Ocean Thermal Energy Conversion (OTEC).** Hawai'i is a pioneer in OTEC research, having demonstrated the first successful OTEC project on Hawai'i Island in the 1970s. Despite the technological promise of OTEC for large-scale electricity generation, no full-scale OTEC plant has yet to be built anywhere in the world. Hawaiian Electric is currently in power purchase negotiations with OTEC International (OTECI) for an OTEC facility to provide power to the island of O'ahu. In order to prove commercial readiness, OTECI would be required to complete and operate a 1 MW demonstration plant for an agreed period of time, and if successful, conduct additional incremental testing of the full-scale facility prior to full operation.

**Wave/Tidal Power.** Successful demonstration tidal and wave power projects have been implemented in several locations, including Hawai'i. We currently partner with the U.S. Navy (and others) in a small scale pilot. Small utility-scale wave power projects have been installed in Europe. Implementing large-scale tidal and wave installations has thus far been hampered by a lack of understanding of the associated siting and permitting challenged. Thus, tidal and wave power generation remains not commercially ready.

### 3. Current Generation Resources

#### Emerging Renewable Generation Technologies

## Technology Planning Assumptions versus Policy Considerations

While we limited our PSIPs plan to currently available technologies, we remain open to including future renewable technologies in our generation resource mix – when they become commercially available. We also remain open to installing pilot and demonstration projects for these and any other viable emerging renewable technology.

We welcome responses to our procurement Request for Proposals (RFPs) that include emerging technologies, and pledge to evaluate these responses on their merits.

Evaluation factors can include:

- Commercial readiness of the proposed technology.
- Community acceptance of the project proposed.
- Viability of its siting, licensing, permitting, and construction.
- Realistic site-specific costs.

Factors deemed relevant to the specific project and technology will also be included in our evaluation.

## 4. Planning Assumptions

The Hawaiian Electric Companies created this PSIP based, in parts, on a realization of the current state of the electric systems in Hawai'i, forecast conditions, and reasonable assumptions regarding technology readiness, availability, performance, applicability, and costs. As a result, this plan presents a reasonable and viable path into the future for the evolution of our power systems. We have attempted to document and be fully transparent about the assumptions and methodologies utilized to develop this plan. We recognize, however, that over time these forecasts and assumptions may or may not prove to be accurate or representative, and that the plan would need to be updated to reflect changes. As we move forward, we will continually evaluate the impacts of any changes to our material assumptions, seek to improve the planning methodologies, and evaluate and revise the plan to best meet the needs of our customers.

The PSIP analyses were conducted using production simulation planning tools that employ industry-accepted algorithms and methodologies (see Appendix C). These tools require the utility planner to develop a set of assumptions and data that allow for consistent analysis of various scenarios of interest. Figure 4-1 is a generalization of the categories of input assumptions and data that is required for production simulation analysis.

## 4. Planning Assumptions

Existing Power Systems

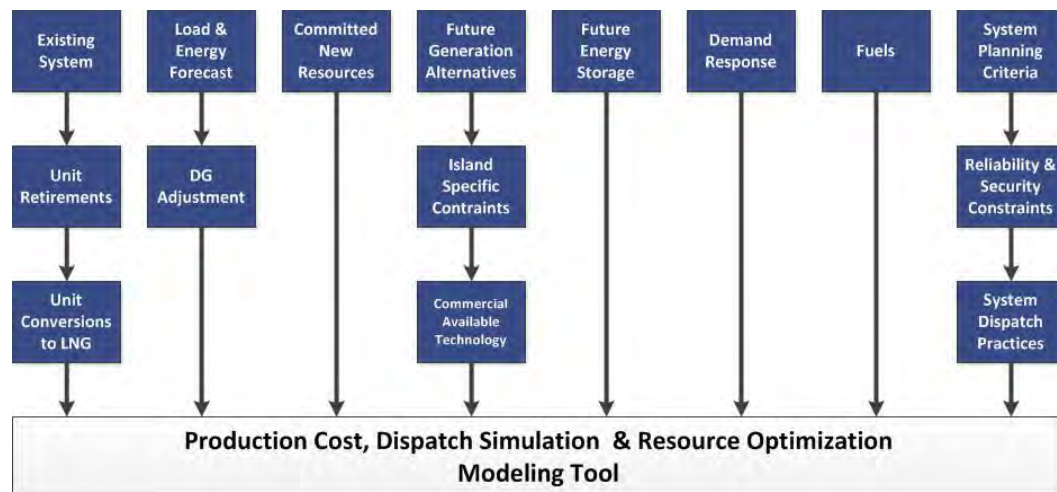


Figure 4-1. PSIP Production Simulation Model Input Hierarchy

This Chapter 4 summarizes the assumptions and data use to develop the scenarios and the results presented in this PSIP. Appendix F: Modeling Assumptions Data contains more detailed quantitative assumptions and data used in the analyses.

## EXISTING POWER SYSTEMS

The starting point for a long-range planning analysis is the existing state of the Companies' individual power systems.

### General System Descriptions

**Hawaiian Electric:** As of the end of 2013, the existing Hawaiian Electric power system on O'ahu consists of 1,298 MW of utility-owned generating capacity, 457 MW of firm Independent Power Producer (IPP) capacity, and 110 MW of variable renewable IPP capacity. There was approximately 167 MW of installed net energy metering capacity from renewable energy technologies (mainly photovoltaic) and 10 MW of installed feed-in tariff capacity. Hawaiian Electric operates 215 circuit miles of overhead 138,000 volt (also expressed as "138 kilovolts" or "138 KV") transmission lines and 8 miles of underground transmission lines, 537 circuit miles of overhead and underground 46KV sub-transmission lines, 2,231 circuit miles of overhead and underground distribution lines (nominal distribution voltages of 4.16 KV, 12.47 KV and 25 KV), 21 transmission substations and 131 distribution substations.

**Maui Electric:** As of the end of 2013, the existing Maui Electric power system on Maui consists of 243 MW of utility-owned generating capacity, 16 MW of firm IPP capacity, and 72.5 MW of variable renewable IPP capacity. Maui Electric's system on Lana'i has

10.23 MW of company-owned thermal generation, and 1.2 MW of variable IPP capacity. Maui Electric’s system on Moloka’i has 12.01 MW of utility owned capacity. There was approximately 35 MW of installed net energy metering capacity, and 2 MW of feed-in-tariff capacity within Maui Electric’s service area. Maui Electric operates 250 miles of 69-KV and 23-KV transmission lines and a 34.5-KV on Moloka’i, 8 transmission-level substations, 71 distribution substations, and 1,520 miles of 12.47-KV, 7.2-KV, 4.16-KV, and 2.4-KV distribution lines.

**Hawai’i Electric Light:** As of the end of 2013, the existing Hawai’i Electric Light power system on Hawai’i Island consists of 195 MW of utility-owned thermal generating capacity, 94.6 MW of firm IPP capacity, 4.5 MW of utility-owned variable generation and 43.1 MW of variable renewable IPP capacity. There was approximately 33 MW of installed net energy metering, and 1 MW of feed-in-tariff capacity. Hawai’i Electric Light operates 641 miles of 69-KV transmission lines, 22 transmission-level substations, 78 distribution substations, and 4,080 miles of 13.2-KV distribution lines.

Table 4-1 contrasts the nature of each of the three operating systems in terms of customer density expressed in customers per mile of distribution circuit.

|                        | Number of Customers (12/31/13) | Distribution Circuit Miles | Customers Per Mile of Distribution Line |
|------------------------|--------------------------------|----------------------------|---|
| Hawaiian Electric      | 299,528                        | 2,231                      | 134.3                                   |
| Maui Electric          | 69,577                         | 1,520                      | 45.8                                    |
| Hawai’i Electric Light | 82,637                         | 4,080                      | 20.3                                    |

Table 4-1. Customers per Mile of Distribution Line by Operating Company

### Existing Generation Units & Retirement Dates

The list of Company’s existing units is provided in Chapter 3. The retirement dates of the Company’s existing generating units, if applicable, are provided in the discussion of the Preferred Plan in Chapter 5.

#### 4. Planning Assumptions

##### Existing Power Systems

### Liquefied Natural Gas (LNG) Unit Conversion

In the preferred plan, it was assumed that certain of the Companies' units would be converted to LNG during the planning period.

#### Hawaiian Electric

- Kahe 1-6 converted to use LNG beginning in 2017
- Waiiau 5-10 converted to use LNG beginning in 2017
- Kalaeloa (IPP) converted to use LNG beginning in 2017 (at Company expense).

#### Maui Electric

- Ma'alea 14, 15, 16, 17, 19 converted to use LNG beginning in 2017
- Waena internal combustion engine (ICE) units (relocated from South Maui) converted to use LNG beginning in 2024.
- Waena Internal Combustion Engine (ICE) units relocated from South Maui and converted to use LNG beginning in 2024.

#### Hawai'i Electric Light

- Puna CT3, Keahole Combined Cycle Units (CT4, CT5) converted in 2017
- Hamakua Energy Partners (HEP) (IPP) converted (at Company expense) to use LNG in 2018.

### Existing Independent Power Producer (IPP) Contract Assumptions

During the planning period, assumptions were made regarding how certain IPP contracts would be renewed, cancelled, or renegotiated during the planning period. Existing IPP contracts expiring within the study period were assumed to continue past the expiration date of the current contract, and switch to the modeled resource pricing at the time of expiration as shown in Appendix F (on January 1 of the next year for modeling purposes). These IPPs were assumed to retain present curtailment priority and methodology. These are planning assumptions only; the dispositions of the Companies' contracts with IPPs are subject to the terms of the existing PPAs, and/or the ability of the third parties and the Company to reach mutual agreement (subject to the Commission's approval) on pricing, terms, and conditions applicable beyond the expirations of the current PPAs.



### Hawaiian Electric

- The Kalaeloa Energy Partners PPA was assumed to be extended at the end of its contract term (May 23, 2016) for six years, to 2022. At its expiration in 2022, the PPA was assumed to be renegotiated, subject to competitive procurement, and extended past the PSIP planning period.
- The AES Hawai'i PPA was assumed to be renegotiated, subject to competitive procurement, at the end of its contract term (September 1, 2022), and extended past the end of the PSIP planning period, at its full 180 MW capacity, but with a mix of 50% coal and 50% biomass for fuel.

### Maui Electric

- The HC&S PPA was assumed terminated on 12/31/18 based on expected efforts to negotiate and extend the current agreement, subject to Commission approval.
- Kaheawa Wind Power (KWP) was assumed to continue at current nameplate capacity beyond the end of its current contract in 2026, but will be paid according to pricing identified in Appendix F.
- Makila Hydro will continue at current nameplate capacity beyond the end of its current contract in 2026. For purposes of this report, the Makila Hydro payment, from January 2015 to December 2026, is assumed to be fixed at Maui Electric's August 2014 Avoided Cost per Docket No. 7310. For the period of 2027 to 2030 Makila Hydro will be paid according to pricing identified in the Appendix F.

### Hawai'i Electric Light

- Conversion of HEP to LNG in 2018.
- Hawi Renewable Development (HRD) – was assumed to continue at current nameplate capacity beyond the end of its current contract in 2021, but will be paid according to pricing identified in Appendix F.
- Wailuku River Hydro – was assumed to continue at current nameplate capacity beyond the end of its current contract in 2023, but will be paid according to pricing identified in Appendix F.
- Tawhiri - was assumed to continue at current nameplate capacity beyond the end of its current contract in 2027, but will be paid according to pricing identified in Appendix F.
- Puna Geothermal Ventures (PGV) - was assumed to continue at current nameplate capacity beyond the end of its current contract in 2027, but will be paid according to pricing identified in Appendix F.

## 4. Planning Assumptions

### Existing Power Systems

## Committed New Resources

The Companies have made certain commitments regarding new resource additions. Several of these resource commitments have received Commission approval. Others are still subject to Commission review and approval.

### Hawaiian Electric

The following future generating resources are considered to be committed for planning purposes, and are therefore included in the Base Plan and Preferred Plan for Hawaiian Electric:

- Waiver Projects: 244 MW of multiple IPP-developed solar PV projects that are being negotiated pursuant to the waivers from the framework for competitive bidding in Dockets Nos. 2013-0156 and 2013-0381. Each separate PPA for the waiver projects will require Commission approval. These projects will contribute to the Companies' RPS requirements. These projects are assumed to enter service by the end of 2016.
- Na Pua Makina Wind: 24 MW IPP-owned wind energy generation facility project near the community of Kahuku on the north shore of O'ahu. This project is assumed to enter service by the end of 2016. This project will contribute to the Companies' RPS requirements. Approval of the PPA for this project is pending in Docket No. 2012-0423.
- Mililani South Solar: 20 MW IPP-owned utility-scale solar PV project facility near Mililani, O'ahu. This project is assumed to enter service by the end of 2016. This project will contribute to the Companies' RPS requirements. Approval of the PPA for this project is pending in Docket No. 2014-0077.
- Kahe Solar PV: 11.5 MW utility-scale solar PV project that is being developed by the Hawaiian Electric at the Kahe generating station site. This project is assumed to enter service by the end of 2016. This project will contribute to the Companies' RPS requirements. Approval of this project is pending in Docket No. 2013-0360.
- Schofield Generating Station: 50 MW total, consisting of six separate reciprocating engines each having a generating capacity of 8.4 MW. Schofield Generating Station will utilize at least 50% biodiesel and will contribute to the Companies' RPS requirements. Approval of this project is pending in Docket No. 2014-0113. This project is assumed to enter service during 2017.

### Maui Electric

There are no committed resources for Maui Electric at the present time. It is assumed that Maui Electric will issue an RFP in 2015 for new generation to become available in 2019.

### Hawai'i Electric Light

The following future generating resources are considered to be committed and are therefore included in the base plan for Hawai'i Electric Light:

- Hu Honua: 21.5 MW biomass IPP-owned project at Pepekeo, Hawai'i Island. The PPA for this project was approved by the Commission in Docket 2012-0212, pursuant to Order No. 31758, issued on December 20, 2013. This project will contribute to the Companies' RPS requirements. This project is assumed to enter service in 2015.
- Geothermal RFP: Hawai'i Electric Light has to committed to modeling 25 and 50 MW of new IPP-owned geothermal projects and to issue a Request for Best and Final Offers for at least 25 MW. Pursuant to Commission Order in Docket No. 2012-0092, the Request for Best and Final Offers shall be filed no later than September 25, 2014 for Commission review and approval.

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## CAPACITY VALUE OF VARIABLE GENERATION AND DEMAND RESPONSE

Wind and solar are variable generating resources. Therefore, determining their capacity value (that is, the variable resource's ability to replace firm generation) with a high level of confidence is a considerable challenge. However this determination is a critical exercise in order to ensure that customer demand is met and system reliability is maintained.

### Capacity Value of Wind Generation

The determination of when additional firm capacity is needed is, in part, based on the application of Hawaiian Electric's generating system reliability guideline, which is 4.5 years per day loss of load probability (LOLP). The capacity value of existing and future wind resources is determined through an LOLP analysis that incorporates this guideline. The wind resources' contribution to serving load is reflected in the LOLP calculations. Accordingly, wind resources' contributions to capacity are dependent upon the composition and assumptions in each plan. Future LOLP analyses that incorporate additional wind resources may affect the actual capacity value of existing wind resources.

### Hawaiian Electric

Based on historical 2013 O'ahu wind data, the aggregate capacity value of the two existing wind farms (30 MW Kahuku Wind and 69 MW Kawailoa Wind) determined through an LOLP analysis is approximately 10 MW, or about 10% of the nameplate value of the existing wind resources.

#### 4. Planning Assumptions

##### Capacity Value of Variable Generation and Demand Response

###### Maui Electric

The aggregate value of the three existing wind farms (20 MW Kaheawa Wind Power I, 21 MW Kaheawa Wind Power II, 21 MW Auwahi Wind Energy) contribution to capacity planning is 2 MW based on historical examination of available wind capacity during the peak period hours to derive an amount which is probable during that period.

The capacity value of future wind farms for PSIP modeling purposes is 3% of the nameplate value of the facility to be added.

###### Hawai'i Electric Light

The aggregate capacity planning value of the two existing wind farms (20.5 MW Tawhiri wind farm and 10.56 MW Hawi Renewable Development wind farm) is 3.1 MW. This is based on an historical examination of available wind capacity during the peak period hours to derive an amount that is probable during the historical period. The capacity value of the hydro facilities was 0.7 MW using the same methodology used to determine the capacity value of wind.

The capacity value of future wind farms for PSIP modeling purposes is 10% of the nameplate value of the facility to be added.

#### Capacity Value of Solar Generation

The capacity value of existing and future utility-scale and rooftop PV is 0, using the same capacity valuation methodology used for the wind and hydro resources. This result is driven by the fact that variable PV does not produce during the utility's peak periods (that is, evenings). It is the utility's net peak demand that determines the need for additional capacity.

#### Capacity Value of Demand Response

The estimated megawatt potential from the Residential and Small Business Direct Load Control Program, Commercial and Industrial Direct Load Control Program, Customer Firm Generation Program, and Time-of-use Programs are included in PISP capacity planning based on the *Integrated Demand Response Portfolio Plan*.<sup>14</sup>

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<sup>14</sup> The Companies filed its *Integrated Demand Response Portfolio Plan (IDRPP)* with the Commission on July 28, 2014.

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## LOAD AND ENERGY PROJECTION METHODOLOGY

The purpose of the load (or demand) and sales (energy) forecasts in a planning study is to provide the peak demands (in MW) and energy requirements (in GWh) that must be served by the Company during the planning study period. Forecasts of peak demand and energy requirements must take into account economic trends and projections and changing end uses, including emerging end-use technologies.

The methodology for arriving at the net peak demand and energy requirements to be served by the Company begins with the identification of key assumptions such as the economic outlook, analysis of existing and proposed large customer loads, and impacts of customer-sited technologies such as energy efficiency measures and customer-owned distributed generation. Impacts from emerging technologies such as electric vehicles are also considered as they can significantly impact sales in the future.

### Sales Forecast

The underlying economic sales forecast is derived first by using econometric methods and historical sales data excluding impacts from energy efficiency measures or customer-sited distributed generation (“underlying economic sales forecast”). Estimates of impacts from energy efficiency measures, customer-sited distributed generation through the Company’s tariffed programs and electric vehicles (referred to as “layers”) were then used to adjust the underlying economic sales forecast to arrive at the final sales forecast.

### Peak Forecast

The Hawaiian Electric peak forecast is derived using Electric Power Research Institute’s Hourly Electric Load Model (HELM). Maui and Hawai’i Electric Light use Itron Inc.’s proprietary modeling software, MetrixLT. Both software programs utilize load profiles by rate schedule from class load studies conducted by the Company and the sales forecast by rate schedule. The rate schedule load profiles adjusted for forecasted sales are aggregated to produce system profiles. The Company employed the highest system demands to calculate the underlying annual system peaks. The underlying peak forecast for Lana’i and Moloka’i Divisions were derived by employing a sales load factor method that compares the annual sales in MWh against the peak load in MW multiplied by the number of hours during the year. After determining the underlying peak forecast, the Company made adjustments that were outside of the underlying forecasts, for example impacts from energy efficiency measures. No adjustments were made to the underlying system peak forecast for customer-sited distributed generation or electric vehicles as forecasted system peaks are expected to occur during the evening. It was assumed most

#### 4. Planning Assumptions

##### Load and Energy Projection Methodology

of the distributed generation would be PV systems without batteries and electric vehicle charging was not expected to significantly affect the evening peak.

### Customer-Sited Distributed Generation

The projections for impacts associated with customer-sited distributed generation were developed separately for residential and commercial customers and aggregated into an overall forecast for distributed generation, predominantly PV systems. Eligible market size was based on technical penetration limits, absolute sizes of customer classes, and future growth assumptions. In the near term (through 2016) a set rate of interconnections under the existing company tariffs were used based on simplified assumptions about queue release and the pace of new applications. Beyond 2016 the Company assumed that a new distributed generation tariff structure (“DG 2.0”) would be implemented across all customer classes. Benchmarked relationships between the payback period of PV systems and customer uptake rates, projected market demand for new PV systems among all residential and commercial customer classes were applied to installed PV capacity as of year-end 2016 as a starting point for the long term. For purposes of modeling, PV energy production levels for hourly or sub-hourly information are derived from actual solar irradiance field data. Consistent with the Distributed Generation Interconnection Plan, beyond 2016, DG PV is assumed to provide active power control and is therefore curtailable during periods when the system cannot accept excess DG energy. The DG curtailment priority is assumed to be senior to transmission-connected utility-scale resources, that is, DG is curtailed after utility-scale resources are curtailed.

### Energy Efficiency

The projections for impacts associated with energy efficiency measures are consistent with impacts achieved by the Public Benefits Fund Administrator, Hawai‘i Energy, over the next five to ten years. The Company assumed that it would take several years before changes to building and manufacturing codes and standards are integrated into the marketplace. Following these types of changes, the impacts would grow at a faster pace in order to meet the longer term energy efficiency goals (expressed in GWh) identified in the framework that governs the achievement of Energy Efficiency Portfolio Standards (EEPS) in the State of Hawai‘i as prescribed in Hawai‘i Revised Statutes § 269-96 and set by the Commission in Decision and Order No. 30089 in Docket No. 2010-0037.

### Electric Vehicles

The development of the electric vehicles forecast was based on estimating the number of electric vehicles purchased per year then multiplying that number by an estimate of “typical” electric consumption using charging requirements for plug-in hybrid electric

vehicles. As with any emerging technology, estimating impacts are challenging because the technology is so new and historical adoption and impact data is limited.

## Demand and Energy Requirements

The demand served and energy generated by the Company is greater than the demand and energy requirements at the customer’s location (net of the amount conserved or self-supplied) due to energy losses that occur in the delivery of power from a generator to a customer. Customer level demand and energy forecasts are increased accordingly to account for these losses.

The net results are the quantities of demand and energy that must be supplied from the Company’s generating fleet, including assets owned by the Company and assets owned by third parties who sell to the Company under Power Purchase Agreements (that is, utility-scale independent power producers).

### Peak Demand Forecasts

The peak demands of each operating Company forecasted through the study period (expressed at the net generation level) are shown in Figure 4-2 through Figure 4-6.

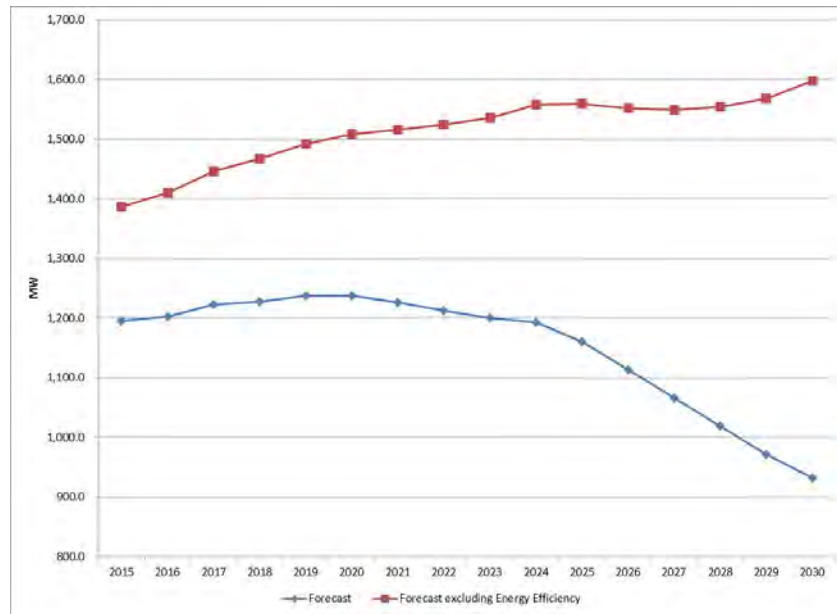


Figure 4-2. Hawaiian Electric Peak Demand Forecast (Generation Level)

#### 4. Planning Assumptions

##### Load and Energy Projection Methodology

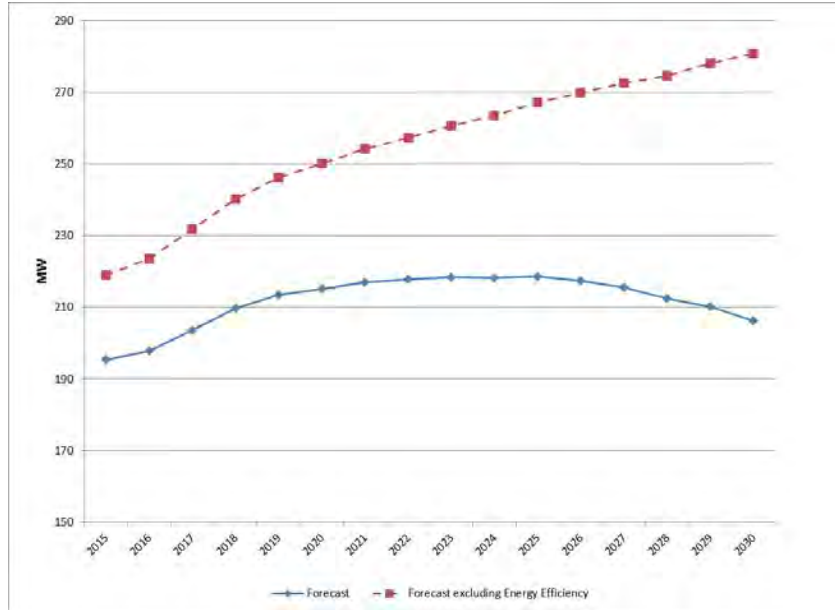


Figure 4-3. Maui Peak Demand Forecast (Generation Level)

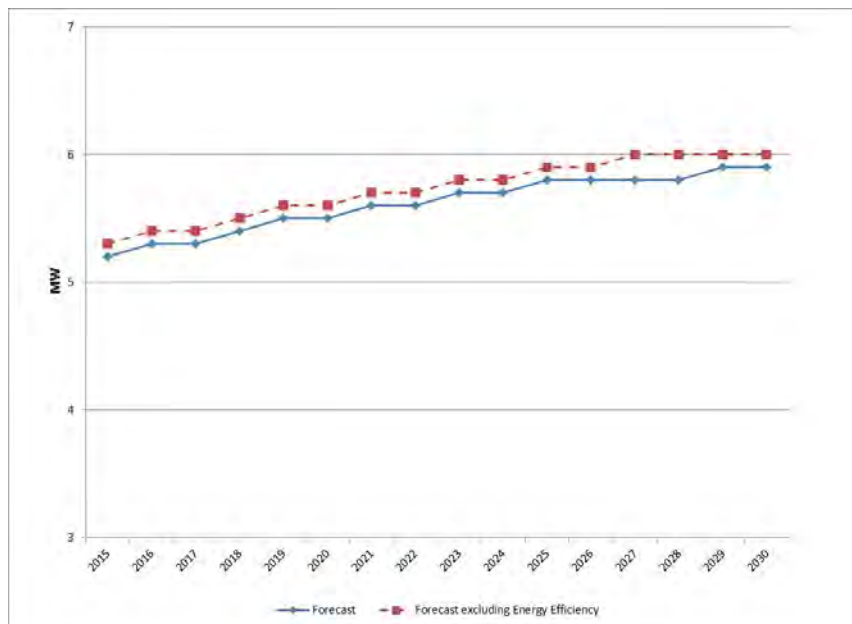


Figure 4-4. Lana'i Peak Demand Forecast (Generation Level)



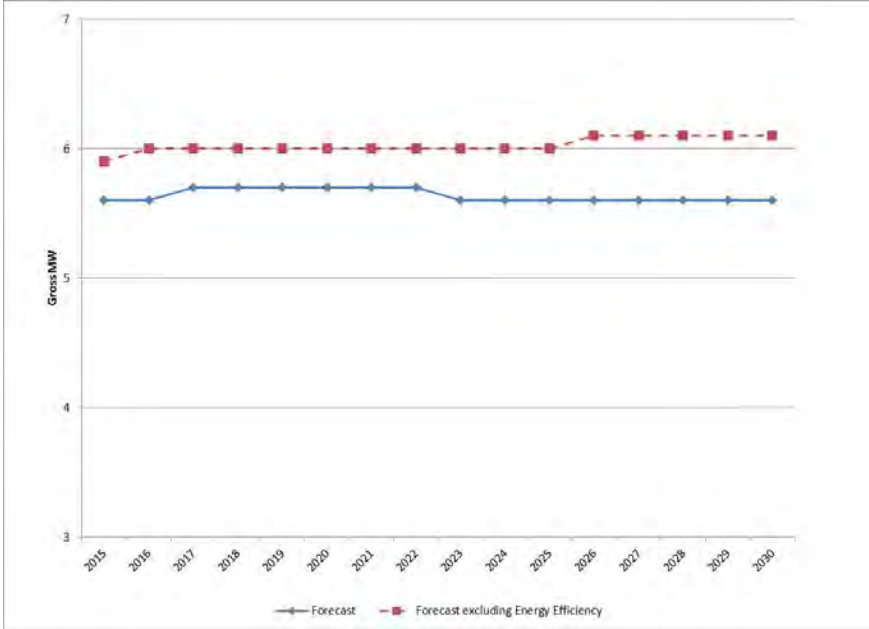


Figure 4-5. Moloka'i Peak Demand Forecast (Generation Level)

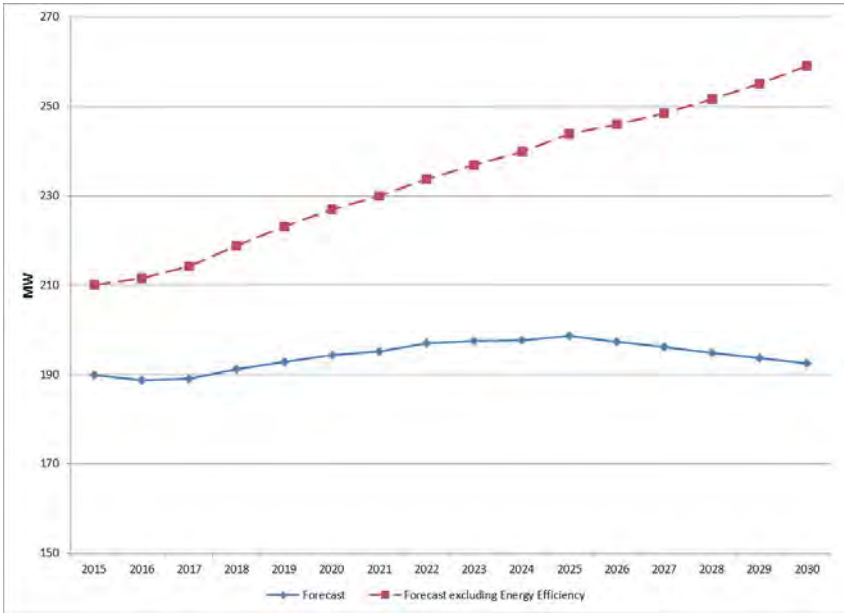


Figure 4-6. Hawai'i Electric Light Peak Demand Forecast (Generation Level)

Energy Sales Forecasts

The forecasts of energy requirements to be served by each operating Company through the study period (expressed at the customer level) are shown in Figures 4-7 through 4-11.

#### 4. Planning Assumptions

##### Load and Energy Projection Methodology

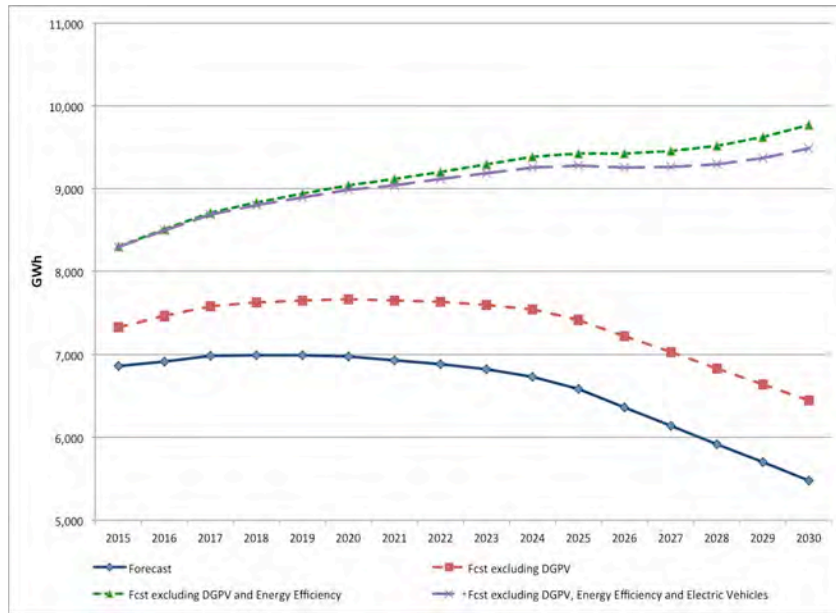


Figure 4-7. Hawaiian Electric Energy Sales Forecast (Customer Level)

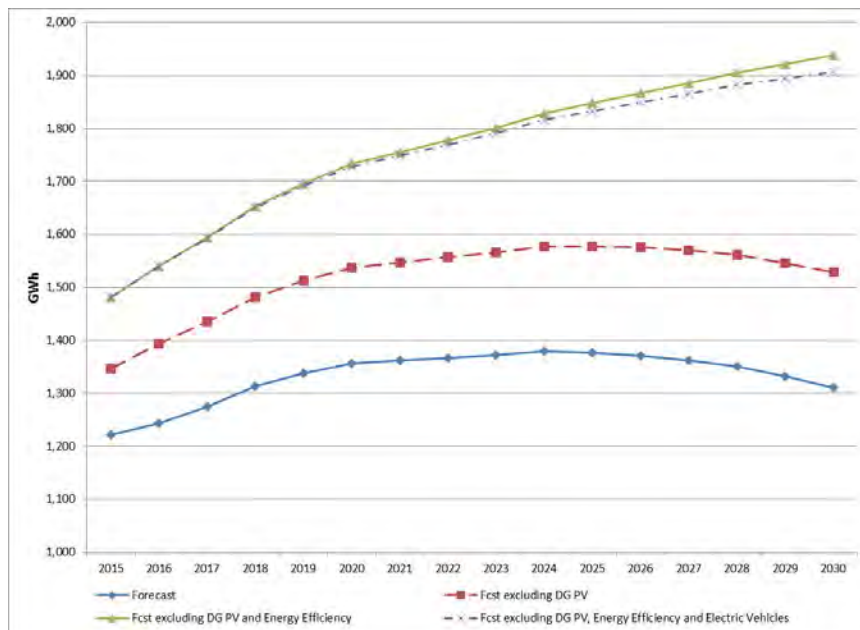


Figure 4-8. Maui Energy Sales Forecast (Customer Level)

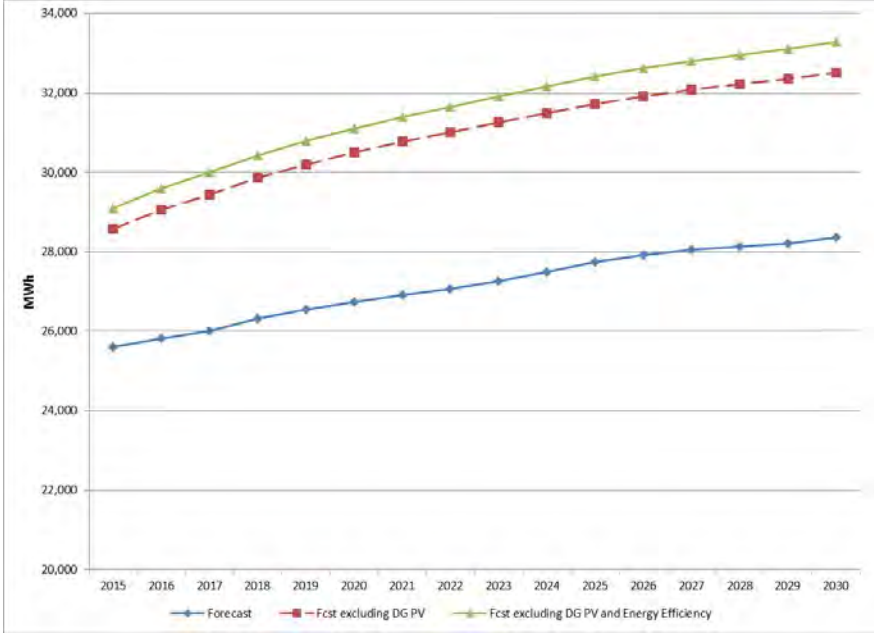


Figure 4-9. Lana'i Energy Sales Forecast (Customer Level)

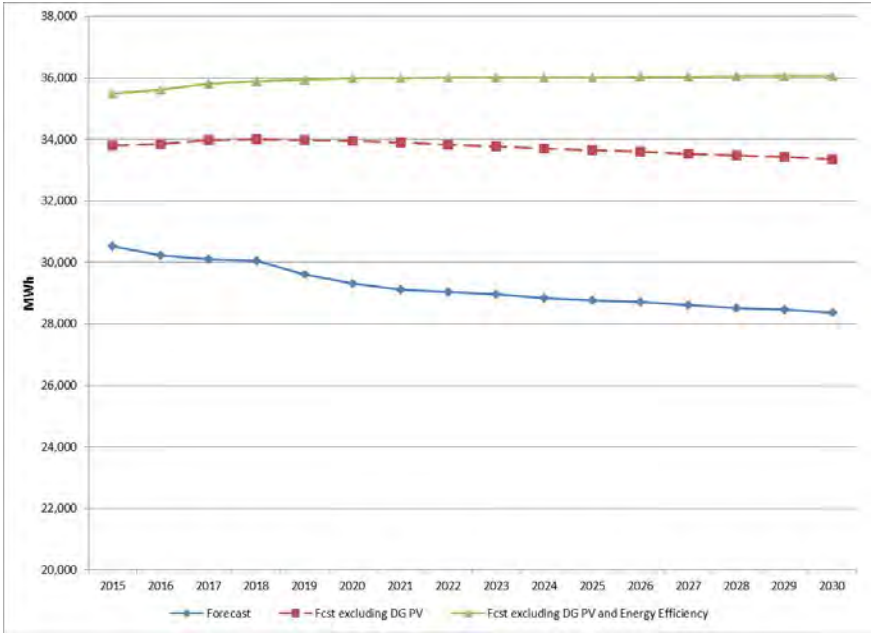


Figure 4-10. Moloka'i Energy Sales Forecast (Customer Level)

## 4. Planning Assumptions

### Load and Energy Projection Methodology

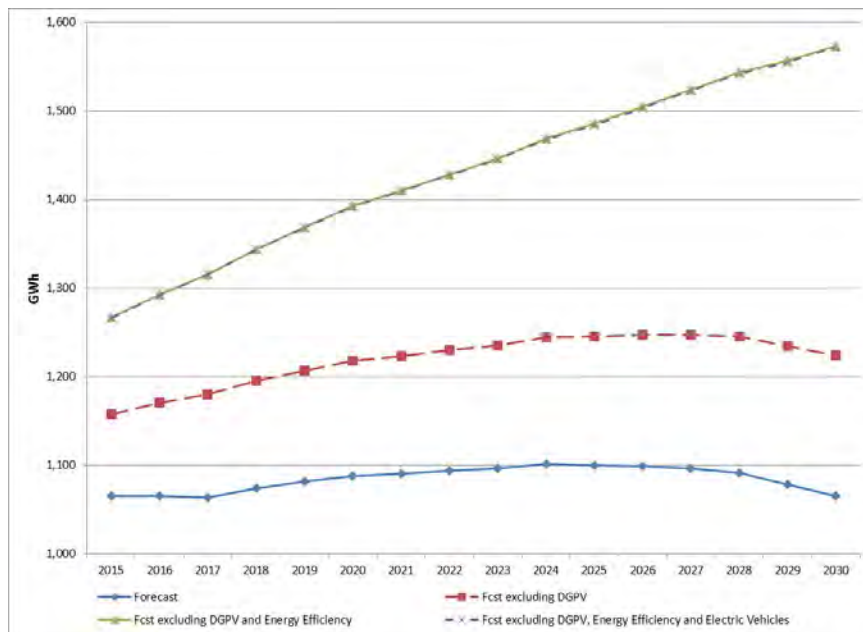


Figure 4-11. Hawai'i Electric Light Energy Sales Forecast (Customer Level)

It is important to note that both the net peak demand and the net energy requirements, which the Company is obligated to serve, are relatively flat and even decline towards the end of the study period. This is the result of energy efficiency and an assumed future level of customer-owned distributed generation (mostly distributed solar PV).

In addition to the forecasts described above, the Company incorporated the effects of implementing dynamic and critical peak pricing programs. Load shifting and energy savings could be realized through the implementation of these programs. Hourly load adjustment factors were based upon the application of demand elasticity adjustments to assumed time of use rate structures. Refer to Chapter 4 of the Integrated Demand Resource Portfolio Plan filed on July 28, 2014 under Docket No. 2007-0341 for additional information on the programs.

## Load Profiles

A very important assumption related to the demand and energy forecast is the profile of the demand over a given time period for example, a day, week, month, or year. Of interest to the modeler is the demand profile net of customer-owned generation, since the net profile is what must be met through the dispatch of resources available to the system.

For the PSIP runs, the load profile was modeled two ways: 1) the PSIP analyses were performed using an annual hourly load profile (that is, 8,760 data points for a year) was used to model the system, and 2) the PSIP sub-hourly analyses used 5-minute load profile data (that is, 105,120 data points for a year). The sub-hourly models were used to

more accurately model intra-hour issues associated with ramping of generating resources and energy storage in response to variable renewable generation.

The net load profile of the system has changed dramatically over the past few years as a result of the proliferation of customer-sited distributed generation in the system. For the PSIP, a system gross load profile is assumed, and the profile of customer-sited distributed generation is subtracted out, resulting in the net load profile.

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## FUTURE RESOURCE ALTERNATIVES

### Generation Alternatives

The following generating technologies were considered as resource options in the PSIP analyses. More detailed descriptions of each are found in Appendix F.:

- Simple-cycle combustion turbines
- Combined-cycle
- Internal combustion engines
- Geothermal
- On-shore wind
- Utility-scale solar PV
- Waste-to-energy
- Pumped-storage hydroelectric (see Appendix J)
- Biomass

### Distributed Solar Generation (DG-PV )

The DG-PV forecast was determined outside of the resource optimization models, and therefore, the DG-PV forecast is a fixed input for purposes of the PSIP optimization models. Therefore, distributed generation was not treated as a resource “option” in the generation optimization models. If DG-PV is added as a resource option in the resource optimization models, DG-PV will never be selected it as an economical choice. In addition, utility-scale fixed-tilt solar will produce more energy per KW of installed solar PV capacity because the panel tilt and orientation of utility-scale solar can be more precise than can be achieved with distributed solar PV. This is reflected in the planning assumptions for solar PV where the utility-scale PV has a higher capacity factor than DG-PV.

During the study period, the amount of total installed DG on the Companies' systems is assumed to increase almost three-fold, from 328 MW (as of 7/15/2014) to just over 900 MW by 2030. The resulting installed DG capacity represents over 65% of the forecasted peak demands of the Companies in 2030, resulting in one of the most aggressive DG-PV programs in the world. Integrating this amount of DG-PV without affecting system reliability is a sizeable challenge that is addressed in Chapter 5. Figure 4-12 shows the forecast assumptions for DG-PV.

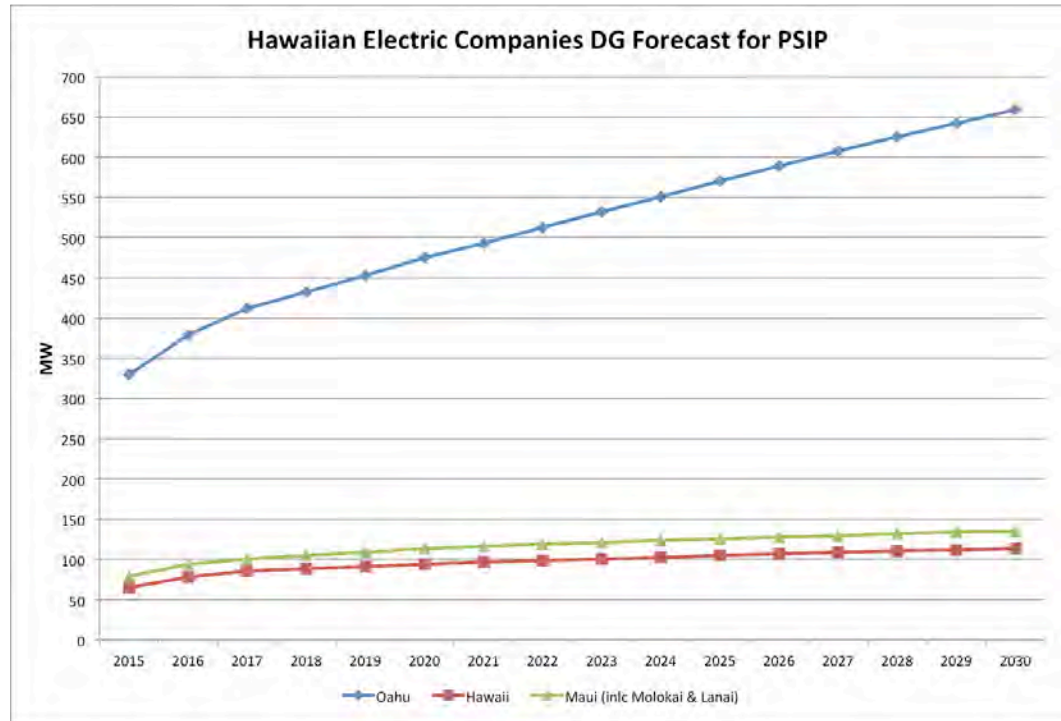


Figure 4-12. Installed DG Forecasts

### Constraints on Generation Alternatives

The Companies made certain assumptions regarding the aggregate amounts of resource-types that can be installed across their service areas ("constraints"). The generation resource constraints were based on land availability, resource (for example, water availability, waste availability, etc.) limitations, available sites, commercial readiness and other factors that constrain the installation of certain resource types on specific islands. Siting constraints were not assumed for thermal generating resources and energy storage; rather it is assumed that those resources can be located on or near existing power plant and substation sites. The generating resource constraints by island are summarized in Table 4-2.

| Constrained Resource Type | Resource Constraint by Island<br>(Incremental to Existing and Committed) |          |          |
|---------------------------|--|----------|----------|
|                           | O'ahu  | Maui     | Hawai'i  |
| Geothermal                | 0 MW   | 25 MW    | 50 MW    |
| On-Shore Wind             | 50 MW  | > 500 MW | > 500 MW |
| Solar PV (Utility Scale)  | 360 MW   | > 500 MW | > 500 MW |
| Waste-to-Energy           | 0 MW   | 10 MW    | 5 MW     |
| Pumped Storage Hydro      | 50 MW  | 120 MW   | 90 MW    |
| OTEC                      | 100 MW   | 0 MW     | 0 MW     |
| Biomass                   | 30 MW  | 0 MW     | 34 MW    |
| Ocean Wave / Tidal        | 0 MW   | 0 MW     | 0 MW     |

Table 4-2. PSIP Assumed Incremental New Resource Constraints by Island

### New Generation Planning Assumptions vs. Future RFPs

The resource options and constraints discussed above are intended only for use as planning assumptions for the 2014 Power Supply Improvement Plans. The resource options and constraint assumptions set forth herein should not be interpreted as a policy position of the Hawaiian Electric Companies. The resource options and constraint assumptions set forth herein do not modify any of the Companies' policies and / or positions with respect to any ongoing or proposed PPA negotiation, pilot projects, or demonstration projects in which the Companies participate.

Third parties' responses to any future Request for Proposals by the Companies for the procurement of power supply resources and/or energy storage resources may include any resource option on any island, unless specifically excluded by the terms of the RFP, based on specific technical requirements. Any such proposals received by the Companies in response to a power supply and/or energy storage RFP will be evaluated on their merits. Such evaluation will include, at a minimum:

- Site control status.
- The commercial readiness of the technology proposed.
- Community acceptance of the project proposed.
- Confidence level regarding the ability to site, license, permit, and constructability the project proposed.
- Confidence level regarding the site-specific costs of the project proposed.
- Any other evaluation factors deemed relevant in an approved RFP document.

## Cost and Operating Characteristics of New Generation Alternatives

The assumptions for capital cost for new generating resource options is based on the *Cost and Performance Data for Power Generation Technologies*, a report prepared for the National Renewable Energy Laboratory, by Black & Veatch, February 2012<sup>15</sup>. The Company intends to seek competitive bids for all new generating resources beyond the present committed additions. If the least cost resource proposals received indicate costs that are higher than what has been assumed in this PSIP, the capital costs associated with resource additions will be higher.

The detailed cost and operating characteristics of generation alternatives are included in Appendix F – Modeling Assumptions Data.

## Acquisition Model for New Generating Resources

For purposes of the PSIP analyses, all new generating resources (beyond committed generating resources) are assumed to be owned by third parties. A surrogate for third party pricing was determined in two steps:

- The projected cash flow associated with the new generation resource (excluding fuel and variable O&M costs) were computed based on capital costs, operating costs, and utility revenue requirement profiles as if the utility owned the project.
- This cash flow was then levelized using the utility's cost of capital to obtain a levelized cost of the resource, which was assumed to be the PPA price.

Fuel costs and variable O&M were treated as pass-through costs for modeling purposes and will be included in bill impact calculations in the financial model.

This is a simplifying assumption for purposes of the PSIPs and is not intended to convey any preference or lack thereof for an acquisition model for future generating resources. At the time a resource acquisition is considered, the Companies will evaluate the appropriate business model for each new resource based on what is in the best interest of customers.

## Energy Storage Alternatives

Utility scale energy storage options are made available as a resource option in the PSIP production modeling. Appendix J: Energy Storage Plan contains a complete discussion of energy storage, including pricing and operating assumptions for energy storage. Energy storage is considered for providing ancillary services, to meet security constraints, and for load shifting.

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<sup>15</sup> This report is available at <http://bv.com/docs/reports-studies/nrel-cost-report.pdf>.



The following storage durations were considered for energy storage to serve the indicated purpose:

- Regulating Reserves: 30 min
- Regulating Capacity: 30 min
- Contingency Reserves: 20 min
- Long-term Reserves: 3 hours
- Inertial, Fast Response Reserves: 0.05 min

## Demand Response

The following demand response programs were considered in the PSIP analysis:

- Residential Direct Load Control (RDLC)
- Residential Flexible
- Commercial & Industrial Direct Load Control (CIDLC)
- Commercial & Industrial Flexible
- Water Pumping
- Customer Generation
- Time-of-Use (TOU) and Critical Peak Pricing (CPP)

The assumed impacts on capacity needs and energy requirements from these programs are detailed in Appendix F – Modeling Assumptions data.

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## FUEL PRICE FORECAST

The Companies anticipate continued consumption of liquid and gaseous fuels during the study period. However, the preferred plan incorporates a major shift away from imported liquid fuels (fuel oil, diesel, etc.) to biofuels and natural gas from LNG. In particular, the following fuels are available to the planning models during the planning period:

- Natural gas (from LNG)
- Biodiesel
- Lower sulfur fuel oil (LSFO)
- Black Pellet Biomass

The price forecast (in \$/MMBtu) is included in Appendix F. Modeling Assumptions Data.

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## NON-TRANSMISSION ALTERNATIVES

Non-transmission alternatives (NTAs) were evaluated to determine whether using technologies and programs like distributed generation, energy storage and demand response could avoid transmission capital investments, and potentially reduce the cost of service to customers. An example of an NTA would be new generation located in specific areas to avoid the construction of transmission lines while allowing the Companies to meet adequacy of supply requirements (see Reliability Criteria assumptions discussion below).

Where applicable, NTA assumptions were made regarding their implementation in the Preferred Plan.

### Hawaiian Electric

A transmission upgrade is anticipated in the Hawaiian Electric system during the study period. NTAs will be evaluated as part of the application to approve capital for this project

### Hawai'i Electric Light

A single transmission upgrade is anticipated in the Hawaiian Electric system during the study period. NTAs will be evaluated as part of the application to approve capital for this project

### Maui Electric

In the Maui Electric system, construction of new transmission lines and substations are being considered to address the following system issues:

- Under voltages, thermal overloads and voltage stability on the Central Maui 23KV system due to the retirement of KPP.
- Under voltages and voltage stability in South Maui.
- Overloading of distribution substations.

These system issues can occur under normal and/or N-1 conditions<sup>16</sup>. Upgrades to the transmission system were purposed as solutions to help address the issues. Table 4-3 lists the issues, affected areas, and system upgrades that were proposed. Figure 4-13 provides a map of Maui identifying related substations and system network.

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<sup>16</sup> A condition that happens when a planned or unplanned outage of a transmission facility occurs while all other transmission facilities are in service. Also known as an N-1 condition.

| Issue   | Area  | System Upgrades  |
|---|---|--|
| Under voltage, thermal overloads, and voltage stability | Central Maui  |  |
| 23kV System   | 23 kV Waiinu-Kanaha upgrade to 69 kV and re-conductoring of MPP-Waiinu and MPP-Pu'unene from 336AAC to 556AAC |  |
| Under voltage and voltage stability                     | South Maui  | Kamalii Substation and MPP-Kamalii 69 kV transmission line                     |
| Overloading of distribution substations                 | Central and South Maui  | Construction of Kuihelani (Central Maui) and Kaonoulu (South Maui) Substations |

Table 4-3. Maui Electric System Issues and Transmission Solutions

The possibility of using the NTAs to fulfill the shortfall of capacity of 40 MW resulting from the Kahului Power Plant (KPP) decommissioning scheduled to begin in 2019 was also considered.

Definition of terms used in this report:

- “23 kV system” – 23 kV substations and feeders except Kula or Haleakala Substations and feeder to Hana Substations.
- “Central Maui” – Key substations include Kahului, Wailuku, and Kanaha.
- “South Maui” – Key substations include Kihei, Wailea, and Auwahi.

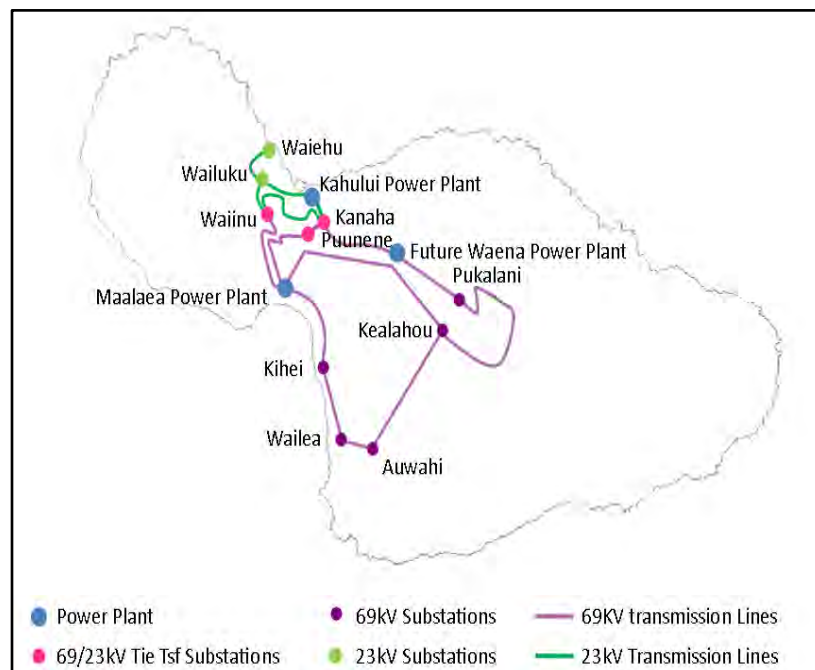


Figure 4-13. Transmission Overview for Key Maui Electric Substations Related to NTAs

#### 4. Planning Assumptions

##### Non-Transmission Alternatives

NTA assumptions are listed below:

- NTAs are considered as possible alternatives to transmission system upgrades
- Combinations of NTAs are possible (requires more detailed studies)
- Transmission overload criteria
  - Normal conditions = normal ratings
  - N-1 contingency conditions = emergency ratings
- Voltage criteria
  - Over voltage violation: bus voltage greater than 1.05 per unit
  - Under voltage violation: bus voltage less than 0.9 per unit
- Kahului Power Plant units K1, K2, K3, and K4 will be decommissioned in 2019, resulting in a capacity shortfall of approximately 40 MW
- Pursuant to the Preferred Plan, Waena Power Plant will be online in 2019
- Ma‘alaea Power Plant units M4, M5, M6, M7, M8, and M9 will be decommissioned in 2022 resulting in a capacity shortfall of approximately 35 MW.

With the transfer capability limitations in Central and South Maui, the best solution should extend the transfer limits to allow the system to operate within a reasonable margin away from the limits. The bus voltages in the area will be used as a guideline to determine how much the load would need to be reduced for the buses to have a voltage around 0.95 per unit, which provides a reasonable margin above the planning criteria minimum of 0.90 per unit.

DR and DGPV were among alternatives examined to potentially eliminate the need for these transmission upgrades, however, they cannot be considered reliable solutions. During an N-1 contingency, DR does not have the ability to respond quickly enough to prevent severe disturbances<sup>17</sup>. Additionally, DGPV provides little to no generation during system peak periods<sup>18</sup>, and therefore cannot help reduce the loads to avoid under voltage and thermal overload violations during normal or N-1 contingency conditions.

#### Central Maui

With the retirement of KPP, the Central Maui load on the 23 kV system will need to solely rely on the generation from MPP. The system has three 69/23 kV transformers that interconnect the 23 kV system and the 69 kV system. These transformers are located at Waiinu, Kanaha, and Pu‘unene substations. During an N-1 contingency where one of

<sup>17</sup> With a large discrepancy between generation and load the frequency can decline immediately (0–3 seconds), where controls for DR have a response time of over 5 seconds.

<sup>18</sup> System peak occurs during the evening around 7:00 PM, when PV has minimal impact to the system.

these feeders<sup>19</sup> becomes unavailable, under voltages and thermal overloads occur on the remaining transformers. If there is too much power being transferred to the 23 kV system from the 69kV system, the system may not be able to manage the transfer and can experience a voltage collapse or island wide blackout. Therefore, the upgrade of the 23 kV Waiinu-Kanaha line to 69 kV and the reconductoring of MPP-Waiinu and MPP-Pu'unene are proposed to shift some of the loads from the 23 kV system onto the 69 kV system.

The *Kahului Power Plant Retirement-Comprehensive Assessment* (included in the Maui Electric PSIP) provides analysis to locally reduce the amount of load and help with the voltage issues on the 23 kV system. The following NTAs were considered: distributed generation (DG), battery energy storage system (BESS), and synchronous condensers from decommissioned KPP units. The DG and BESS NTAs could provide the system with generation to meet the adequacy of supply, however, acres of property would be required to accommodate the large amount of DG or BESS. Installing these NTAs would be difficult due to the size of available property and need for zoning and air quality permits in Central Maui. Converting the KPP units to synchronous condensers or installing DG or BESS at the KPP location were determined to be unfeasible because, KPP is located in a tsunami inundation zone<sup>20</sup>. Upgrading the transmission system in Central Maui is the most feasible option given in Central Maui the lack of available real-estate, existing residential communities, and the tsunami inundation zones.

### South Maui

In South Maui, the loads from Kihei and Wailea are mainly served through the MPP-Kihei 69 kV transmission line. If there is an outage of the MPP-Kihei line, the South Maui load will need to be served from the MPP-Kealahou 69 kV line, which increases the electrical distance serving loads. The longer distance would result in major losses<sup>21</sup> and possibility of a voltage collapse. The distance would increase to approximately 23 miles, as shown in Figure 4-14.

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<sup>19</sup> MPP-Waiinu or MPP-Pu'unene.

<sup>20</sup> Maui Electric's preference is to avoid Tsunami inundation zones as locations for new generation, where feasible.

<sup>21</sup> Due to higher impedance and an increased voltage drop from the source to the load.

#### 4. Planning Assumptions

##### Non-Transmission Alternatives

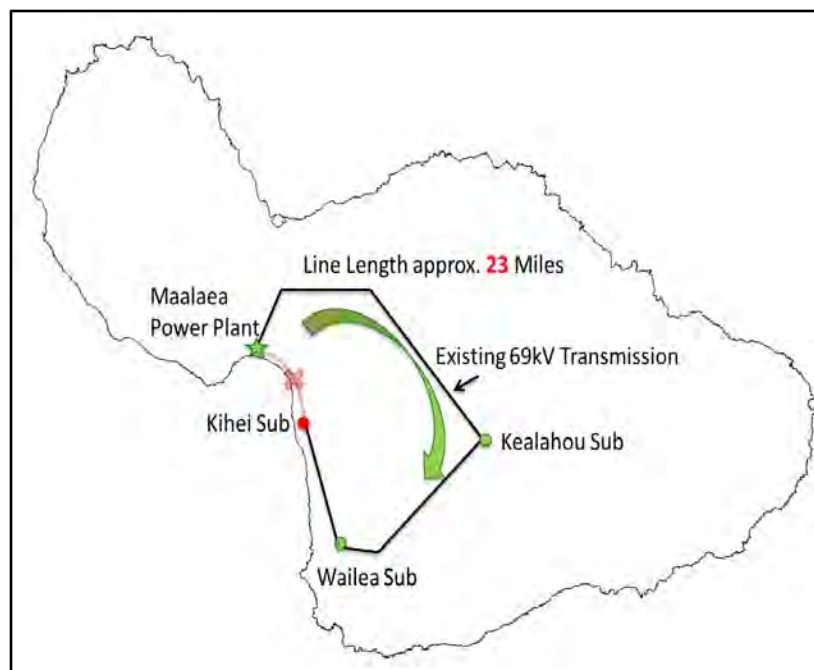


Figure 4-14. Longer Distance Required to Serve Loads in Kihei Under an N-1 Contingency

The *Ma'alaea-Kamalii Transmission Line Alternatives* report (included in the Maui Electric PSIP) analyzed various NTAs to defer the construction of new transmission infrastructure. For voltages to remain within a reasonable margin above 0.90 per unit, the total load in South Maui would need to be reduced by at least 20 MW. Several of the NTAs considered increased the voltages in South Maui, but did not effectively reduce both the load issue and possibility of a voltage collapse.<sup>22</sup> For example, the synchronous condensers and static capacitors can increase the voltages but these transmission system facilities do not generate MW to serve the load.

The hybrid of a BESS and DG is considered to be the optimal plan. A hybrid combination of a BESS and DG would shorten the duration of the BESS needed (reducing costs) and allow the DG to only be started in the case of a contingency, as opposed to being run whenever the system load is above 150 MW (lowering fuel consumption). Maui Electric plans to pursue this option based on the following:

All plans in the Maui Electric PSIP include a BESS for Contingency Reserve in compliance with EPS System Security Study.

The Contingency Reserve BESS (20MW: 30 Min) is assumed to be located in South Maui so that when a transmission event occurs in South Maui, the BESS will be able to operate

<sup>22</sup> An under-voltage load shed (UVLS) scheme is currently imposed at Kihei and Wailea substations during system loads greater than 150 MW, in order to avoid a voltage collapse. With load curtailment, customers remain offline until the system returns to normal conditions, or the system load decreases below 150 MW. The UVLS scheme is not a viable long-term solution.

for 30minutes. Within that time, the 24MW of Internal Combustion Engine (ICE) generation, located in South Maui, will be able to start in order to support South Maui transmission system.

If the Contingency Reserve BESS is not located in South Maui, then the 24MW of ICE generation in South Maui will have to operate daily when the system load is 150MW or greater to support the South Maui system in case a transmission event occurs.

### Maui Electric Distribution Transformer Overloads

Our forecasts indicate that several distribution transformers will be overloaded in Central and South Maui in the near future. This prompted the need for a new distribution substations<sup>23</sup> to be built to help alleviate the loads on the existing distribution transformers. DG and BESS were considered as alternatives to building a new distribution substation that could potentially lessen the load on existing substations where the overloading occurs, contribute towards firm capacity, and help alleviate the need for additional transmission lines in the area. Preliminary assessments found these options to be unfavorable due to permitting, physical, and/or financial constraints.

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## RELIABILITY CRITERIA

The Hawai'i Reliability Standards Working Group (RSWG) Glossary of Terms<sup>24</sup> defines "Reliability" as follows:

**Reliability.** An electricity service level or the degree of performance of the bulk power ("utility" in Hawai'i) system defined by accepted standards and other public criteria. There are two basic, functional components of reliability: operating reliability and adequacy.

The RSWG Glossary of Terms goes on to define "adequacy" and "operating reliability" and as follows:

**Adequacy.** The ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

**Operating reliability.** The ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components.

The North American Electric Reliability Corporation (NERC) formally replaced the term "security" with the term "operating reliability" after September 2011, when the term

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<sup>23</sup> Kuihelani in central and Kaonoulu and Kamali'i in South Maui.

<sup>24</sup> RSWG Glossary of Terms. Docket No. 2011-0206.

#### 4. Planning Assumptions

##### System Security Requirements

“security” became synonymous with homeland protection in general, and critical infrastructure protection in particular<sup>25</sup>.

The Hawaiian Electric Companies have continued to use the term “system security” with the exact same meaning as “operating reliability.” “System security” is therefore the term used herein.

### Adequacy of Supply

One of the most commonly used planning metrics for designing a system to meet the adequacy of supply requirements is “reserve margin.” For purposes of the PSIPs the production modeling teams assumed a minimum 30% planning reserve margin for generation. As the systems evolve, the target reserve margin will be periodically evaluated to ensure resource adequacy and supply, with consideration of the resource risk based historical performance of the types of resources providing the capacity.

### System Security

The derivation of system security requirements for the PSIP analyses is explained in detail in the following section.

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## SYSTEM SECURITY REQUIREMENTS

Electric power grids operate in a manner that provides reliable and secure power during both normal conditions and through reasonably anticipated events. To achieve this reliable and secure operation, the grids operate under system security constraints. These constraints include requiring certain resources to be utilized and require the power system to be operated in certain ways.

In traditional power systems<sup>26</sup>, conventional thermal generating units provide most of the electric energy and meet most of the security constraints by supplying system inertia, frequency response, and other ancillary services as part of their inherent operating characteristics and governor controls. As new types of generation, such as wind and solar PV, became significant providers of energy and displaced conventional thermal generation, the requirements to ensure there is a sufficient supply of grid services for

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<sup>25</sup> Source: <http://www.nerc.com/docs/pc/Definition-of-ALR-approved-at-Dec-07-OC-PC-mtgs.pdf>.

<sup>26</sup> In this context, a “traditional power system” or a bulk power system (BPS) is a large interconnected electrical system made up of generation and transmission facilities and their control systems. A BPS does not include facilities used in the local distribution of electric energy. If a bulk power system is disrupted, the effects are felt in more than one location. In the United States, the North American Electric Reliability Corporation (NERC) oversees bulk power systems.



security and reliability becomes more important. Due to their inherent characteristics, variable generation resources often cannot supply these services, requiring other standalone services to be provided to the grid or special design modifications be made to the variable generators. Further, the variable output from these resources can increase the need for grid services.

The majority of variable energy resources are connected to the power system through an inverter. The inverter isolates a variable energy resource from the grid and converts the energy produced into alternating current (AC) power that is then supplied to the electric grid. The inverter allows the power system and the variable energy resources to operate at different voltages and frequencies, optimizing the performance of the variable energy resource in its conversion of source energy (wind and sun for example) to electric energy. Variable energy resources typically do not have the capability to store their energy and do not typically utilize a governor type control, which would automatically adjust energy in response to system balance (frequency). Instead, unless incorporating advanced control systems, they produce the energy that is available from their resource (for example, solar or wind) regardless of system conditions. If the power system suddenly requires more energy, variable energy resources cannot increase their output beyond the available resource energy (unless it was previously curtailed to less than the available resource energy). Because of this reliance on available energy, variable energy resources can typically supply downward regulation – decreasing their power output – but have limited ability to supply upward regulation – increasing their output.

Some variable energy resources (such as wind turbines) may be able supply inertia or fast frequency response through advanced inverter controls. Like conventional generators, this inertia does act to help slow the rate of frequency decline, and can be a faster response – but unlike conventional plants, this response is not sustained and is eventually withdrawn. Variable energy generation does not have the ability to replace the short-duration inertia energy with energy through governor response.

For the Companies' island grids, several ancillary services are required to reliably operate the power system: regulating reserve, contingency reserve, 10-minute reserve, 30-minute reserve, long lead-time reserve, black start resource, primary frequency response, fast frequency response<sup>27</sup>, and secondary frequency control. (These services are more fully explained in Appendix E: Essential Grid Services.)

Establishing regulating reserve, contingency reserve, primary frequency response, and fast frequency response are defined by characteristics of the system requirements to maintain target reliability and planning standards. Technical studies have defined these

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<sup>27</sup> Fast frequency response is a subcategory of the 10-minute reserve ancillary service.

#### 4. Planning Assumptions

##### System Security Requirements

security requirements; the choice as to how to meet the requirements is often an economic decision based on generation and resource planning studies.

Although the size and resource mix of the Companies' electrical systems have a large degree of variation, the proliferation of variable generation on each of the islands results in similar constraints and challenges among them.

The security requirements for each island can be defined by the requirements for regulating reserve, contingency reserve, voltage support, and fast frequency response. Other constraints (such as ramp rates, 10-minute reserve, and 30-minute reserve) are required but are not the limiting conditions for the power system security.

### Regulating Reserve

Regulating reserve is the amount of capacity that is available to respond to changes in variable generation or system load demand to maintain system operation at a target frequency (maintaining close to 60 Hz). Regulating reserve is required for both upward regulation (additional generation or decreased load through demand response) and downward regulation (less generation or increased load through demand response). These responses are required to maintain the balance between total system load demand and supply.

Regulating reserve provides for the normal fluctuation of system load plus the changes in variable generation. Normal fluctuations of system load demand in the Companies' systems are relatively slow and very predictable from day to day. Variable generation—wind generation, distributed solar generation, and utility-scale solar generation—can have extreme variations and dwarf the regulation requirements of normal load demand changes.

### Wind Generation

The regulation requirements for wind generation were determined by plotting a years' worth of 2-second data from the SCADA systems for the wind generation facilities on each of the islands. By using 2-second SCADA data from all wind resources, time skew error between the sites is minimized and the actual frequency impact from the changes in total amount of wind is identified.

The amount of regulation capacity that is required is determined by the magnitude of change in wind generation over a given period of time. In wind systems, regulation requirements increase with increasing time intervals. The time interval is largely dictated by the amount of 10-minute reserve available. The 10-minute reserve is critical to the system operator to replace regulating or contingency reserve as they are used by the system. When a wind ramp begins to occur, the system operator cannot predict in real

time the duration or magnitude of the ramp event, consequently there is some time in each ramp event where the operator is evaluating the ramp and estimating the severity of the ramp. That time period is assumed to be within the first 10 minutes (or less) of the ramp event. After assessing the ramp event will require mitigation, the operator would typically call upon a reserve resource that will be online within 10 minutes or less (a 10 minute reserve resource). Considering the time for evaluating the event and bringing reserves online, the mitigating resources could be online 20 minutes after the ramp condition started. Therefore, a 20-minute ramp condition is used as the basis to determine the regulation capacity.

The plots in Figure 4-15 through Figure 4-17 depict the variability of wind resources in a typical month on each of the islands.

**Hawaiian Electric Wind Generation:** The regulating reserve is carried on a 1:1 basis until the actual wind generation exceeds 50% of the nameplate capacity. No additional regulating reserve is necessary for generation levels in excess of 50% of nameplate capacity. The regulation criterion was based on the 20-minute wind ramp events between July 1, 2013 and June 30, 2014 of the Kawaiiloa Makai, Kawaiiloa Mauka, and Kuhuku wind generation facilities.

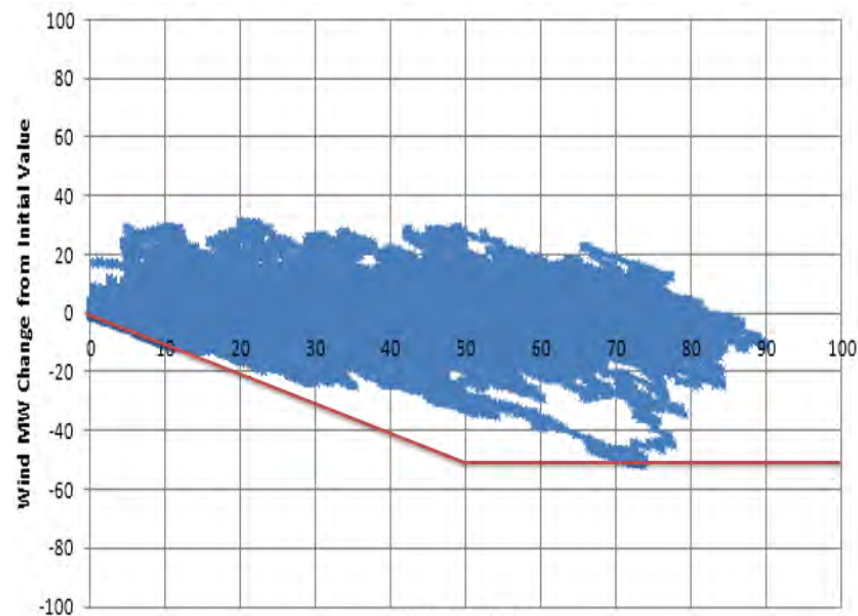


Figure 4-15. 20-Minute Scatter Plot for Hawaiian Electric Wind Generation

Each point in the scatter-plot shown in Figure 4-15 represents one two-second scan from the wind power data. The y-axis shows the total change in wind power between the initial power and 20 minutes after the initial power point. The x-axis shows the initial power output of the wind generation facilities. Interpreting the data for a point (20,-10), the initial total wind power output was 20 MW; twenty minutes later, the wind power

output was 10 MW. Therefore, there was a net loss of 10 MW of wind power over those 20 minutes.

The red line represents the recommended regulation capacity. The regulation capacity will not be sufficient for all possible wind ramps, but will be sufficient for the vast majority of wind ramp events.

**Hawai'i Electric Light Wind Generation:** The wind ramps on the Hawai'i Electric Light system require a similar level of regulating reserve as the Hawaiian Electric system, despite the wind generation facilities having a higher capacity factor. Figure 4-16 shows the wind variability on the Hawai'i Electric Light system for the first half of May 2014 for the Hawai'i Renewable Development (HRD) and Tawhiri wind generation facilities.

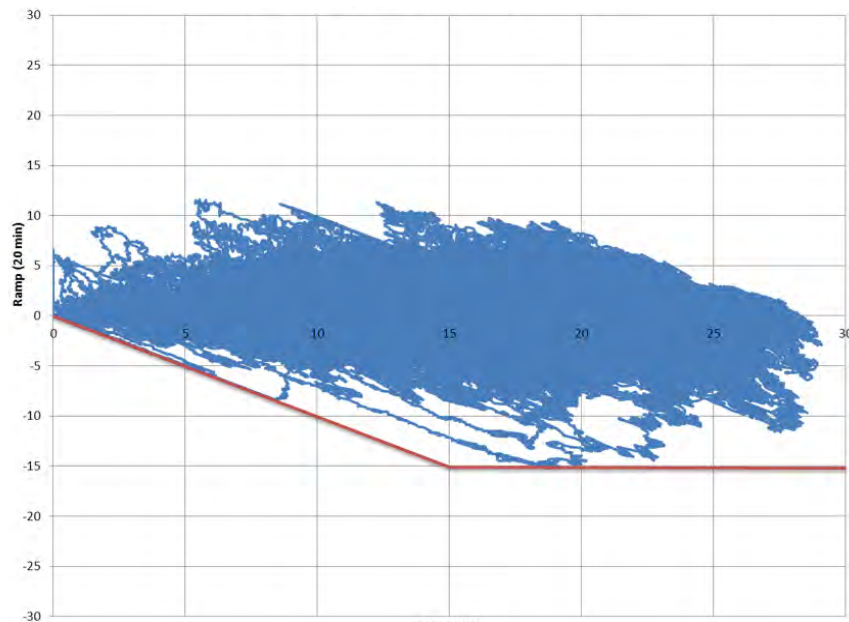


Figure 4-16. 20-Minute Scatter Plot for Hawai'i Electric Light Wind Generation

**Maui Electric Wind Generation:** The wind ramps on the Maui Electric system require less regulating reserve compared to those for the Hawai'i Electric Light and Hawaiian Electric power systems. The battery energy storage systems (BESS) associated with the wind generation facilities mask some of the more severe ramp rates. Figure 4-17 shows the wind variability on the Maui Electric system for the first half of December 2013 for the Kaheawa One, Kaheawa Two, and Auwahi wind generation facilities.

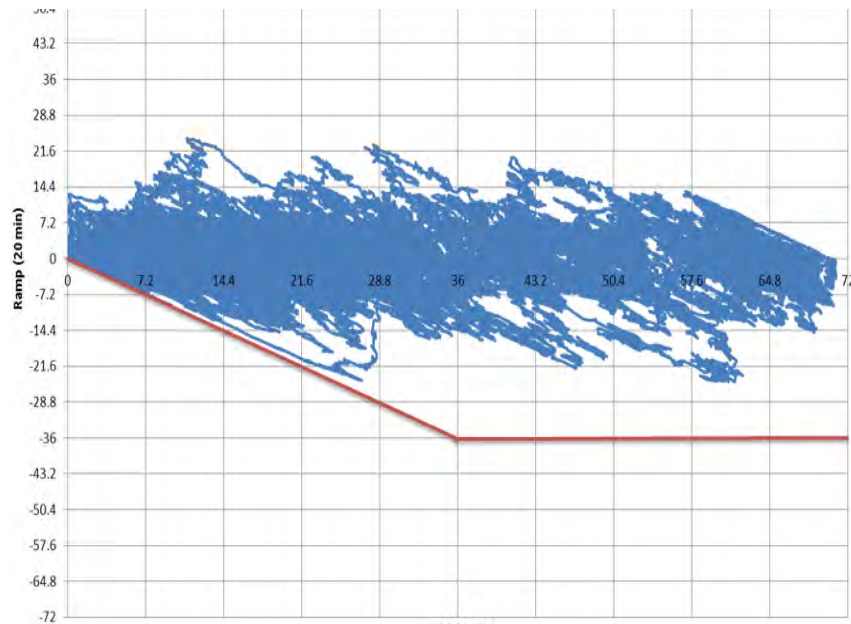


Figure 4-17. 20-Minute Scatter Plot for Maui Electric Wind Generation

Maui Electric is assumed to have a similar requirement to Hawai'i Electric Light if the BESS were used for optimized system requirements as opposed to simply providing ramp rate control of an individual wind generation facility.

### Distributed Solar

Distributed solar (referred to as DG-PV in this report) for the power system on Maui Island for 2007 and 2008 estimated island-wide distributed solar generation with a 2-second sample rate. The data assumed an installed DG-PV capacity of 15 MW. The raw data was scaled to estimate the DG-PV generation with 30 MW installed DG-PV capacity. The PV data was analyzed to determine the change in DG-PV generation over a 20-minute time frame for the months from January to July. The results are shown in Figure 4-18, which shows the 20-minute distributed solar generation ramp rate data for the Maui island electric system with 30 MW capacity

#### 4. Planning Assumptions

##### System Security Requirements

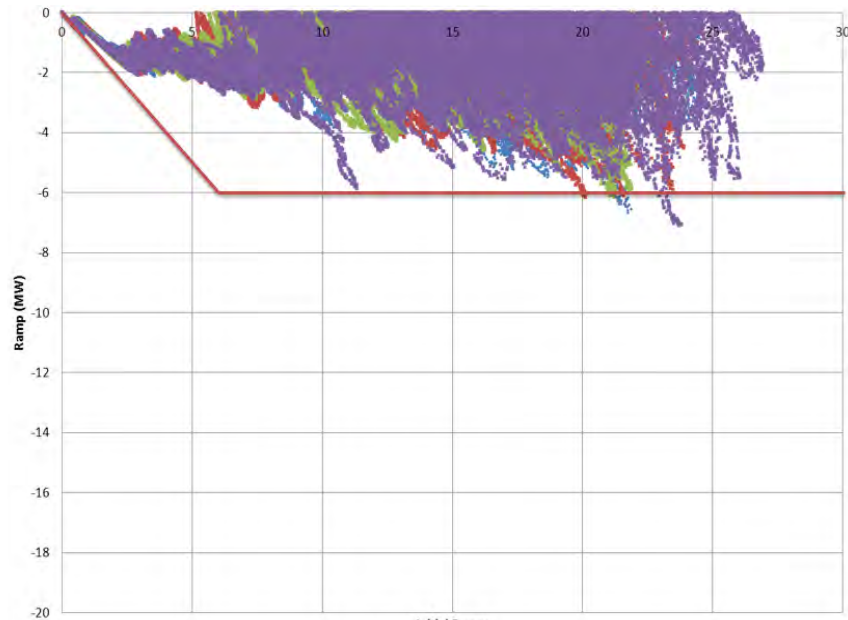


Figure 4-18. Maui Electric 20-Minute Solar Ramps

The x-axis represents the initial solar generation level of 20 MW. The y-axis shows the solar generation change 20 minutes later. Interpreting the data for a point (20,-10), the initial solar generation level was 25 MW; 20 minutes later, the total solar generation level was 15 MW. So the change in solar generation was -10 MW.

The two piece red line shows the recommended solar regulation capacity characteristic: that is, the system operator maintains a regulating reserve with a 1:1 ratio for solar generation levels up to 20% of the solar nameplate capacity and no additional reserve for solar generation levels between 20% to 100%.

Figure 4-19 shows the same regulating reserve criterion applied to the Hawai'i Electric Light DG-PV. The Hawai'i Electric Light data was derived from actual solar recordings at approximately 45 locations on the Hawai'i Electric Light power system. These recordings were scaled based on the distributed solar generation installed near the recording location. The total generation was scaled to represent a system having 100 MW of DG-PV (nameplate capacity).

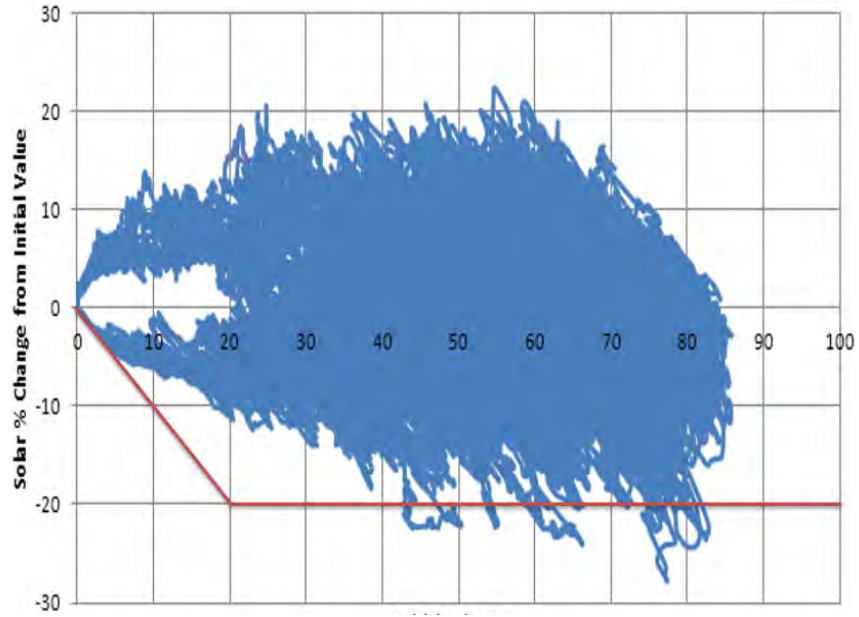


Figure 4-19. Hawai'i Electric Light 20-Minute Solar Ramps for Half of February

Using a 1:1 generation level to regulating reserve capacity ratio, both the Maui Electric and Hawai'i Electric Light data sets produce similar results.

### Hawaiian Electric Utility-Scale Solar

There are currently only two utility-scale solar facilities (referred to as PV in this report) on the Hawaiian Electric power system on O‘ahu. Results indicate that over both 30-second and 20-minute time periods, the output of each individual PV facility can vary from 100% to 0%. The estimated, combined effect of the two plants together results in considerable improvement as shown in the 20-minute scatter plots totaling 100 MW of PV capacity in Figure 4-20.

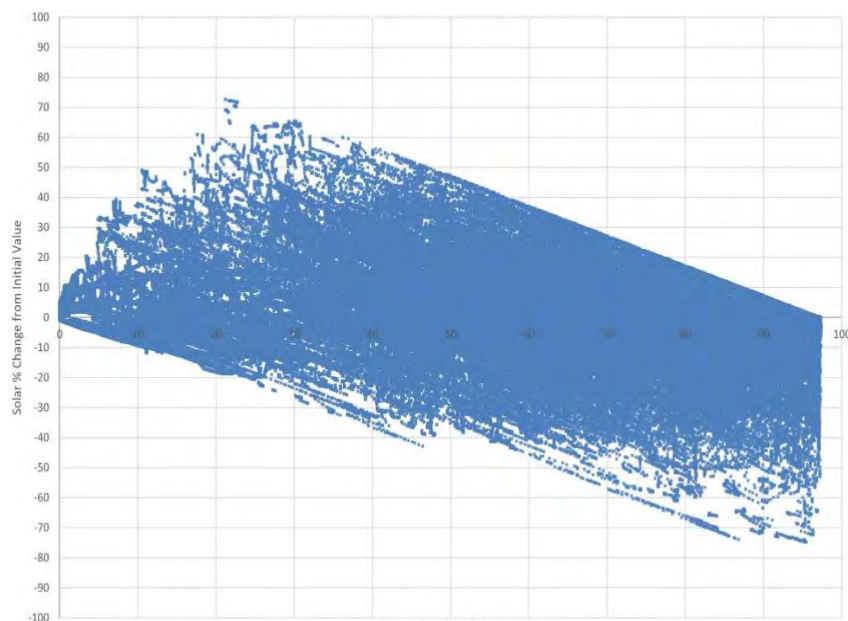


Figure 4-20. Hawaiian Electric Combined Station Class PV

Based on these plots, the required regulation of the two combined wind generation facilities drops from a ratio of 1 MW regulation:1 MW of PV to a ratio of 0.5–0.6:1. The installation of additional PV facilities over a wider area may allow this number to decrease further. Accordingly, the ratio is estimated to decrease to 0.3:1 by 2017 with the addition of more utility-scale solar facilities.

Two-second SCADA data shows that the ramps between wind, DG-PV, and PV do not have 100% correlation. Although there are periods where the ramps cancel each other out, these appear to be random events and not systematic occurrences. Many events are observed when the ramps overlap each other for a portion of the event. Consequently, all regulation requirements are assumed to be additive.

Regulating reserve is a security constraint, however the choice of resource used for the reserve is often determined by economics. Regulation can be supplied by resources immediately responsive to Automatic Generation Control (AGC) and meeting the time frames and accuracy of the response. This can include firm dispatchable generation



which may be conventional or renewable, variable generation (which requires partial curtailment for upward reserves), energy storage, and/or demand response.

Some of the resources that can provide regulating reserve can also contribute to contingency reserve. These are the resources that respond to system events without requiring a control signal from AGC, through inertial and governor response (such as thermal generating units). Since allocation of regulating reserves considers economics and therefore may not result in use of resources that can contribute to contingency reserves, additional regulating reserve is not assumed to contribute to contingency reserve. The use of additional thermal generating units to provide regulating reserve would satisfy the contingency reserves requirement, however, the regulating reserve may be supplied by resources with different characteristics than thermal generation, therefore increasing the amount of required contingency reserve.

## Contingency Reserve

In planning and operating the power system, care must be taken to ensure that under any circumstances, the system remains operable following the largest single potential loss of energy. This largest possible loss might be due to a trip of a particular generating plant or the loss of critical interconnection equipment. This requirement is known as the single largest contingency criteria and is included as a requirement within TPL-001.<sup>28</sup> The system is able to withstand the loss of the largest single contingency through the implementation of contingency reserve.

Contingency reserve can be provided through resources that respond immediately and automatically to system imbalances. This can include resources such as conventional generation with governor's response, energy storage, or through "fast-acting" demand response. In isolated power systems (such as those on islands), the response requirement of contingency reserve is extremely fast. As the power system evolves and displaces thermal generation with increasing amounts of variable generation, the required response time of the contingency reserve becomes even faster due to the reduced available inertia and frequency response. This very fast response time precludes many types of energy systems from providing effective contingency reserve. Even traditional contingency reserve carried on conventional generation will not be fast enough to provide acceptable contingency response with the reduction in inertia and frequency response resulting from the change in resource mix.

TPL-001 establishes the allowable system performance criteria for the loss of the largest single contingency. The criteria allow a certain amount of the contingency reserve to be

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<sup>28</sup> See Appendix M: Planning Standards for the details of TPL-001 as well as details on BAL-052: Planning Resource Adequacy Analysis, Assessment and Documentation Standard. Together, these two standards form the basis for performing system studies.

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provided by automatic under frequency load shedding (UFLS) for each system. These amounts currently vary from 12% of the system’s customers for Hawaiian Electric to 15% for Hawai’i Electric Light and Maui Electric.

As system inertia continues to decline (for example as the thermal generation is displaced by increasing amounts of variable generation ), providing contingency reserve capable of responding fast enough to meet the criteria in TPL-001 becomes more difficult. For instance, the contingency reserve implemented as part of the UFLS system must be fully deployed within 7 cycles (0.12 seconds) of reaching the target frequency. Deployment of effective contingency reserve through governor action of thermal generation also becomes more difficult as the rate of change of frequency decline increases. Many of the contingency reserves that have historically been utilized on the power systems in the Hawaiian Islands are now simply too slow to respond to the new system characteristics.

For instance, the April 2, 2013 loss of the sudden trip of the AES Hawai’i facility totaling 200 MW (that is, 180 MW of net generation to the grid plus 20 MW of ancillary load) occurred at a time when the system had over 400 MW of contingency reserve available as unloaded generation. However, the system frequency declined so fast, that few of the reserves were able to be deployed by the thermal unit governors before experiencing three stages of load shedding (Figure 4-21).

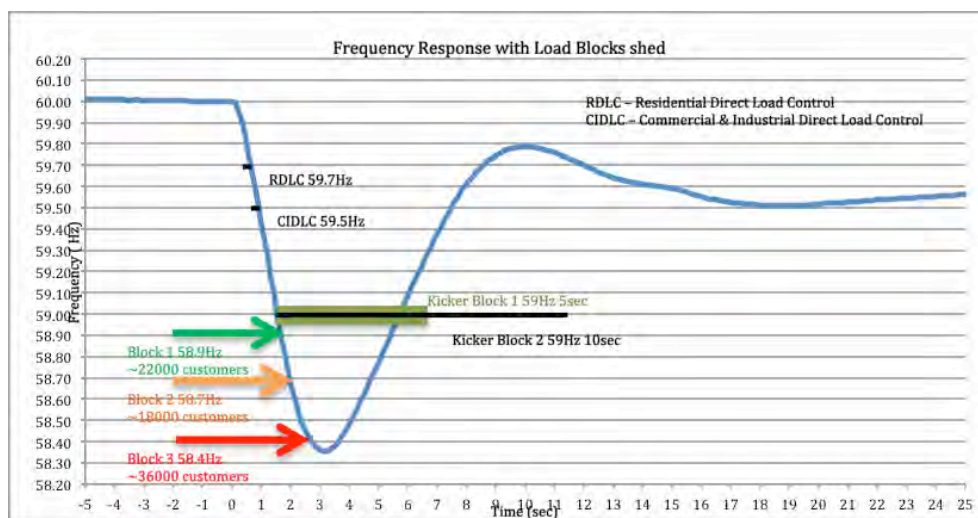


Figure 4-21. Frequency Response with Load Blocks Shed

As the system continues to displace conventional generation from online operation, reliability decreases and security risks increase for contingencies unless mitigated by fast acting contingency reserve. The amount of fast acting contingency reserve required for each system in order to meet the criteria defined by TPL-001 has been studied as part of the PSIP analytics.

For each of the systems, transient stability simulations were used to evaluate the response of the system to the loss of the largest contingency for various operating conditions for the planning years 2015–2030. The simulations were developed to model the boundary conditions for the system, ensuring the criteria developed provide satisfactory security performance for the most severe conditions experienced under actual expected system operations.

The conditions for each of the planning years were determined based on the forecast amount of variable generation added to the system, retirement of existing units, and/or the addition of new generating units. Not all years were studied. If there were no significant deviations from year-to-year, the results from the years on either end of the quiescent period were assumed applicable to the years not studied.

For each year selected, a unit commitment schedule was developed that resulted in the minimum number of conventional units being operated and the maximum use of variable generation. The largest contingency, whether it resulted from the use of conventional generation or variable generation, was tripped offline at full load. The results were analyzed and “fast-acting” energy storage was added until acceptable performance was achieved. This process was repeated for all selected years.

For systems with high availability of wind, new wind resources were compared to energy storage systems to determine if curtailed wind resources could provide the desired characteristics of energy storage systems.

The results for all of the islands are very similar. In the near term, it is difficult or infeasible to meet the planning criteria for existing conditions. With existing DG-PV characteristics, each system collapses (that is, island-wide blackout) for a number of different conditions. All three systems could also experience a system collapse for transmission faults unless cleared in less than 9–11 cycles. The Hawaiian Electric system is vulnerable to collapse following the loss of the largest single contingency.

In the immediate future, the retrofits of control features to DG-PV installations are essential to mitigating the chance of system collapse for these events. The DG-PV must be retrofitted to the ride-through standards in the proposed changes to Rule 14H. It is assumed that most of the DG-PV can be retrofitted with only a small amount on each legacy system that cannot be retrofitted.

Another immediate improvement is to decrease the time required to reliably detect and clear faults on the systems’ transmission lines. Historically, a fault could be present on the system for 18–21 cycles (0.30–0.35 seconds) in almost all systems. Today, for faults that exist longer than 9–11 cycles (0.15–0.18 seconds), the faults can result in a total system collapse. This time is referred to as the “critical clearing time” for the respective

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power system. Critical clearing times less than 18 cycles require the use of communications assisted relaying on all transmission terminals.

As the amount of variable generation increases, the critical clearing time will continue to decrease and the rate of frequency collapse will continue to increase. It was therefore assumed that retrofitting of the DG-PV would be completed prior to 2015, and the installation of improved relay and communications systems would be completed prior to 2016. It was assumed that the first year any new variable energy resources could be added to any system is 2017.

To mitigate the number of customers impacted by such contingencies and improve system security, the UFLS should be upgraded to recognize a system contingency and its characteristics. For instance, as the amount of DG-PV continues to increase, the amount of load controlled by each stage and the effectiveness of the UFLS will correspondingly degrade. In order to prevent frequency excursions into the regions that place the entire system at risk of collapse, more feeder breakers need to be activated at Stage 1 of the UFLS. This would result in the loss of more customers for Stage 1 events than historically experienced. However, in the evening when the DG-PV and PV is not producing, the operation of these additional breakers in Stage 1 would result in shedding more load than is necessary, producing an over frequency condition that could also place the system at a high risk. The load shedding system needs to be adaptive and dynamic. It needs to be able to activate the correct amount of breakers to cover the contingency and minimize the number of customers whose service is interrupted. An adaptive load shedding system is assumed to be operational at all three major utilities prior to 2016.

#### Hawaiian Electric: Years 2015–2016

The amount of DG-PV that cannot be retrofitted to meet the proposed ride-through settings is critical for the security of the power system. The existing amount of DG-PV tripping for original standard IEEE 1547 trip settings on the Hawaiian Electric system is estimated to be 70 MW. With 70 MW of legacy DG-PV, the system cannot survive the largest contingency. As the legacy DG-PV is reduced, the system response improves. The maximum amount of legacy DG-PV is recommended to be no more than 40 MW. This level of legacy DG-PV still results in significant load shedding and violations of TPL-001, however, the power system would be more resistant to collapse.

Legacy DG-PV also impacts the over frequency performance of the power system, since the legacy DG-PV currently trips off-line at 60.5 Hz. The loss of 250+ MW of legacy DG-PV results in the collapse of the Hawaiian Electric system. The reduction in the amount of legacy DG-PV that trips at 60.5 Hz is also recommended to be reduced to less than 40 MW.

In 2015, aside from modification of DG-PV settings to provide ride-through, options are limited to only changes in system operations, protective relaying, and communications improvements. A transfer trip scheme between AES, Kahe 5, Kahe 6, and the UFLS breakers can help prevent, in some instances, one stage of load shedding for the loss of one of the larger units. Reducing the maximum output of AES is the only other mitigation strategy that was identified as feasible for 2015.

By the end of 2016, approximately 286 MW of utility-scale PV is expected to be installed on the power system. While this PV forces other generation offline and further decreasing the system inertia, it also has the potential to supply fast-acting contingency reserve through curtailed energy. Without curtailment and additional contingency reserve, the displacement of the thermal unit by the station PV cannot be mitigated. The additional contingency reserve could be supplied by energy storage.

In 2017, the system requires 200 MW of contingency reserve to meet the requirements of TPL-001. It should be noted that due to the extremely fast frequency decay associated with the sudden trip of a large generator, the contingency reserve must be provided by systems other than thermal generation (such as fast acting storage or other similarly fast responding device). Following the installation of the contingency reserve, the system can operate with few system constraints providing faults meet the critical clearing time. Although simulations to assess the system stability with as few as two firm (and dispatchable) units were completed, this was done only to assess the stability of the system during a boundary condition. System operating considerations would preclude operation with fewer than three dispatchable units.

Following the installation of 200 MW of contingency reserve in 2017 (for example, energy storage), additional contingency reserve may be required if additional variable generation is added and the single largest contingency remains at 180 MW (that is, AES).

The system security constraints are summarized in Table 4-4 through Table 4-7 for Hawaiian Electric. The Thermal Units Required column specifies the minimum number of thermal units required for stability. The remaining columns designate the specific constraint.

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| Value                | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time                         | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | Voltage Support (SVC) |
|----------------------|---------------|------------------------|--------------------|--|--------------------------------|---------------------|-------------------|-----------------------|
| 2017 200 MW AES Trip |               |                        |                    |  |                                |                     |                   |                       |
| Station PV           | 272           | 4                      | 86.6 MW/min        | 281 MW<br>(20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW<br>(50% Wind)            | 200 MW              | 200 MW            | ±80 MVar              |
| DG-PV                | 471           |                        |                    |  |                                |                     |                   |                       |
| Wind                 | 123           |                        |                    |  |                                |                     |                   |                       |
| Largest Unit         | 200           |                        |                    |  |                                |                     |                   |                       |
| 2017 100 MW AES Trip |               |                        |                    |  |                                |                     |                   |                       |
| Station PV           | 272           | 4                      | 86.6 MW/min        | 281 MW<br>(20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW<br>(50% Wind)            | 100 MW              | 100 MW            | ±80 MVar              |
| DG-PV                | 471           |                        |                    |  |                                |                     |                   |                       |
| Wind                 | 123           |                        |                    |  |                                |                     |                   |                       |
| Largest Unit         | 200           |                        |                    |  |                                |                     |                   |                       |

Table 4-4. Hawaiian Electric 2017 System Security Constraints

| Value                    | Capacity (MW) | Thermal Units Required  | Ramp Rate Required | Regulating Reserve: Day Time                         | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | Voltage Support (SVC) |
|--------------------------|---------------|-------------------------|--------------------|--|--------------------------------|---------------------|-------------------|-----------------------|
| 2022 AES + LM6000 Units  |               |                         |                    |  |                                |                     |                   |                       |
| Station PV               | 272           | 3:<br>AES + 2<br>LM6000 | 95.1 MW/min        | 311 MW<br>(20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW<br>(50% Wind)            | 100 MW              | 100 MW            | ±80 MVar              |
| DG-PV                    | 556           |                         |                    |  |                                |                     |                   |                       |
| Wind                     | 123           |                         |                    |  |                                |                     |                   |                       |
| Largest Unit             | 100           |                         |                    |  |                                |                     |                   |                       |
| 2022 AES + LMS1000 Units |               |                         |                    |  |                                |                     |                   |                       |
| Station PV               | 272           | 2:<br>AES + 1<br>LMS100 | 95.1 MW/min        | 311 MW<br>(20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW<br>(50% Wind)            | 100 MW              | 100 MW            | ±80 MVar              |
| DG-PV                    | 556           |                         |                    |  |                                |                     |                   |                       |
| Wind                     | 123           |                         |                    |  |                                |                     |                   |                       |
| Largest Unit             | 100           |                         |                    |  |                                |                     |                   |                       |

Table 4-5. Hawaiian Electric 2022 System Security Constraints

| Value             | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time                      | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | Voltage Support (SVC) |
|-------------------|---------------|------------------------|--------------------|---|--------------------------------|---------------------|-------------------|-----------------------|
| 2030 LM6000 Units |               |                        |                    |   |                                |                     |                   |                       |
| Station PV        | 272           | 7                      | 95.1 MW/min        | 337 MW (20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW (50% Wind)               | 60 MW               | 100 MW            | ±80 MVar              |
| DG-PV             | 631           |                        |                    |   |                                |                     |                   |                       |
| Wind              | 123           |                        |                    |   |                                |                     |                   |                       |
| Largest Unit      | 100           |                        |                    |   |                                |                     |                   |                       |
| 2030 LMS100 Units |               |                        |                    |   |                                |                     |                   |                       |
| Station PV        | 272           | 5                      | 95.1 MW/min        | 337 MW (20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW (50% Wind)               | 60 MW               | 100 MW            | ±80 MVar              |
| DG-PV             | 631           |                        |                    |   |                                |                     |                   |                       |
| Wind              | 123           |                        |                    |   |                                |                     |                   |                       |
| Largest Unit      | 100           |                        |                    |   |                                |                     |                   |                       |

Table 4-6. Hawaiian Electric 2030 System Security Constraints

| Value                                 | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time                      | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | Voltage Support (SVC) |
|---------------------------------------|---------------|------------------------|--------------------|---|--------------------------------|---------------------|-------------------|-----------------------|
| 2030 Minimum LM6000 Units; 60 MW BESS |               |                        |                    |   |                                |                     |                   |                       |
| Station PV                            | 272           | 3                      | 95.1 MW/min        | 337 MW (20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW (50% Wind)               | 100 MW              | 100 MW            | ±80 MVar              |
| DG-PV                                 | 631           |                        |                    |   |                                |                     |                   |                       |
| Wind                                  | 123           |                        |                    |   |                                |                     |                   |                       |
| Largest Unit                          | 100           |                        |                    |   |                                |                     |                   |                       |
| 2030 Minimum LMS100 Units; 60 MW BESS |               |                        |                    |   |                                |                     |                   |                       |
| Station PV                            | 272           | 2                      | 95.1 MW/min        | 337 MW (20% of DG-PV + 35% Station PV + 50% Wind) | 62 MW (50% Wind)               | 100 MW              | 100 MW            | ±80 MVar              |
| DG-PV                                 | 631           |                        |                    |   |                                |                     |                   |                       |
| Wind                                  | 123           |                        |                    |   |                                |                     |                   |                       |
| Largest Unit                          | 100           |                        |                    |   |                                |                     |                   |                       |

Table 4-7. Hawaiian Electric 2030 System Security Constraints with 60 MW BESS

### Hawai'i Electric Light: Years 2015–2016

The Hawai'i Electric Light system was one of the first island systems to revise the tripping points of the DG-PV systems from 59.3 Hz to 57.0 Hz. Consequently, they have a smaller percentage of DG-PV that trips at 59.3 Hz on the power system as compared to the other islands. However, all of the DG-PV has over frequency trip points of 60.5 Hz. Due to this condition, fault durations longer than 9 cycles result in the potential for system collapse in simulations.

Simulations for years 2015–2016 assumed improvements to protective relaying and communications were in service. Direct transfer tripping of system load following the

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loss of the largest contingency is recommended to mitigate the number of customers impacted by single contingency events.

#### Hawai'i Electric Light: Years 2017–2030

The security of the Hawai'i Electric Light system requires the addition of contingency reserve and additional regulating reserve in 2017 as the level of DG-PV increases. The regulating reserve can be supplied by either thermal units, energy storage units, curtailed wind, curtailed solar, or controlled load.

Although simulations to assess the system stability with as few as two firm (and dispatchable) units were completed, this only assessed the stability of the system during a boundary condition. System operating considerations would preclude operation with fewer than three firm (and dispatchable) facilities under automatic generation control. The assessment assumed typical dispatchable PGV, Hu Honua, and Keahole Combined Cycle (single train).

The system security constraints are summarized in Table 4-8 through Table 4-10 for Hawai'i Electric Light. The Thermal Units Required column specifies the minimum number of thermal units required for stability. The remaining columns designate the specific constraint.

| Value                     | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve |
|---------------------------|---------------|------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|
| 2015 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                  | 56            | 3                      | 9.6 MW/min         | 27 MW maximum                | 16 MW maximum                  | 31 MW               | 27 MW             |
| Thermal Units             | 3 online      |                        |                    |                              |                                |                     |                   |
| 2016 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                  | 67            | 3                      | 10.9 MW/min        | 29 MW maximum                | 16 MW maximum                  | 29 MW               | 27 MW             |
| Thermal Units             | 3 online      |                        |                    |                              |                                |                     |                   |

Table 4-8. Hawai'i Electric Light 2015–2016 System Security Constraint





| Value                                       | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve |
|---|---------------|------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|
| <b>2019 Scenario 1 Security Constraints</b> |               |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 78            | 2                      | 12.2 MW/min        | 32 MW maximum                | 16 MW maximum                  | 20 MW               | 22 MW             |
| Thermal Units                               | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 78            | 3                      | 12.2 MW/min        | 32 MW maximum                | 16 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                               | 3 online      |                        |                    |                              |                                |                     |                   |
| <b>2025 Scenario 2 Security Constraints</b> |               |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 2                      | 13.6 MW/min        | 34 MW maximum                | 16 MW maximum                  | 25 MW               | 25 MW             |
| Thermal Units                               | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 3                      | 13.6 MW/min        | 34 MW maximum                | 16 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                               | 3 online      |                        |                    |                              |                                |                     |                   |
| <b>2025 Scenario 3 Security Constraints</b> |               |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 2                      | 14.6 MW/min        | 21 MW maximum                | 3 MW maximum                   | 25 MW               | 22 MW             |
| Thermal Units                               | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 3                      | 14.6 MW/min        | 21 MW maximum                | 3 MW maximum                   | 20 MW               | 25 MW             |
| Thermal Units                               | 3 online      |                        |                    |                              |                                |                     |                   |
| <b>2025 Scenario 4 Security Constraints</b> |               |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 2                      | 17.6 MW/min        | 54 MW maximum                | 36 MW maximum                  | 25 MW               | 22 MW             |
| Thermal Units                               | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                                    | 89            | 3                      | 17.6 MW/min        | 54 MW maximum                | 36 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                               | 3 online      |                        |                    |                              |                                |                     |                   |

Table 4-9. Hawai'i Electric Light 2019–2025 Scenarios System Security Constraints

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| Value                                | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve |
|--------------------------------------|---------------|------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|
| 2030 Scenario 1 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 2                      | 14.5 MW/min        | 35 MW maximum                | 16 MW maximum                  | 20 MW               | 22 MW             |
| Thermal Units                        | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 3                      | 14.5 MW/min        | 35 MW maximum                | 16 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                        | 3 online      |                        |                    |                              |                                |                     |                   |
| 2030 Scenario 2 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 2                      | 14.5 MW/min        | 35 MW maximum                | 16 MW maximum                  | 25 MW               | 25 MW             |
| Thermal Units                        | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 3                      | 14.5 MW/min        | 35 MW maximum                | 16 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                        | 3 online      |                        |                    |                              |                                |                     |                   |
| 2030 Scenario 3 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 2                      | 15.5 MW/min        | 23 MW maximum                | 3 MW maximum                   | 25 MW               | 22 MW             |
| Thermal Units                        | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 3                      | 15.5 MW/min        | 23 MW maximum                | 3 MW maximum                   | 20 MW               | 25 MW             |
| Thermal Units                        | 3 online      |                        |                    |                              |                                |                     |                   |
| 2030 Scenario 4 Security Constraints |               |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 2                      | 18.5 MW/min        | 55 MW maximum                | 36 MW maximum                  | 25 MW               | 22 MW             |
| Thermal Units                        | 2 online      |                        |                    |                              |                                |                     |                   |
| PV Level                             | 97            | 3                      | 18.5 MW/min        | 55 MW maximum                | 36 MW maximum                  | 20 MW               | 25 MW             |
| Thermal Units                        | 3 online      |                        |                    |                              |                                |                     |                   |

Table 4-10. Hawai'i Electric Light 2030 Scenarios System Security Constraints

#### Maui Electric

The amount of legacy DG-PV on the Maui Electric system on Maui Island should not exceed 10 MW. Quantities in excess of 10 MW can result in excessive load shedding and the potential for system collapse. Improved relaying and communications are assumed to be installed in 2015 to help mitigate the potential for this consequence.

Maui Electric currently has two BESS connected to its system, one at Kaheawa Two and one at the Auwahi wind generating facilities. One BESS currently only manages the ramp rate of its associated wind generating facility, and the other has 10 MW of reserve available for the Maui Electric system. Years 2017 and 2019 represent significant changes to the Maui Electric system with the addition of substantial amounts of DG-PV and the permanent retirement of the four generating units at Kahului Power Plant.

The system security study for Maui Electric identified the energy requirements for the south Maui system to operate without the construction of new transmission lines to the area.

The system security constraints for Maui Electric are summarized Table 4-11 through Table 4-14. The Thermal Units Required column specifies the minimum number of thermal units required for stability. The remaining columns designate the specific constraint.

| Value                         | Capacity (MW) | Thermal Units Required     | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | DTT Scheme <sup>§</sup> Required |
|-------------------------------|---------------|----------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|----------------------------------|
| Minimum Thermal Units, No EES |               |                            |                    |                              |                                |                     |                   |                                  |
| Wind                          | 72            | DTCCI + KPP3, KPP4         | 12.5 MW            | 47.25 MW                     | 36 MW                          | 24 MW               | 40.2 MW           | Yes                              |
| DG-PV                         | 75            |                            |                    |                              |                                |                     |                   |                                  |
| Largest Unit                  | 30            |                            |                    |                              |                                |                     |                   |                                  |
| Wind                          | 72            | DTCCI + ½ DTCC2 KPP3, KPP4 | 12.5 MW            | 47.25 MW                     | 36 MW                          | 45 MW               | 40.2 MW           | No                               |
| DG-PV                         | 75            |                            |                    |                              |                                |                     |                   |                                  |
| Largest Unit                  | 30            |                            |                    |                              |                                |                     |                   |                                  |

§ DTT Scheme refers to a direct transfer trip of the first stage of load shedding for select unit outages. In order to prevent the tripping of the second stage of load shedding, the first stage should be transfer tripped for the loss of the KWP plant or any of the combustion turbines.

Table 4-11. Maui Electric 2015 System Security Constraints

| Value                         | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | DTT Scheme <sup>§</sup> Required |
|-------------------------------|---------------|------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|----------------------------------|
| Minimum Thermal Units, No EES |               |                        |                    |                              |                                |                     |                   |                                  |
| Wind                          | 72            | DTCCI + KPP3, KPP4     | 14 MW              | 49.5 MW                      | 36 MW                          | 45 MW               | 40.2 MW           | No                               |
| DG-PV                         | 90            |                        |                    |                              |                                |                     |                   |                                  |
| Largest Unit                  | 30            |                        |                    |                              |                                |                     |                   |                                  |

§ DTT Scheme refers to a direct transfer trip of the first stage of load shedding for select unit outages.

Table 4-12. Maui Electric 2016 System Security Constraints

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The security constraints for years after 2016 (Table 4-13 and Table 4-14) assume that the utility will have the capability to install an energy storage system to meet the criteria.

| Value                              | Capacity (MW) | Thermal Units Required        | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve |
|------------------------------------|---------------|-------------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|
| Minimum Thermal Units, Maximum EES |               |                               |                    |                              |                                |                     |                   |
| Wind                               | 72            | DTCCI                         | 14.6 MW            | 50.4 MW                      | 36 MW                          | 25 MW               | 38.5 MW           |
| DG-PV                              | 96            |                               |                    |                              |                                |                     |                   |
| Largest Unit                       | 30            |                               |                    |                              |                                |                     |                   |
| Wind                               | 72            | DTCCI + ½ DTCC2 <sup>§</sup>  | 14.6 MW            | 50.4 MW                      | 36 MW                          | 10 MW               | 38.5 MW           |
| DG-PV                              | 96            |                               |                    |                              |                                |                     |                   |
| Largest Unit                       | 30            |                               |                    |                              |                                |                     |                   |
| Wind                               | 72            | DTCCI + KPP3, KPP4            | 14.6 MW            | 50.4 MW                      | 36 MW                          | 10 MW               | 38.5 MW           |
| DG-PV                              | 96            |                               |                    |                              |                                |                     |                   |
| Largest Unit                       | 30            |                               |                    |                              |                                |                     |                   |
| Wind                               | 72            | DTCCI + ½ DTCC2<br>KPP3, KPP4 | 14.6 MW            | 50.4 MW                      | 36 MW                          | 0 MW                | 38.5 MW           |
| DG-PV                              | 96            |                               |                    |                              |                                |                     |                   |
| Largest Unit                       | 30            |                               |                    |                              |                                |                     |                   |

§ The DTCCI + ½ DTCC2 minimum unit combination closely matches the 2019 daytime cases since the load increase during the day is offset by the increase in the solar capacity. For this reason, 2019 cases were not run.

Table 4-13. Maui Electric 2017 System Security Constraints



| Value  | Capacity (MW) | Thermal Units Required | Ramp Rate Required | Regulating Reserve: Day Time | Regulating Reserve: Night Time | Contingency Reserve | 30-Minute Reserve | Transmission Constraint <sup>§</sup> |
|--|---------------|------------------------|--------------------|------------------------------|--------------------------------|---------------------|-------------------|--------------------------------------|
| Baseline: Minimum Thermal Units, Maximum EES |               |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI                  | 18 MW              | 55.5 MW                      | 36 MW                          | 25 MW               | 38.5 MW           | No                                   |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI + ½ DTCC2        | 18 MW              | 55.5 MW                      | 36 MW                          | 20 MW               | 38.5 MW           | No                                   |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |
| NTA-PSH Minimum Thermal Units, Maximum EES   |               |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI                  | 18 MW              | 55.5 MW                      | 36 MW                          | 25 MW               | 38.5 MW           | Yes                                  |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI + ½ DTCC2        | 18 MW              | 55.5 MW                      | 36 MW                          | 10 MW               | 38.5 MW           | Yes                                  |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |
| NTA ICE Minimum Thermal Units, Maximum EES   |               |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI                  | 18 MW              | 55.5 MW                      | 36 MW                          | 25 MW               | 38.5 MW           | Yes                                  |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |
| Wind   | 72            | DTCCI + ½ DTCC2        | 18 MW              | 55.5 MW                      | 36 MW                          | 10 MW               | 38.5 MW           | Yes                                  |
| DG-PV  | 130           |                        |                    |                              |                                |                     |                   |                                      |
| Largest Unit                                 | 30            |                        |                    |                              |                                |                     |                   |                                      |

1. With the proposed transmission upgrades, the generation dispatch is not constrained by transmission.
2. With a 30 MW PSH located in South Maui, all transmission constraints can be relieved. Minimum frequency for unit trip events are slightly lower compared to the same contingencies with the proposed ICE units located in South Maui.
3. With a 24 MW of ICE units located in South Maui, all transmission constraints can be relieved. Minimum frequency for unit trip events is slightly better compared to the same contingencies with the proposed PSH unit located in South Maui. The difference in response between the PSH and ICE units does not warrant a change in the contingency reserve requirements.

Table 4-14. Maui Electric 2030 System Security Constraints

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## 5. Preferred Plan

Maui Electric developed this Preferred Plan for transforming the system from current state to a future vision of the utility in 2030 that is consistent with the Strategic Direction (presented in Chapter 2).

Implementation of this Preferred Plan would safely transform the electric systems of Maui, Lana'i, and Moloka'i, and achieve unprecedented levels of renewable energy production. The electric systems of the future would be balanced portfolio of renewable energy resources, thermal generation, energy storage, and demand response.

The Preferred Plan for the island of Maui reduces “must-run” generation, increases variable renewable energy, and uses firm renewable sources to help stabilize the grid. Existing fossil-fuel steam generating units will be replaced with more flexible, fast-starting, peaking and/or cycling thermal generating units, and renewable firm baseload generation is scheduled to replace existing diesel generating units. Demand response will also be used to further reduce fossil fuel utilization. The Preferred Plans for Lana'i and Moloka'i increase variable renewable energy, and switch to using lower costs fuels in our generators.

The tactical, year-by-year plans for executing this transformation are described and discussed in this chapter.

## 5. Preferred Plan

Maui Electric of 2030: A Vision of Our Plan

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### MAUI ELECTRIC OF 2030: A VISION OF OUR PLAN

Our vision will advance our systems towards our goal of decreasing fossil fuels, integrating more renewable energy, and reducing customers' bills while maintaining system reliability. Our commitment to reshaping our systems will result in Renewable Portfolio Standards (RPS) of approximately 72%, substantially exceeding the requirement of 40% by 2030.

The Preferred Plans outline the transformation that we will undertake to evolve into a utility of the future—meeting the current and future needs of the community and customers we serve.

Maintaining flexibility in the resource options positions us to provide the lowest cost alternatives, while increasing renewable energy and ensuring reliability. As we execute the Maui Preferred Plan we will incorporate more firm renewable resources, such as geothermal, biomass, and more variable renewable resources, such as wind and solar PV. We will take advantage of PV technology that can produce larger, centralized projects that can benefit the entire community, and also distributed generation (DG-PV) projects that are sited at customers' residential and business premises.

Our plan also includes a non-transmission alternative for the South Maui Area. Firm generation is planned for South Maui to support the electrical system instead of new overhead transmission infrastructure. Initially, the firm generation will be comprised of internal combustion engines, which will later be replaced by geothermal, a renewable resource. The internal combustion engines will likely be relocated to Central Maui when the geothermal is commercialized.



Maui Preferred Plan

The timeline for the Maui Preferred Plan is presented in Figure 5- below, and it shows when new resources would be added (“above the date line”) and existing resources would be retired (“below the date line”).

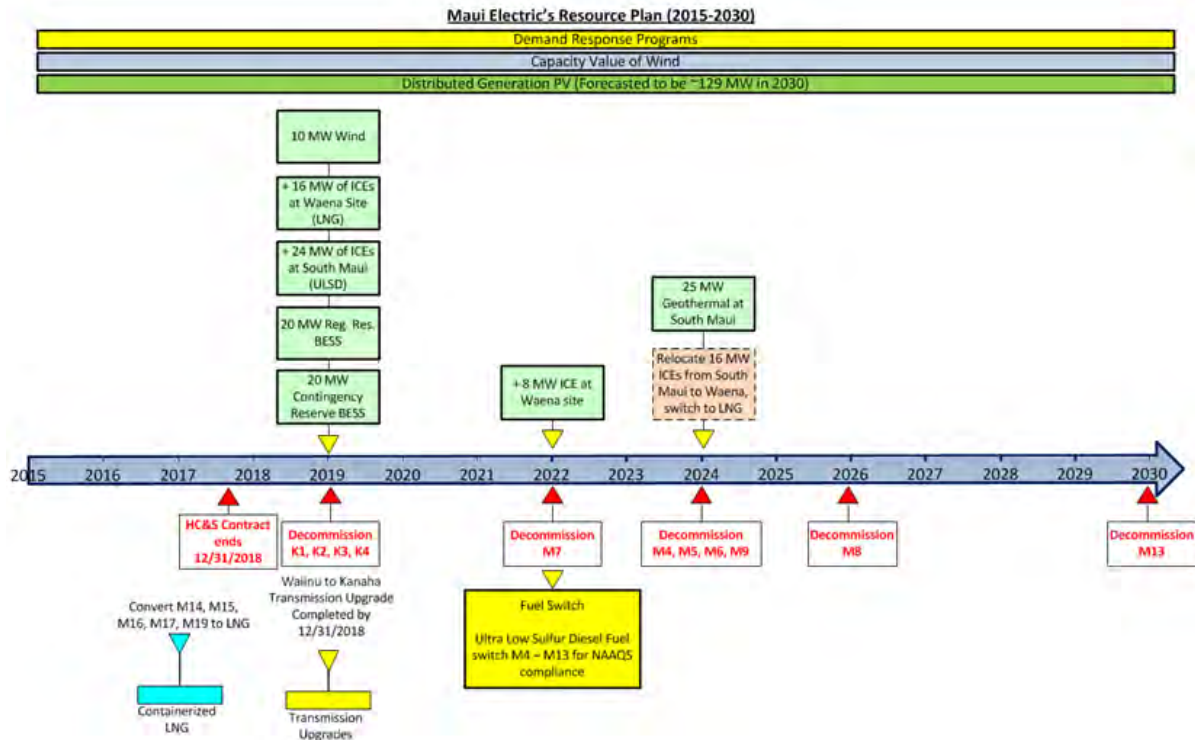


Figure 5-1. Timeline Diagram of Maui Electric: Maui Preferred Plan

The Preferred Plan allows us to increase renewable energy utilization by:

1. Retiring existing less flexible, less efficient generating units at the Kahului Power Plant
  - Install contingency Energy Storage Systems (ESS) in combination with quick starting generation in South Maui as a non-transmission alternative
  - Install LNG fueled fast starting generation as needed in Waena to ensure sufficient capacity to meet reserve margin criteria is maintained
  - Upgrade the Waiinu to Kanaha Transmission Line
  - Implement Demand Response Programs
3. Installing resources that reduce on-line reserves
  - Install Regulating Reserve ESS to maintain system security after Kahului Power Plant is retired

## 5. Preferred Plan

Maui Electric of 2030: A Vision of Our Plan

The Preferred Plan also controls costs to its customers by:

1. Implementing lower cost energy resources
  - Wind Power
  - Geothermal in South Maui
  - Retire more expensive diesel units when no longer needed for capacity
  - Solar Photovoltaic
2. Operating existing high efficiency and new quick-starting thermal generating units on LNG
  - Install LNG regasification facility at Waena
  - Switch dual-train combined cycle units to LNG
  - Operate new quick starting generation fueled by LNG at Waena
  - Quick starting generation replaced by geothermal in South Maui will be relocated to Waena for LNG fueling

### Lana'i and Moloka'i Preferred Plans

We conducted analysis for the islands of Lana'i and Moloka'i to develop preferred plans that are described below. Neither Lana'i nor Moloka'i required additional firm generation capacity to reliably meet the forecasted peak demand. However, we analyzed 100% renewable options, 50% LNG options, and options to reduce cost for each island.<sup>29</sup> The Preferred Plans below are based on modeling results and could change in response to community acceptance, refinement of system analysis, and actual costs of additional resources.

Based on the analysis, the preferred plans for both Lana'i and Moloka'i islands are:

- 50% LNG fuel switch in 2017
- 50% biodiesel fuel switch should the cost decrease to below that of USLD
- Utility scale solar installed in 2018
- Large-scale energy storage installed in 2018

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<sup>29</sup> There is significant uncertainty around activities of large developers that may impact future analysis. We found that more in-depth study would be required to refine the various resource capacity requirements, more accurately evaluate potential curtailment issues, and to assess the feasibility of operating the system given the various resources in each plan.

The timeline for the Lana'i and Moloka'i Preferred Plans are presented in Figure 5-2 and Figure 5-3 below.

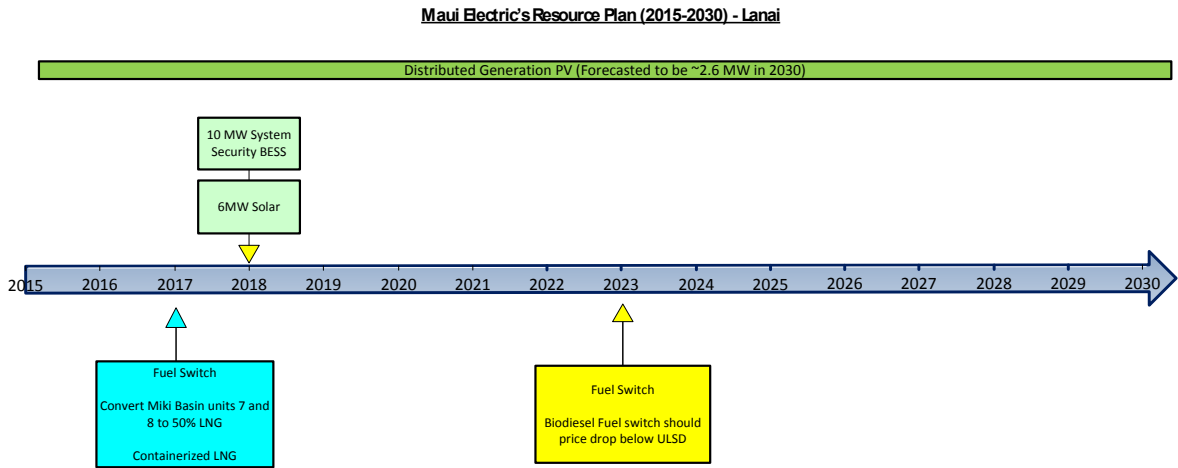


Figure 5-2. Timeline Diagram of Maui Electric: Lana'i Preferred Plan

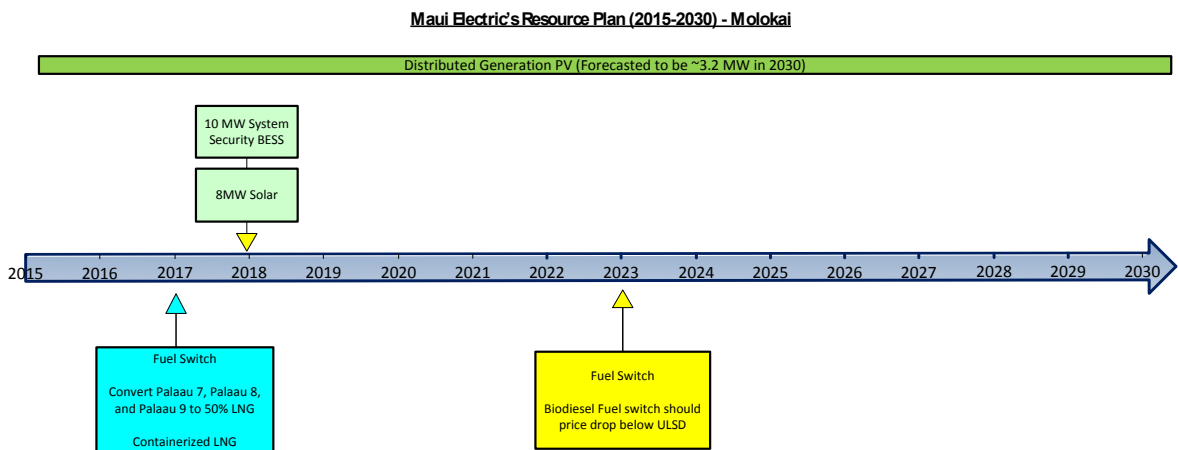


Figure 5-3. Timeline Diagram of Maui Electric: Moloka'i Preferred Plan

## 5. Preferred Plan

### Generation Resource Configuration

## GENERATION RESOURCE CONFIGURATION

The transformation of the electric system design allows for substantial renewable energy integration. To accomplish this, the firm generation resource mix must evolve to ensure system reliability and stability.

### Adequacy of Power

Our first priority is providing safe and reliable service to our customers. This starts with maintaining an adequate amount of capacity to meet our customers' needs.

Maui's Preferred Plan complies with current capacity planning criteria<sup>30</sup>, as well as draft planning criteria, BAL-502, provided in Appendix M. The draft planning criteria in BAL-502 includes providing capacity value to demand response, grid-side variable renewable generation, and energy storage. For the purposes of the PSIP, a minimum of 30% reserve margin was targeted. Table 5-1. shows the resulting reserve margin for the Preferred Plan.

| Year                                   | Peak (MW) | Total Thermal Capacity (MW) | New Thermal Generation (MW) | Retirements (MW) | DR for Capacity (MW) | Energy Storage for Capacity (MW) | Wind Capacity (MW) | Notes   | Reserve Margin (%) Base | Reserve Margin (%) w/ DR | Reserve Margin (%) w/ Energy Storage | Reserve Margin (%) w/ Capacity Value of Wind |
|--|-----------|-----------------------------|-----------------------------|------------------|----------------------|----------------------------------|--------------------|---|-------------------------|--------------------------|--------------------------------------|--|
| Included in Reserve Margin Calculation |           |                             |                             |                  |                      |                                  |                    |   | x                       | x                        | x                                    | x  |
|  |           |                             |                             |                  |                      |                                  |                    |   | x                       | x                        | x                                    | x  |
|  |           |                             |                             |                  |                      |                                  |                    |   |                         |                          | x                                    | x  |
|  |           |                             |                             |                  |                      |                                  |                    |   |                         |                          |                                      | x  |
| 2014                                   | 194       | 262                         | 0                           | 0                | 0                    | 0                                | 2.0                |   | 35.4%                   | 35.6%                    | 35.6%                                | 36.6%  |
| 2015                                   | 195       | 250                         | 4                           | (16)             | 1                    | 0                                | 2.0                | HC&S Capacity Reduced to 4MW 1/1/2015   | 28.1%                   | 28.7%                    | 28.7%                                | 29.7%  |
| 2016                                   | 197       | 250                         | 0                           | 0                | 5                    | 0                                | 2.0                |   | 26.9%                   | 30.2%                    | 30.2%                                | 31.3%  |
| 2017                                   | 192       | 250                         | 0                           | 0                | 6                    | 0                                | 2.0                |   | 30.5%                   | 34.8%                    | 34.8%                                | 35.8%  |
| 2018                                   | 197       | 250                         | 0                           | 0                | 7                    | 0                                | 2.0                | HC&S Contact Completed 12/31/2018   | 26.8%                   | 31.5%                    | 31.5%                                | 32.5%  |
| 2019                                   | 201       | 251                         | 41                          | (40)             | 8                    | 0                                | 2.3                | Decommission Kahului Units 1, 2, 3, 4<br>5 x 8 MW ICE in service<br>10 MW Wind in service | 24.9%                   | 30.2%                    | 30.2%                                | 31.4%  |
| 2020                                   | 202       | 251                         | 0                           | 0                | 9                    | 0                                | 2.3                |   | 24.1%                   | 30.0%                    | 30.0%                                | 31.2%  |
| 2021                                   | 204       | 251                         | 0                           | 0                | 9                    | 0                                | 2.3                |   | 23.0%                   | 29.0%                    | 29.0%                                | 30.1%  |
| 2022                                   | 205       | 254                         | 8                           | (6)              | 10                   | 0                                | 2.3                | Decommission Maalaea Unit 7<br>1 x 8 MW ICE in service                                    | 23.9%                   | 29.9%                    | 29.9%                                | 31.1%  |
| 2023                                   | 205       | 254                         | 0                           | 0                | 10                   | 0                                | 2.3                |   | 23.5%                   | 29.5%                    | 29.5%                                | 30.7%  |
| 2024                                   | 205       | 257                         | 25                          | (22)             | 10                   | 0                                | 2.3                | Decommission Maalaea Units 4, 5, 6, 9<br>25 MW Geothermal in service                      | 25.1%                   | 31.2%                    | 31.2%                                | 32.4%  |
| 2025                                   | 205       | 257                         | 0                           | 0                | 10                   | 0                                | 2.3                |   | 25.0%                   | 31.0%                    | 31.0%                                | 32.2%  |
| 2026                                   | 204       | 251                         | 0                           | (5)              | 10                   | 0                                | 2.3                | Decommission Maalaea Unit 8   | 23.0%                   | 29.0%                    | 29.0%                                | 30.1%  |
| 2027                                   | 203       | 251                         | 0                           | 0                | 10                   | 0                                | 2.3                |   | 23.9%                   | 30.0%                    | 30.0%                                | 31.2%  |
| 2028                                   | 200       | 251                         | 0                           | 0                | 10                   | 0                                | 2.3                |   | 25.8%                   | 32.1%                    | 32.1%                                | 33.3%  |
| 2029                                   | 198       | 251                         | 0                           | 0                | 10                   | 0                                | 2.3                |   | 27.2%                   | 33.6%                    | 33.6%                                | 34.8%  |
| 2030                                   | 194       | 239                         | 0                           | (12)             | 10                   | 0                                | 2.3                | Decommission Maalaea Unit 13  | 23.2%                   | 29.5%                    | 29.5%                                | 30.8%  |
| Total                                  |           |                             | 78                          | (101)            |                      |                                  |                    |   |                         |                          |                                      |  |

Table 5-1. Reserve Margin for the Maui Preferred Plan

<sup>30</sup> Docket No. 2012-0036, Integrated Resource Planning, Appendix L: Capacity Planning Criteria.

### Capacity Value of Demand Response

The demand response programs identified in the *Integrated Demand Response Portfolio Plan (IDRPP)* that provide capacity value are included in the calculation for the reserve margin.<sup>31</sup>

### Capacity Value of Variable Generation

Future wind resources are assigned a capacity value of 3% of nameplate capacity. This 3% capacity value was determined using a statistical correlation of variable generation output during the peak hour of each day. A 90% probability level was used to determine the capacity value.

PV was not assigned any capacity value due to the annual peak of the system occurring in the evening when PV is not available.

### Lana'i and Moloka'i

Generation resources on Lana'i and Moloka'i were determined to provide sufficient capacity to meet our customers' needs over the planning period.

## System Reliability

To move to a future with substantial variable renewable energy, the physical design of the system must be able to operate safely and reliably. The criteria and requirements for developing a plan to adequately accomplish this was described, in part, in Chapter 4. All the generation and transmission planning criteria are met to achieve the unprecedented levels of RPS in the Preferred Plan.

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<sup>31</sup> See Appendix F for details on the assumptions used in the PSIP.

## 5. Preferred Plan

### Generation and Energy Mix

## GENERATION AND ENERGY MIX

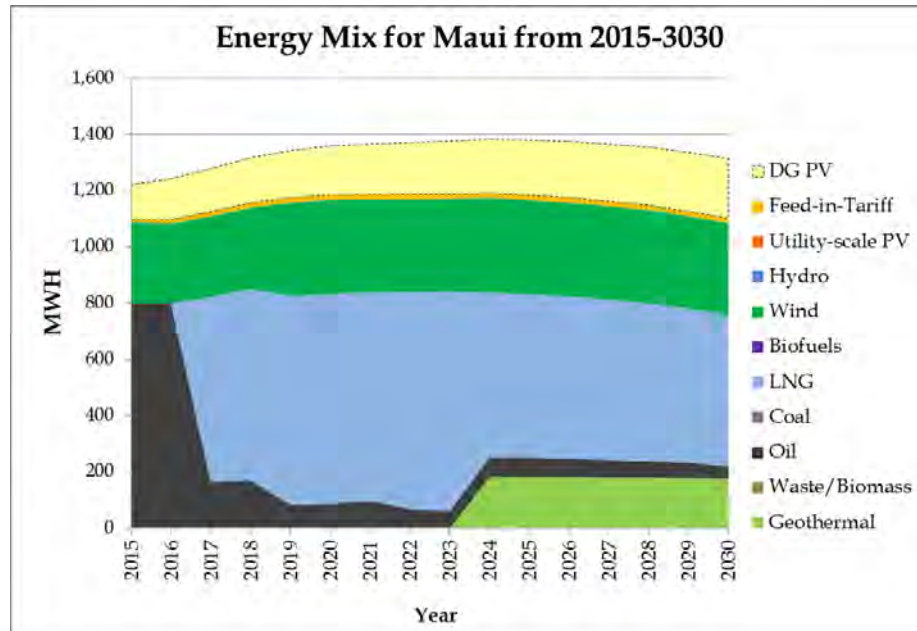


Figure 5-4. Annual Generation Portfolio: Maui

The generation mix has increasing levels of renewable energy replacing fossil generation. Renewable energy from distributed PV continues to grow over time and new wind and geothermal are also added to the system. As firm generating units are decommissioned, new flexible firm generation is added in its place.

A summary of the generation resources providing this portfolio mix over time is shown in Table 5-2 below.

| Generation Resources for the Maui Preferred Plan<br>("X" indicates resources included) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |                |
|--|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----------------|
| Unit   | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030           |
| DG PV  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Fit  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| KWP 1  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Auwahi   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| KWP 2  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Makila Hydro   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Future Wind  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| 20 MW BESS (Contingency)   |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| 20 MW BESS (Regulation)  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| HC & S   | X    | X    | X    | X    |      |      |      |      |      |      |      |      |      |      |      |                |
| Kahului 1  | X    | X    | X    | X    | X    |      |      |      |      |      |      |      |      |      |      | Decommissioned |
| Kahului 2  | X    | X    | X    | X    | X    |      |      |      |      |      |      |      |      |      |      | Decommissioned |
| Kahului 3  | X    | X    | X    | X    | X    |      |      |      |      |      |      |      |      |      |      | Decommissioned |
| Kahului 4  | X    | X    | X    | X    | X    |      |      |      |      |      |      |      |      |      |      | Decommissioned |
| Maalaea 1  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 2  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 3  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 4  | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |      |      |      |      |      | Decommissioned |
| Maalaea 5  | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |      |      |      |      |      | Decommissioned |
| Maalaea 6  | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |      |      |      |      |      | Decommissioned |
| Maalaea 7  | X    | X    | X    | X    | X    | X    | X    |      |      |      |      |      |      |      |      | Decommissioned |
| Maalaea 8  | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |      |      |      | Decommissioned |
| Maalaea 9  | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |      |      |      |      |      | Decommissioned |
| Maalaea 10   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 11   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 12   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 13   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | Decommissioned |
| Maalaea 14   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 15   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 16   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 17   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 18   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea 19   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea X2   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Maalaea X2   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Hana   | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 1  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 2  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 3  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 4  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 5  |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| ICE 6  |      |      |      |      |      |      |      | X    | X    | X    | X    | X    | X    | X    | X    | X              |
| Geothermal   |      |      |      |      |      |      |      |      |      | X    | X    | X    | X    | X    | X    | X              |

Table 5-2. Generation Resources for the Maui Preferred Plan, 2015–2030

DG-PV continues to increase from 2015 through 2030. DG-PV resources can possibly be obtained through either customer rooftop or larger-scale community solar projects.

In 2017, Ma’alaea Units M14, M16, M17, and M19 combustion turbines are converted to use LNG. Kahului Unit 3, Kahului Unit 4, one dual-train combined cycle and one single-train combined cycle units are designated as “must run” for system security.

In 2019, Kahului Power Plant is decommissioned and ten megawatts (MW) of wind is added to the system. Two LNG fired 8.14 MW internal combustion engines (ICE) are installed at Waena as cycling units. Three ULSD-fired 8.14 MW ICE are installed in South

## 5. Preferred Plan

### Generation and Energy Mix

Maui for contingency and capacity purposes. One dual-train combined cycle and one single-train combined cycle units are designated as must run with a 20 MW regulating-reserve energy storage system for system security.

In 2024, a 25 MW geothermal plant is installed. Two ICE units would be relocated from South Maui to Waena, converted to LNG, and operated as cycling units. One dual train combined cycle unit and a new geothermal plant are designated as must run with a 20 MW regulating-reserve energy storage system for system security.

## Renewable Generation Resource Mix

The Preferred Plans for the Hawaiian Electric Companies will result in significantly exceeding the Renewable Portfolio Standards (RPS) requirement of 40% by 2030 at each operating company. Table 5-3 depicts the RPS percentages attained through the Preferred Plans for Hawaiian Electric, Maui Electric, Hawai'i Electric Light, and consolidated for all three utilities.

| Company                | Renewable Portfolio Standard |
|------------------------|------------------------------|
| Hawaiian Electric      | 61%                          |
| Maui Electric          | 72%                          |
| Hawai'i Electric Light | 92%                          |
| Consolidated           | 67%                          |

Table 5-3. 2030 Renewable Portfolio Standard Percentages for Preferred Plans



## Projection of Compliance with Renewable Portfolio Standards

As shown in Figure 5-1, the Hawaiian Electric Companies' Preferred Plans will add significantly more renewable energy and substantially exceed the mandated Consolidated 2030 RPS of 40%. This Consolidated RPS would be 67%, and would more than double between 2015 and 2030.

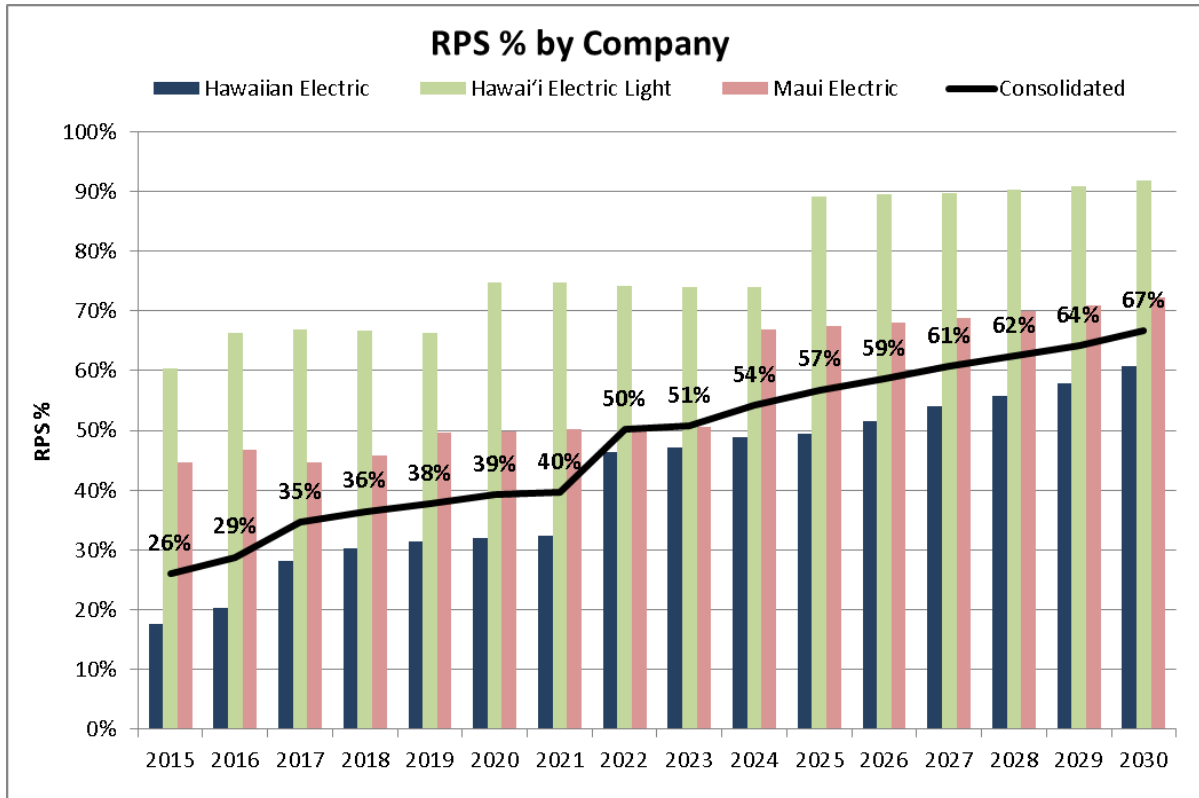


Figure 5-5. Consolidated RPS of Hawaiian Electric Companies Preferred Plans

For the Maui Electric Preferred Plans for Maui, Lana'i, and Moloka'i, the RPS would more almost double from 2015 to 2030, from 41% to 72%, respectively, as shown in Figure 5-6 below. The relative constriction of distributed generation photovoltaic (DG-PV also referred to as "rooftop PV") would be almost one-third of the RPS value.

Our forecasts indicate that we can meet 40% renewable energy utilization by 2018. In 2019, the retirement of the units at Kahului Power Plant, the addition of ICE units, the addition of BESS, and the addition of 10 MW of wind, renewable energy utilization will allow us to meet 45% annually through 2023. With the addition of a geothermal resource in 2024, renewable energy utilization will exceed 65%. Demand response programs are also implemented during this period and contribute to an increasing amount of renewable energy. Our forecast indicates that we will achieve 129 MW of DG-PV on the Maui system by 2030.

## 5. Preferred Plan

### Generation and Energy Mix

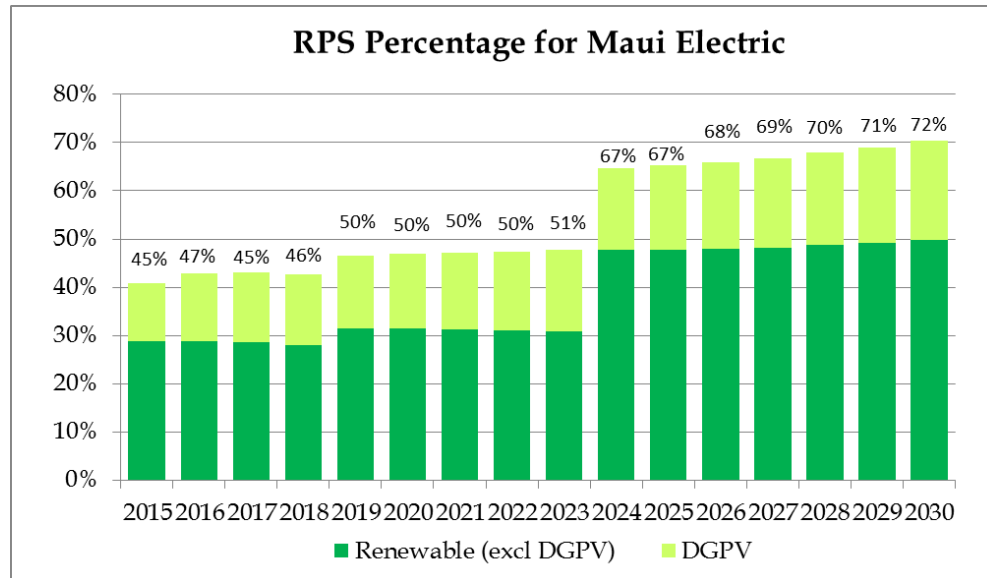


Figure 5-6. Maui Electric Preferred Plans RPS

We performed analyses incorporating existing generating resources, demand response programs, and new generating resources to develop a Preferred Plan that increases the amount of renewable generation accepted and minimizes costs relative to the other resources considered. It contains a mix of resources that allows for increased renewable energy on the Maui system including DG-PV, additional wind, and a new geothermal resource. Geothermal is a firm renewable generation resource that can provide cost-effective must-run generation.

The overall mix of renewable energy resources contributing to the RPS in 2030 is shown in Figure 5-7.

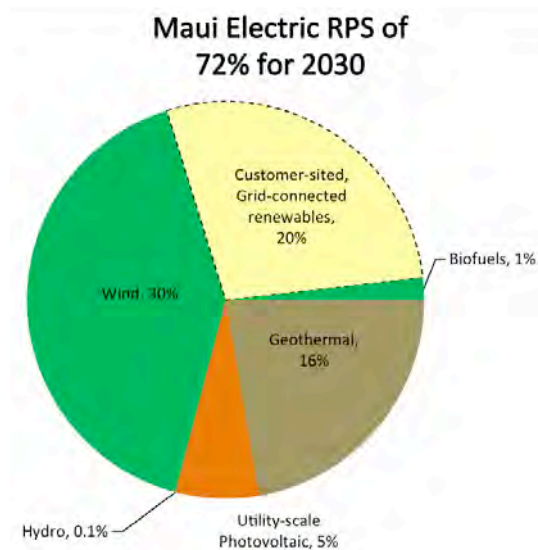


Figure 5-7. 2030 RPS for Maui Electric Preferred Plans

Figure 5-8 below shows that the system is able to utilize (that is, not curtail) 95.8% to 99.2% each year of the renewable energy that is produced throughout the planning period.

| % RE Utilized | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  | 2024  | 2025  | 2026  | 2027  | 2028  | 2029  | 2030  | 2015-2030 |
|---------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----------|
|               | 99.2% | 98.6% | 97.5% | 97.9% | 96.7% | 96.8% | 96.9% | 96.2% | 95.8% | 98.7% | 98.6% | 98.4% | 98.0% | 97.7% | 97.2% | 96.6% | 97.9%     |

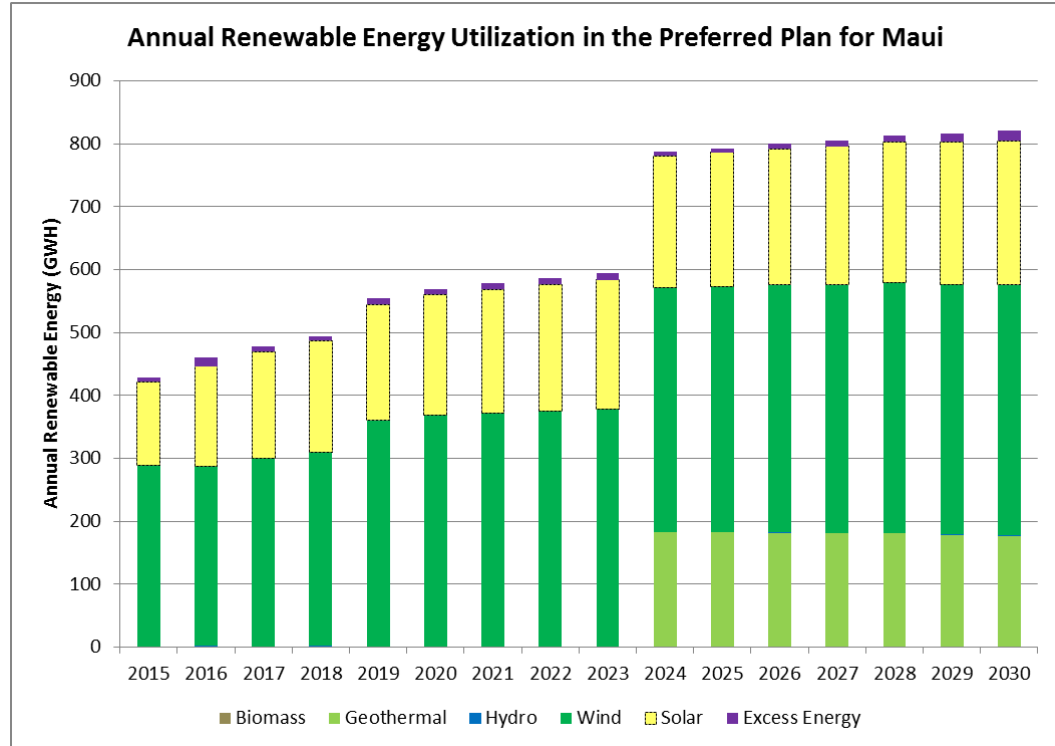


Figure 5-8. Total Maui System Renewable Energy

### Annual Fuel Consumption

In alignment with our vision, the Preferred Plan reduces the reliance on imported fossil fuels to Maui. With the addition of new variable renewable resources and new firm renewable resources, we are able to reduce the total amount of fossil fuel consumption.

## 5. Preferred Plan

### Generation and Energy Mix

Figure 5-9 through Figure 5-11 show how the annual fuel consumption for Maui, Lana'i, and Moloka'i, respectively, decreases as the mix of generation changes over the analysis period.

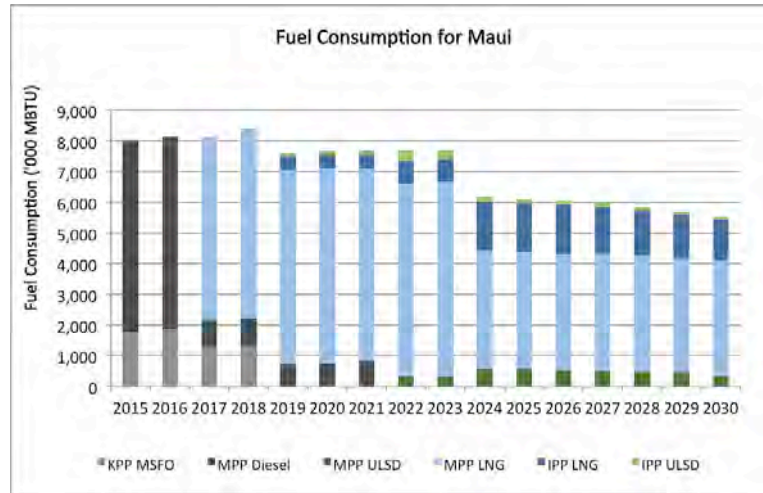


Figure 5-9. Annual Fuel Consumption for Maui

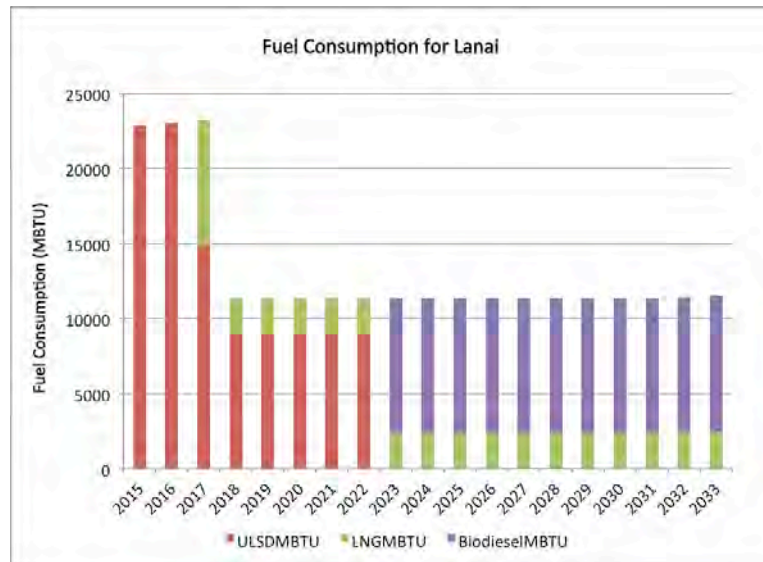


Figure 5-10. Annual Fuel Consumption for Lana'i

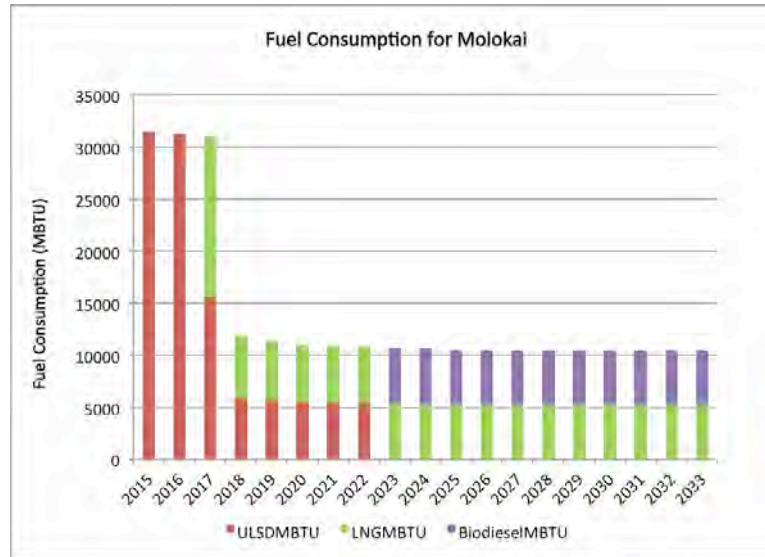


Figure 5-11. Annual Fuel Consumption for Molokai

As we introduce new resources to the system and retire Maui Electric’s generating units from 2019 to 2030, the fossil fuel consumption the power system on each island decreases. The annual fuel consumption of Maui Electric’s baseload and cycling generating units decrease, as shown in Figure 5-12 below, as existing generating units are retired and renewable energy is added to the system.

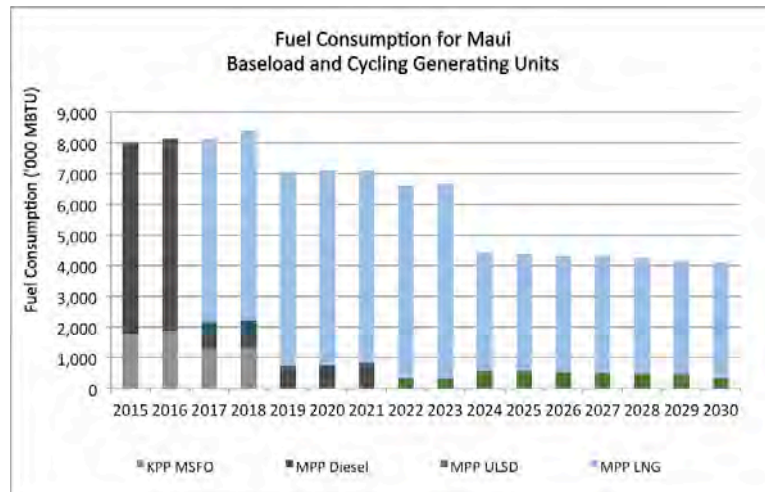


Figure 5-12. Annual Fuel Consumption for Maui Baseload & Cycling Generating Units

### Annual Capacity Factors for Each Resource

Our generation portfolio constantly evolves based on the needs of our customers and our community. System load changes as energy efficiency programs, demand response programs, and DG-PV mature. The remaining system load is provided by a mix of utility and IPP generation. The mix of generation also evolves as existing resources are

## 5. Preferred Plan

### Generation and Energy Mix

decommitted or the contract terms of power purchase agreements are completed. New generation resources are added to the system accordingly.

Table 5-4 for years 2015, 2020, 2025, and 2030 shows the annual capacity factors of each generating resource on the Maui system.

| Units             | Type                       | Capacity Factor |      |      |      |
|-------------------|----------------------------|-----------------|------|------|------|
|                   |                            | 2015            | 2020 | 2025 | 2030 |
| Kahului 1         | Thermal Steam              | 0%              | –    | –    | –    |
| Kahului 2         | Thermal Steam              | 7%              | –    | –    | –    |
| Kahului 3         | Thermal Steam              | 64%             | –    | –    | –    |
| Kahului 4         | Thermal Steam              | 53%             | –    | –    | –    |
| Ma'alaea X1       | Internal Combustion Engine | 2%              | 0%   | 0%   | 1%   |
| Ma'alaea X2       | Internal Combustion Engine | 3%              | 0%   | 0%   | 0%   |
| Ma'alaea 1        | Internal Combustion Engine | 6%              | 0%   | 0%   | 1%   |
| Ma'alaea 2        | Internal Combustion Engine | 5%              | 0%   | 0%   | 0%   |
| Ma'alaea 3        | Internal Combustion Engine | 4%              | 0%   | 0%   | 1%   |
| Ma'alaea 4        | Internal Combustion Engine | 13%             | 0%   | –    | –    |
| Ma'alaea 5        | Internal Combustion Engine | 6%              | 0%   | –    | –    |
| Ma'alaea 6        | Internal Combustion Engine | 13%             | 1%   | –    | –    |
| Ma'alaea 7        | Internal Combustion Engine | 1%              | 0%   | –    | –    |
| Ma'alaea 8        | Internal Combustion Engine | 11%             | 1%   | 3%   |      |
| Ma'alaea 9        | Internal Combustion Engine | 8%              | 2%   | –    | –    |
| Ma'alaea 10       | Internal Combustion Engine | 49%             | 13%  | 21%  | 13%  |
| Ma'alaea 11       | Internal Combustion Engine | 40%             | 8%   | 14%  | 11%  |
| Ma'alaea 12       | Internal Combustion Engine | 32%             | 26%  | 8%   | 6%   |
| Ma'alaea 13       | Internal Combustion Engine | 22%             | 20%  | 7%   |      |
| Ma'alaea 14-15-16 | Dual Train Combined Cycle  | 83%             | 73%  | 81%  | 77%  |
| Ma'alaea 17-18-19 | Dual Train Combined Cycle  | 24%             | 79%  | 9%   | 10%  |
| Hana              | Internal Combustion Engine | 0%              | 0%   | 0%   | 0%   |
| HC&S              | Biomass                    | 0%              | –    | –    | –    |
| KWPI              | Wind                       | 44%             | 44%  | 44%  | 44%  |
| AWE               | Wind                       | 52%             | 52%  | 52%  | 51%  |
| KWP2              | Wind                       | 42%             | 44%  | 44%  | 42%  |
| NewWind1          | Wind                       | –               | 46%  | 48%  | 45%  |
| Geothermal        | Geothermal                 | –               | –    | 83%  | 81%  |
| Makila Hydro      | Run-of-River Hydro         | 23%             | 23%  | 23%  | 23%  |
| 8 MW ICE 1        | Internal Combustion Engine | –               | 8%   | 20%  | 14%  |
| 8 MW ICE 2        | Internal Combustion Engine | –               | 5%   | 56%  | 48%  |
| 8 MW ICE 3        | Internal Combustion Engine | –               | 3%   | 51%  | 44%  |

| Units      | Type  | Capacity Factor |      |      |      |
|------------|---|-----------------|------|------|------|
|            |   | 2015            | 2020 | 2025 | 2030 |
| 8 MW ICE 4 | Internal Combustion Engine                      | –               | 33%  | 46%  | 38%  |
| 8 MW ICE 5 | Internal Combustion Engine                      | –               | 27%  | 42%  | 34%  |
| 8 MW ICE 6 | Internal Combustion Engine                      | –               | –    | 36%  | 29%  |
| DG-PV      | Solar Photovoltaic                              | 19%             | 19%  | 19%  | 19%  |
| FIT Solar  | Solar Photovoltaic and Concentrated Solar Power | 19%             | 19%  | 19%  | 18%  |

Table 5-4. Total System Renewable Energy: Maui

## ROLES OF GENERATION RESOURCES

Our system has evolved with the addition of variable renewable resources; both developer and customer owned, in the form of solar, hydro-electric, and wind technologies. Variable renewable resources have changed the system stability requirements that Maui Electric and Independent Power Producers need to adapt to, in order to continue to provide safe, reliable power to all customers.

Our vision of a future with even greater renewable generation on the system requires that new renewable generation has the operating characteristics that contribute to system stability to maintain and improve the reliability. Our current generation fleet is comprised of firm capacity resources that have provided system security and safe, reliable power for many years. As our firm fossil fueled generators are retired, the flexibility from these units must be provided by new renewable resources.

### Utility-Owned Generation Retirements

#### Roles of Current Generation

The current generation fleet of Maui Electric is comprised of:

- Four (4) Steam Units: located at the Kahului Power Plant, these units provide firm generation, regulating reserve, system inertia, voltage support to central Maui, contribute to system security. These units use an industrial fuel oil that is lower cost than diesel.
- Two (2) Dual Train Combined Cycle units: located at the Ma’alaea Power Plant, these units are the most efficient generating resources on the island. These units provide firm generation, regulating reserve, system inertia. These units can start and provide generation in a relatively short time period.

## 5. Preferred Plan

### Roles of Generation Resources

- Fifteen (15) Internal Combustion Diesel Engines: located at the Ma'alaia Power Plant, these units provide firm generation and regulating reserve. These units can start and provide firm generation in a relatively short time period. Five of these units (X1, X2, M1, M2, and M3) are quick starting units that can be used for emergency and transition unit to starting a larger diesel unit.
- Two (2) Internal Combustion Diesel Engines: located in Hana, these units provide firm generation and primarily provide support to the Hana area during transmission maintenance and system disturbance.
- Eight (8) Internal Combustion Diesel Engines: located in Lana'i-Miki Basin. These units can start and provide firm generation in a relatively short time period.
- Nine (9) Internal Combustion Diesel Engines: located in Moloka'i-Pala'au. These units can start and provide firm generation in a relatively short time period.
- 1 Combustion Turbine Engine: located in Moloka'i-Pala'au. This unit provides firm generation and peaking load capability

The existing Maui Electric generation fleet is expected to perform in the future as follows:

- Four (4) Steam Units at Kahului Power Plant: these units will continue to operate in its present configuration until retirement in 2019.
- Two (2) Dual Train Combined Cycle Units at Ma'alaia Power Plant:  
One of the dual train combined cycle units is scheduled to be modified to operate at lower capacity minimum level and will transition to LNG fuel starting in 2017. This unit will continue to operate as a must-run generating unit and contribute to the system security, but operation at lower load levels will allow more opportunity to integrate variable renewable energy when available, and transition to LNG will lower cost to customers.

The other dual train combined cycle unit will be held off-line and operated in simple cycle or combined cycle as needed. This unit is also scheduled to transition to LNG fuel starting in 2017. To comply with system security and operate a high efficient, low fuel cost resource, this unit will be operated in single train combined cycle and designated as must-run starting in 2017. In 2024, this unit will be removed from must-run designation and replaced with a geothermal resource. The geothermal resource is expected to contribute to system security at the same level as the single train combined cycle unit it will replace.

- Fifteen (15) Internal Combustion Diesel Engines: These units will remain off-line and be available for contribution to system security and system load as needed after other off-line non-fossil fuel resources, such as DR and energy storage, have been used to its fullest availability and ability. Units will be retired in accordance with Table 5-5.



- Two (2) Internal Combustion Diesel Engines at Hana: these units will continue to be operated to support the Hana area.

### Additional Renewable Generation Integration

The existing Maui Electric generation fleet has operating characteristics that are quick-starting, flexible, fuel-efficient, and dispatchable to accommodate the integration of existing and additional variable renewable energy resources without significant curtailment.<sup>32</sup>

Quick-Starting generation has the ability to remain off-line until it is required to support the system, like during a large down ramp event when the wind or solar resources suddenly become unavailable. Other units that may need additional time to start and connect to the system will need a resource to bridge the time required to supply generation (for example, demand response and energy storage).

- Ma'alaea diesel generating units MX1, MX2, M1, M2, M3 can be started and synchronized to the system in 3 minutes.
- The combustion turbines (Ma'alaea Units M14, M16, M17, M19) can be started and synchronized to the system in less than 20 minutes in simple cycle mode.
- Ma'alaea diesel generating units M10, M11, M12, M13 can be started and synchronized to the system in less than 20 minutes.
- Ma'alaea diesel generating units M4, M5, M6, M7, M8, M9 can be started and synchronized to the system in less than 40 minutes.

Flexible generation refers to units that can be held off-line until called upon for generation, allowing us to maximize variable renewable generation. All Ma'alaea generating units are flexible.

The most fuel efficient units on the Maui system are the dual train combined cycle units.

Units that have operating ranges that can ramp up and down to follow the system load as well as the variable energy production of the as-available generating resources to reduce curtailment include M4-M13, DTCC1, and DTCC2.

### Retirement Schedule

Our vision of providing a future with more renewable energy, while also minimizing cost impacts to customers, requires our fossil fueled generating units to be replaced with new generating resources. Although new generation resources require capital investment, we anticipate the addition of these new resources will lower future energy costs compared with the current energy mix, and over time, our customers will be able to

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<sup>32</sup> The thermal generation fleet on Lana'i and Moloka'i is comprised of flexible, quick-starting units.

## 5. Preferred Plan

### Roles of Generation Resources

realize the cost benefits. Retiring existing generation will also reduce dependency on fossil fuels.

Table 5-5 is Maui Electric’s retirement plan for its existing fossil fuel generating resources.

| Unit Description | Unit Rating (MW) | Retirement Date |
|------------------|------------------|-----------------|
| Kahului Unit 1   | 4.71             | 2019            |
| Kahului Unit 2   | 4.76             | 2019            |
| Kahului Unit 3   | 10.98            | 2019            |
| Kahului Unit 4   | 11.88            | 2019            |
| Ma’alaea Unit 7  | 5.51             | 2022            |
| Ma’alaea Unit 4  | 5.51             | 2024            |
| Ma’alaea Unit 5  | 5.51             | 2024            |
| Ma’alaea Unit 6  | 5.51             | 2024            |
| Ma’alaea Unit 9  | 5.48             | 2024            |
| Ma’alaea Unit 8  | 5.48             | 2026            |
| Ma’alaea Unit 13 | 12.34            | 2030            |

Table 5-5. Fossil Fuel Generation Retirement Plan

### Fossil Fuel Generation Retirement Plan

The units at the Kahului Power Plant are scheduled for retirement to comply with environmental standards. These units provide firm capacity and contribute to system security. Therefore, replacement firm generating ICE units are planned to be installed in 2019, and an ESS is planned to be in-service on the Maui system in 2019 to provide system security.

The Ma’alaea generating units that are scheduled for retirement will be replaced with more cost effective, flexible ICE generation and a lower energy cost generation resource (for example, geothermal). Ma’alaea generating units are also retired when the system peak load is forecasted to decline and there is an anticipation of excess firm capacity.

To account for existing unit retirements and ensure adequate amounts of firm generation on the Maui system, new firm generation must be installed. We will pursue new firm generation through a competitive procurement process (described below).

Several of our existing generating units will not be retired during the PSIP analysis period. The units listed below provide benefits to the Maui system that include system security, minimized costs through efficiency and low cost LNG fuel, or flexibility.

- Dual Train Combined Cycle units: high efficiency, low LNG fuel cost, provides regulating reserves, provides contingency reserves.

- Combustion Turbines: low LNG fuel costs, operational flexibility through startup availability and dispatch.
- Small diesel internal combustion engines (MX1, MX2, M1, M2, M3): quick-starting
- Mid-size diesel internal combustion engines (M10, M11, M12): operational flexibility through startup availability and dispatch.

It is also anticipated that the small and mid-size diesel units will be operated very infrequently, as they will be designated to operate during peak load periods or when variable renewable resources are un-available.

### Must-Run Designations

We are committed to providing to its customers safe and reliable power at all times. To accomplish this, system security and stability is our first priority. A combination of firm generating resources and resources that provide system reserves will ensure that the system demand is met. As we have incorporated significant amounts of variable renewable energy on our system, system security requirements have changed, prompting adjustment in the operation of existing resources. Our system security needs will continue to evolve with our generation resource mix as we continue to increase our renewable energy portfolio.

The high penetration of variable renewable resources on our system creates new challenges to maintaining system security and stability. Must-run generation can be reduced to allow the system to accept more renewable energy, but the generation resource configuration and operational practices must be adjusted to ensure that system security is not compromised.

Table 5-6 shows the units that are designated as must-run and the additional resources that are required to meet the system security requirements.

| Year | Must-Run Resources       | Regulation Reserve Resource | Contingency Reserve Resource | System Security Criteria |
|------|--------------------------|-----------------------------|------------------------------|--------------------------|
| 2015 | DTCCI; K3, K4            |                             |                              | Non-Compliant            |
| 2017 | DTCCI, STCC2, K3, K4     |                             |                              | Compliant                |
| 2019 | DTCCI, STCC2             | Add 20 MW: 10 MWh BESS      | Add 20 MW: 30 Minute BESS    | Compliant                |
| 2024 | DTCCI, Geothermal (25MW) |                             |                              | Compliant                |

Table 5-6. Must-Run Designations

To reduce must-run generation while increasing variable renewable generation, we will need to add resources without minimum load settings that can provide reserve requirements that will comply with system security criteria. Reducing fossil fueled must-

## 5. Preferred Plan

### Roles of Generation Resources

run generation will reduce fossil fuel generation costs, but it requires capital investment in new resources, such as batteries, and will increase power purchase payments to independent power producers.

For the island of Lanaʻi, Miki Basin Units 7 & 8 are designated as must run during the day to meet system security needs.

For the island of Molokaʻi two (2) of the baseload-capable units (Palaʻau units 7, 8, and 9) must run during the day to meet system security needs.

### Must-Run Generation Designation Plan

System reliability will remain our priority, with efforts also focused on reducing our energy costs by reducing fossil fuel generation and transitioning to LNG. Maui Electric will also implement DR programs as described in the IDRPP<sup>33</sup> that will contribute to system reliability and reduce fossil fuel consumption.

The action plan in Table 5-7 follows the must-run designations listed in Table 5-6, and utilizes the high efficiency of the existing dual train combined cycle units to comply with system reliability criteria.

| #  | Description  | Target Date | Benefit   |
|----|--|-------------|---|
| 1. | Acquire LNG  | 2017        | Low cost fuel   |
| 2. | Modify DTCC1 and DTCC2 to use LNG  | 2017        | High efficiency units using low cost fuel   |
| 3. | Modify DTCC1 to operate at lower minimum operating levels                    | 2017        | Accommodates integration of existing and substantial additional variable renewable energy   |
| 4. | Retire all units at Kahului Power Plant (Units K3 and K4 are must-run units) | 2019        | Accommodates integration of existing and substantial additional variable renewable energy   |
| 5. | Add 20MW:10MWh Regulating Reserve BESS                                       | 2019        | Accommodates integration of existing and substantial additional variable renewable energy by reducing regulating reserve requirement provided by fossil fuel generation |
| 6. | Add 20MW:30 Minute Contingency Reserve BESS                                  | 2019        | Allows for a non-fossil fuel, off-line resource to provide system security for a contingency event in lieu of on-line fossil fuel resource                              |
| 7. | Add Internal Combustion Engines  | 2019        | Flexible, firm generating units. Quick starting capability allows ICE to remain off-line until called upon to support the system.                                       |
| 8. | Retire Maʻalaea diesel internal combustion engine, Unit M7                   | 2022        | Retire less efficient diesel unit   |

<sup>33</sup> The Companies filed its *Integrated Demand Response Portfolio Plan (IDRPP)* with the Commission on July 26, 2014.

| #   | Description  | Target Date | Benefit  |
|-----|--|-------------|--|
| 9.  | Add Internal Combustion Engine   | 2022        | Flexible, firm generating unit. Quick starting capability allows ICE to remain off-line until called upon to support the system. |
| 10. | Add 25MW Geothermal must-run resource                                  | 2024        | Add low energy cost, firm renewable resource to provide system security  |
| 11. | Remove must-run designation from DTCC2                                 | 2024        | Accommodates integration of existing and substantial additional firm (geothermal) and variable renewable energy                  |
| 12. | Retire Ma'alea diesel internal combustion engines, Units M4,M5, M6, M9 | 2024        | Retire less efficient diesel units   |
| 13. | Retire Ma'alea diesel internal combustion engine, Unit M8              | 2026        | Retire less efficient diesel unit  |
| 14. | Retire Ma'alea diesel internal combustion engine, Unit M13             | 2030        | Retire less efficient diesel unit  |

Table 5-7. Action Plan for Reducing Must-Run Generation

### Procurement of Replacement/New Generation

The PSIPs for O'ahu and Maui identify replacement generation being needed in 2022 and 2019, respectively. In addition, demand response programs and energy storage are planned to be implemented during in the immediate future that are expected to provide capacity reserves for both island power systems. The most urgent replacement generation is needed on Maui Island, as it would provide for the timely retirement of the four generating units at Kahului Power Plant by 2019. Below is a recommended process for competitively procuring the needed replacement generation for the Maui power system. A similar process is recommended for O'ahu.

The PSIP for Maui Island includes procurement of replacement/new firm generation resources in advance of the retirement of 36 MW and 4 MW of capacity at Kahului Power Plant and HC&S Power Purchase Agreement (PPA) termination, respectively, on or before 2019. The PSIP also indicates a need to locate a portion of the replacement/new generation in the South Maui Area in order to mitigate an under-voltage contingency without building new overhead transmission lines in the area. Subject to the Commission's concurrence, the following competitive process (not a waiver to the competitive bidding framework) will be implemented in the immediate future to procure the needed replacement/new generation.

- I. Maui Electric will implement Demand Response programs in accordance with the *Integrated Demand Response Portfolio Plan (IDRPP)* to secure demand response (DR) capacity reserved on Maui Island.

## 5. Preferred Plan

### Roles of Generation Resources

2. A technical specification will be prepared that describes the situation on Maui island, including the need for replacement generation for the retirement of KPP and termination of the PPA with HC&S. The specification will also describe the need for non-traditional alternatives (NTA) to new overhead transmission in the South Maui Area, and how new generation and/or energy storage may be implemented to address the under-voltage contingency that exists.
3. The technical specification will describe the size, type, locations and timing of resources that may be proposed for implementation to meet the specified needs. Alternative resources and resource configurations that would meet the need would be invited to be proposed and will be given full consideration.
4. The technical specification would not provide target capacity for individual generating units or in total, but would likely specify minimum capacity size for individual units and capacities, and a maximum size for individual units (to meet system security and system operation and dispatch requirements).
5. At the Commission's direction, Maui Electric or an independent third party will run a competitive procurement process, including the issuance of a Request for Proposals (RFP) that utilizes the technical specification.
6. In parallel with Step 5, if requested by the Commission, Maui Electric would run a competitive process for the selection and contracting of an Independent Observer (IO).
7. In parallel with Step 5, Maui Electric would run a competitive process for the selection and procurement of energy storage systems (based on the needs defined by the PSIP).
8. Maui Electric will prepare a self-build option for replacement/new generation in accordance with the technical specification described in Steps 2 and 3.
9. Maui Electric (or the third party designated by the Commission), in cooperation with the IO (if the Commission requested an IO) would evaluate the proposals received in response to the RFP issued in Step 5. The evaluation of proposals will be based, in parts, on the needs for the Maui island power system taking into account the results to procure energy storage and DR capacity reserves in Steps 7 and 8, respectively.
10. The results of the evaluation of the competitive proposals and the Maui Electric self-build option would be submitted to Commission, with an accompanying recommendation by the IO (if the Commission requested an IO) on the selection of projects. The recommendation to the Commission would include a portfolio of energy storage, DR, and generation resources that meet the power system's needs as defined by Adequacy of Supply analyses and PSIP.

- II. Pending approval by the Commission on the path forward, applications for approval of specific projects and/or power purchase agreements will be prepared and submitted to the Commission for approval. If approved, the projects and/or PPA would be implemented.

## Flexibility for Integrating Additional Renewable Generation

Reduction in must-run generation, regulating reserves provided by flexible resources or generation (such as ESS, demand response, and ICE) and load shifting resources (such as storage and demand response on our system).

To support our commitment to increasing renewables on the system, the units at the Kahului Power Plant are scheduled for decommission in 2019. They will be replaced with firm generating resources in the form of Internal Combustion Engines (ICE). In addition to providing firm capacity, the ICE units are designed to start and stop multiple times a day and can provide ramping capability. An ESS will also be added to the system to provide regulating reserves.

The Preferred Plan also adds demand response programs that shift loads to reduce curtailment and reduce the load during peak electrical consumption periods. Demand response programs also provide reserves that assist the system during periods when variable renewable resources are not available to contribute to the system.<sup>34</sup>

### Key Generation Units

The units listed below provide benefits to the Maui system that include system security, minimized costs through efficiency and low cost LNG fuel, or flexibility.

- Dual Train Combined Cycle units: high efficiency, low LNG fuel cost, provides regulating reserves, provides contingency reserves.
- Combustion Turbines: low LNG fuel costs, operational flexibility through startup availability and dispatch.
- Small diesel internal combustion engines (MX1, MX2, M1, M2, M3): quick-starting
- Mid-size diesel internal combustion engines (M10, M11, M12): operational flexibility through startup availability and dispatch.

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<sup>34</sup> ICE units can also be utilized when demand response and ESS resources have been used to their limitations.

## 5. Preferred Plan

### Roles of Generation Resources

#### Roles of Existing Independent Power Producer (IPP) Generation

Over the period of the PSIP analysis there are three existing IPP have Power Purchase Agreements (PPA) that are expiring:

- HC&S: expiration date 2014<sup>35</sup>
- Makila Hydro: expiration date 2026
- Kaheawa Wind Power I, LLC (KWP1): expiration date 2026

We plan to negotiate extensions to all expiring PPAs. However, PPA extensions need to be in the best interest of the community and customers. Substantially lower costs are expected, as the period for recovery of project development and execution costs has been completed. If renegotiations do not result in substantially lower costs, then we will pursue replacement renewable generation through a competitive procurement process similar to the described above.

#### HC&S

In addition to providing firm renewable power to the Maui grid HC&S also provides the most necessary ancillary services, including emergency power, voltage and frequency regulation, and system inertia. As more variable renewable resources are integrated on the Maui system, the conventional thermal generation provided by HC&S becomes increasingly important because it can adjust its output based on system conditions.

Electric water pumps are an integral part of HC&S' irrigation system<sup>36</sup>. HC&S configures their generating facilities to provide for automatic shedding of their irrigation water pump load (and factory), to provide additional immediate power to meet sudden and severe failures on the Maui grid<sup>37</sup>. The system protection provided by HC&S at any time shall not exceed the sum of the firm power which would otherwise be required under the PPA plus four (4) MW; provided, however, that in no event shall the maximum exceed sixteen (16) MW. HC&S has no obligation to provide system protection during their shutdown periods.

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<sup>35</sup> Assumes HC&S contract extended through 2018 for PSIP analysis

<sup>36</sup> HC&S requires approximately 200 million gallons of water per day to sustain its 36,000 acres of sugarcane.

<sup>37</sup> In accordance with PPA.



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## TRANSMISSION AND DISTRIBUTION SYSTEM DESIGN

### Transmission

The role of the transmission systems for the Hawaiian Electric Companies remains the same – that is to transmit bulk power from one point to another in a networked configuration at current transmission voltages.

While the role of the transmission system on O’ahu remains the same, changes in its design have been identified as part of the PSIP. Specifically, the Hawaiian Electric PSIP identifies the expansion of the O’ahu 138kV transmission system through a transmission loop from the central area to the northern area of the island. Currently, O’ahu’s 138kV transmission system is limited to the leeward, central and southern portions of the island. Yet, there has been much interest and demand for interconnection of utility-scale and distributed renewables from the northern and central areas of the island. A new transmission loop can interconnect renewable generation from this part of the island beyond the capacity of existing subtransmission circuits in the area in-line with the Preferred Resource Plan for O’ahu.

Similarly, the role of the transmission system on Maui and Moloka’i<sup>38</sup> remains the same. However, the PSIP identifies transmission upgrades in order to provide greater voltage regulation of the 23kV system in Central Maui, defer overloads of 69-23kV transformers, and allow for the retirement of all generators of Kahului Power Plant as identified in the Maui Electric PSIP for 2019.

On the island of Hawai’i, the role and the design of the transmission system remains the same. However, if additional generation is built on the East side of the island beyond what is included in the Hawai’i Electric Light PSIP (such as an additional increase in geothermal generation), the design of Hawai’i island’s transmission system would require additional transmission capacity to reliably transmit bulk generation from the East side to the West side of the island.

### Distribution

In contrast to the transmission system, the role of the distribution systems does change dramatically as part of each Company’s preferred resource plans. The previous role of distribution system was to serve local power loads only. As part of the PSIP and DGIP, the distribution system will continue in its role to serve in the role of serving local loads, but now will also have an additional role of collecting and reliably delivering DG power and energy up to the sub-transmission or transmission systems. This is necessary in

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<sup>38</sup> Lana’i does not have transmission lines.

## 5. Preferred Plan

### Transmission and Distribution System Design

order to accommodate approximately 600 MW and 120 MW of DG-PV on O'ahu, and Hawai'i islands, respectively and approximately 140 MW in Maui County.

As detailed in the Companies' DGIP report, the Hawaiian Electric Companies plan to continue to use a radial architecture for the distribution system as a more cost-effective alternative compared with building a new networked distribution system. But in order to fulfill its new role to collect and reliably deliver DG power up with a radial architecture, the design of the distribution will need to be modified by: 1) upgrading circuit components such as replacing LTCs with newer designs capable of regulating voltage in two directions; 2) adding new circuit components, such as the addition of grounding transformers to address ground fault over-voltage events, to ensure operating conditions on all circuits remain within expected and allowable limits; and 3) adding intelligence and controls throughout the distribution circuit and substation along with two-way communications to monitor and control inverter operation, switching, regulation of voltages and management of power flows on distribution feeders.

It should be noted that as part of design of the Transmission and Distribution System over the planning period, the utility's telecommunications system will play an increasingly important role in the operation of the T&D system. In fact, one should think of the Transmission and Distribution system evolving into a Transmission, Distribution, and Communications system design. This communications system is not only an essential part of the Company's Smart Grid Program,<sup>39</sup> it is an essential part of the Companies' plan to modify and upgrade its distribution system to allow for the integration of greater levels of DG, as well as to allow for the interoperations between utility's grid systems with customer-side equipment such as advanced inverters, storage devices, and control systems.

Such design changes for the distribution system are common to all Hawaiian Electric Companies and they are discussed in detailed in our DGIP.

In order for the transmission and distribution system to reliably operate in its various roles through the planning period of the PSIPs, the Hawaiian Electric Companies must intelligently integrate its Smart Grid and DGIP upgrades with its Asset Management programs. All components of a circuit, such as conductors, wires, breakers, switchgear, transformers, poles, and others must be replaced on a programmatic basis in an asset management program to ensure that the Transmission and Distribution system remains reliable and able to serve in its increasingly important role in the grid. However, such replacement and upgrades must be done not just for age or condition reasons, but to also be done to add the control and communications functionality described in the Smart Grid plan and DGIP. By integrating plans for Smart Grid, DGIP with the Asset Management

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<sup>39</sup> *Smart Grid Roadmap and High Level Business Case*, filed with the Commission on March 18, 2014.

program, savings and efficiencies can be achieved as grid components are replaced and upgraded.

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## ENERGY STORAGE DESIGN

Integrating energy storage is key to adding increased amounts of both distributed and utility- scale renewable generation into our power supply mix.

Energy storage provides unique operational and technical capabilities, including the ability to provide essential grid services. In addition, energy storage can be part of a portfolio of potential resources that can increase grid flexibility, operability, and reliability in a rapidly changing operating environment.

The Companies will evaluate and implement energy storage technologies and applications from two perspectives:

- 1. Utility Perspective:** Evaluate energy storage in parallel with other resource options, such as new types of generation, modified operations of existing generating units, advanced planning and operational tools, smart grid and micro-grid technologies, and demand response programs.
- 2. Customer Perspective:** Explore ways to utilize energy storage to provide a broader range of services for customers, including the utilization of energy storage within micro-grid environments, demand response, and thermal storage (for example, grid interactive water heating and ice storage). This perspective also includes the need to incorporate customer-owned energy storage as a grid resource, including possible ownership and operation of behind-the-meter energy storage assets.

The Strategic Energy Storage Plan (Energy Storage Plan) applies to all three operating Companies; however, due to differences in generation portfolios and operational needs, the action plans and timeframes for Hawaiian Electric, Hawai'i Electric Light, and Maui Electric are expected to be different.

Appendix J: Energy Storage for Grid Applications, provides background information regarding the commercial status of energy storage, applications for energy storage, grid energy storage technologies, and the economics of energy storage, including capital and operating cost assumptions utilized in the PSIP.

## Goals and Objectives of the Energy Storage Plan

The primary goal of the Companies' Energy Storage Plan is to utilize energy storage in cost-effective applications that enhance grid services to accomplish three outcomes:

- Optimize the costs of power system operation;
- Maintain acceptable reliability and security of the power system; and
- Expanded services to customers.

The following objectives will be pursued to achieve the Companies' strategic goal:

- Pursue utility-owned and -operated energy storage projects under applications that make technical and financial sense, but at the same time, be open to non-utility storage options.
- Develop utility-owned and -operated distributed energy storage solutions and collaborate with industry and customers to utilize customer-sited storage as grid assets.
- Explore and pursue actions that address business model, utility cost recovery, customer rate schedules for different services, and regulatory issues that affect the Companies' ability to implement energy storage.
- Foster innovation and build internal operating experience through energy storage research and development activities.

The Companies are willing to consider multiple mechanisms in support of achieving the goal of developing a resource portfolio enabling lower costs and reliable power for our customers.

## Guiding Principles of the Energy Storage Plan

The following guiding principles will govern the implementation of the Companies' Energy Storage Plan:

- **Implement energy storage under a programmatic approach with a broad portfolio of assets consisting of both utility-scale and customer-sited systems.** Assess and implement an energy storage program for the deployment and operation of energy storage assets such that reliability, public policy, and customer interests are considered.
- **Own and operate energy storage assets only when in the best interest of customers.** When energy storage is shown to be a viable alternative, the Companies' preference will be to own and operate energy storage systems. However, various business and ownership models, as well as service contracting arrangements, will be considered to best meet the Companies' strategic goals objectives and customer needs.

- **Pursue energy storage to broaden the level of services for customers.** The Companies will evaluate energy storage applications at the distribution level that increase customer value, including the contributions of customer-sited energy storage systems. The Companies are also open to owning energy storage systems on the customer-side of the meter to provide services to its customers. An example is the use of distributed, community-based and/or customer-sited storage to perform bulk load-shifting. Another potential application of customer-sited energy storage is the use of EV batteries as energy storage for grid management purposes (Grid to Vehicle (G2V) and Vehicle to Grid (V2G) applications).
- **Balance system security with public policy-based renewable energy goals.** The planning and implementation of energy storage is, in part, driven by system security/reliability requirements as additional amounts of variable renewable energy generation drive the need for additional grid services.
- **Pursue cost-effective energy storage by balancing cost with system reliability.** The costs to implement energy storage systems will be a factor in project development decisions as financial impacts to customers must be considered when integrating renewable energy resources. Therefore, it is critical that business decisions be based on best-available pricing intelligence (current and future), and a clear understanding of the cost benefits that the energy storage asset can provide to the system.
- **The timing of the Companies' plans to deploy energy storage and enter into contracts for services will consider technology maturity/development, pricing trends and development lead times.** When determining the timing of energy storage system installation, the Companies must consider technology development and pricing trends and the estimated timelines required to design, permit, and construction such facilities. As discussed earlier, it is anticipated that some energy storage technologies will require considerable project development time.
- **Control of energy storage systems will be coordinated with other resources on the system through the Companies' Energy Management Systems (EMS).** Any energy storage system providing system-level services, such as frequency regulation or response, must be coordinated with other resources on the grid; the system operator may accomplish this through the storage asset's local frequency response settings or through actual control of the energy storage asset. Although control will be centralized at the Companies' System Operation Control Center, distributed storage systems may be aggregated through a third party or through the Company's EMS or Advanced Distribution Management System (ADMS). Also, since energy storage systems are finite energy resources, their operation must be transitioned to appropriate generation sources in a coordinated and controlled manner so that other resources can be made available when the storage is depleted. It is essential that any

resource that is integral to system operations, including energy storage, be monitored at the system control center.

- **Energy storage will be considered in generation and transmission/distribution planning analyses to assess alternatives to generation and T&D projects.** Planning for generation, transmission, and distribution assets and applications will include energy storage (and load management). A balanced portfolio of resources will be pursued during utility planning.
- **Collaborate with stakeholders and leverage external resources when available.** The Companies will seek collaborative opportunities for energy storage solution development, especially on the customer side of the meter. External participation in energy storage solutions should be considered where it makes operational and financial sense. To offset technical and financial risks of unproven technologies or applications within a nascent energy storage industry, the Companies will seek opportunities for collaboration with external entities to leverage labor, expertise, and funding.

## Energy Storage Operating Philosophy

The implementation plans for energy storage must be developed in concert with modified operating practices such as generation unit dispatch, load shed schemes, load management, and customer-focused solutions. By executing the energy storage strategy, the Companies will strive to:

- Ensure the Safety of the Company's crews and contractors working on either energized or non-energized distribution lines<sup>40</sup>;
- Maintain or improve system reliability, and provide acceptable system reliability which is security through normal operation conditions and disturbances;
- Increase the value of electric services and lower cost to customers; and
- Develop a diverse portfolio of resources to reduce dependence on imported fossil fuels.

## Energy Storage Operating Issues

Existing and growing levels of variable renewable energy resources, primarily wind farms and distributed PV, are creating the need for additional grid services. In the PSIP, Appendix E provides a description of essential grid services, and Chapter 5 provides a description of security analysis for increasing levels of distributed PV and new resources.

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<sup>40</sup> The Companies will implement additional safety procedures to protect the safety of line crews, including design and installation of appropriate breakers and switching to ensure that energy storage will not inadvertently energize lines when our crews are performing repairs and maintenance.

System impacts of the aggregate contribution of variable generation affect various time frames. These time frames determine the particular grid services that are required to mitigate these impacts.

#### Sub-Seconds to Seconds (primary frequency response time frame)

These impacts increase the need for frequency-responsive contingency reserves and regulating reserves:

- Fast ramping events (ramping of renewable resources exceeds ramping of dispatchable generation and; primary frequency response for generation with governor response)
- Increased second-to-second frequency variation due to fast variability
- Increased rate-of-change of frequency during faults and contingencies
- Larger frequency impacts from faults and contingencies (lower frequency nadir, result in increased under-frequency load-shedding)

#### Seconds to Minutes (supplemental frequency response and regulation time frame)

These impacts increase the need for regulating reserves and off-line quick-start reserves (10-minute, 30-minute reserves):

- Increased need for second-to-second system balancing due to changes in variable generation output
- Sustained ramp events resulting in significant loss in wind or PV production to the system

#### Minutes to Hours

These impacts increase the need for off-line reserves and require flexible options to balance supply and demand:

- Less predictability in the net demand to be served by generation
- Increased flexibility required from resources due to change in the nature of the demand served (morning and evening peaks with low daytime and night time demand).

### Energy Storage Uses in the Companies' Systems

Chapter 5 of the PSIP describes system security analysis that identified ancillary services for the existing and future possible system resource combinations. These services can be provided by storage. Detailed operational requirements are provided in PSIP Appendix E: Essential Grid Services. To adapt to the changing power grids, energy

storage will be evaluated for its technical and cost effectiveness in providing the following applications/ grid services:

### Frequency Responsive Contingency Reserve

#### *Application*

- Respond very quickly to a change in frequency, to arrest frequency decay and mitigate under-frequency load shedding (UFLS).
- Provide sufficient energy capacity (MWh) during recovery period to provide time for operators to turn on units that cover generation deficit, that is until combustion turbines can be started.

#### *Storage System Characteristics*

- Fast response: Detect and respond within the first few cycles of sudden change in frequency
- High MW rating: Exact size is dependent on desired results
- Minimum MWh rating: Equal to MW rating x amount of time needed to implement replacement reserves
- Must be constantly charged to a specific level of charge
- Must have the appropriate safety features to prevent energizing during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)

### Regulating Reserve

#### *Application*

- Dampen momentary frequency variations through governor-droop type response (if frequency responsive, this is required for a portion of the regulating reserve)
- Respond to AGC signals to increase or decrease output to regulate system frequency

#### *Storage System Characteristics*

- Governor-droop like response to changes in system frequency (for frequency responsive regulating reserve)
- MW rating dependent on desired up/down regulation amount
- Control interface to AGC, responds within one AGC cycle.
- Frequent charge/discharge cycle (may be every AGC cycle, 4-6 seconds)
- Must maintain energy for long enough for supplemental reserves to be brought online.



- Must have the appropriate safety features to prevent energizing during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)
- Must have the appropriate safety features to prevent energization during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)

### Load/Peak Shifting: System Ramping, Curtailment of Renewables, Economic Benefits

#### *Application*

- Absorb energy (charge) during periods of excess energy to minimize curtailment of variable renewables and optimize use of more efficient generation resources
- Provide power (discharge) during periods where there is demand for the energy

#### *Storage System Characteristics*

- MW rating dependent on desired deficit compensation
- High MWh rating (multiple hours) driven by amounts and duration of excess energy
- Must have the appropriate safety features to prevent energizing during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)

### Voltage Support: System Stability and Security

#### *Application*

- Provide dynamic VARs to regulate voltage (site specific)
- May be used to replace dynamic voltage support from generation resources, allowing them to be taken offline

#### *Storage System Characteristics*

- MVAR dependent on need
- Site-specific: MVAR support must be at location needed.
- Fast-responding, dynamic, at a droop setting determined by specific requirement.
- Discharge duration and minimum cycles per year not relevant for this use
- Must have the appropriate safety features to prevent energizing during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)

### Black Start

#### *Application*

- Provide power that can be used for system restoration following system failure
- Used as an energy source to provide station power to bring power plants online and re-energize transmission and distribution lines following grid failure

#### *Storage System Characteristics*

- Able to self-start without grid power
- Able to be controlled remotely by the system operator
- MW rating able to provide startup energy to major generation resources, and absorb transformer inrush currents
- Must maintain enough charge after grid failure to provide system restoration services
- Must have capability to regulate voltage and frequency
- Must have the appropriate safety features to prevent energization during periods when not required (that is, when workers are working on a de-energized portion of the line, or must be able to trip off due to a maintenance situation where a worker may be in the line)

## Incorporating Energy Storage and Unit Commitment/Dispatch

Properly designed energy storage can provide the system operator with a flexible resource capable of providing capacity and ancillary services. In order to provide the system operator with appropriate control and visibility of energy storage, storage assets will be equipped with essentially the same telemetry and controls necessary to operate generating units. The specific interface requirements depend upon whether the storage device is responding automatically, or is under the control of the system operator. For devices that are integrated to the system control center, telemetry requirements include:

- Real-time telemetry indicating charging state, amount of energy being produced, device status, and
- Control interface to the operations control center to control the storage charging and discharging of energy.

Depending on the specific application, storage may also be required to respond to local signals. For example, storage may need the capability to respond to a system frequency change in a manner similar to generator governor droop response, which may be used for a contingency reserve response or for frequency responsive regulating reserve. Another example of local response includes the ability of the storage to change output (or absorb energy) in response to another input signal from a variable renewable energy resource in order to provide “smoothing” of the renewable resource output.

A special consideration of short-duration storage is the fact that it is a limited energy resource. This introduces the need for the system operator to be informed regarding the storage asset's charging state, and the need to ensure that the integration and operation of these resources allows for replacement energy sources prior to depletion of the storage. This replacement could be in the form of longer-term storage or generation resources.

Incorporating energy storage into daily unit commitment and generator dispatch is dependent on how the storage is to be used.

**Storage Used for Regulating Reserves:** When used to provide regulating reserves, the energy storage will be committed and dispatched like any other resource used to provide regulating reserves via AGC commands. The storage would contribute to available reserves. In order to emulate the response of generator, the storage will be equipped with frequency-response (droop) capabilities. The interface must provide enough information so the operator may bring online replacement reserves if the storage is depleted.

**Storage Used for Frequency Responsive Contingency Reserves:** When used to provide frequency responsive contingency reserves the storage asset must be operating on the power system as a security requirement. This storage stands ready to respond to short-term events and should not be deployed for regulation. The availability of storage for contingency reserves may reduce the number of on-line units required for system security and can be used to improve the response of the system to loss of generation events or similar disturbances that require an automatic response. It is important that the storage provides for sufficient energy duration so that replacement energy sources can come online before the storage is depleted.

**Storage Used to Provide Capacity:** If the storage is used to provide capacity to serve load, then it will be treated like a generator and will be committed and dispatched in the same manner as a generator, based on marginal costs. However, because the energy storage resource will be limited in terms of how long it can provide capacity to the system, additional status monitoring capabilities will be required to ensure that the energy storage device is utilized in a manner consistent with its capabilities (for example, depth of discharge). This will also require that the daily unit commitment to be performed to take into account the limits on duration of capacity available from the storage asset.

## Customer-Side Energy Storage

The PSIPs did not specifically utilize customer-side energy storage devices. However, customer-side energy storage might be aggregated to achieve the same operational attributes as utility scale energy storage. The aggregated storage concept allows storage assets to be properly sized and installed to meet bulk power supply needs and to help customers manage their electricity use. In order for distributed energy storage to be of value in bulk power applications, the following considerations must be taken into account:

*Distributed energy storage can smooth the output of distributed solar PV.* However under the existing net energy metering rules, there is very little incentive for a customer to install their own energy storage device because customers essentially utilize the grid as a storage system. If the NEM arrangement is modified or eliminated and replaced with an arrangement that compensates customers based on a price that is more in line with the Company's marginal cost of generating energy for the system, then customers will have specific price signals that they can use to evaluate the benefits of installing their own storage.

*Distributed energy storage may be useful through aggregation programs.* Storage sited at customer facilities can not only play an active role in balancing load for the customer's site, but if aggregated, multiple customers' storage systems can provide a tool for providing grid services. Proper design of distributed storage programs will require additional investigation. However, the overhaul and expansion of time-based pricing programs that are part of the Companies' Integrated Demand Response Portfolio Plan<sup>41</sup> (IDRPP), and the concept of third-party aggregator programs provide opportunities to utilize aggregated energy storage for providing grid services.

*Distributed energy storage will likely cost more than grid scale storage, however, it may be possible for distributed energy storage systems to be implemented faster than grid-scale systems.* Due to economies of scale inherent in utility scale storage applications, customer-side energy storage is expected to have a higher capital cost on a per unit of storage capacity installed. Even as battery costs decline, this cost disadvantage relative to grid scale storage will remain since the balance of plant components are expected to be higher per unit of capacity for distributed storage. While it is assumed that any customer-side energy storage project would be paid for by the customer, the compensation that can be paid by the Companies to customers for customer-side energy storage must reflect the cost of alternatives available to the Companies; otherwise excess costs will be borne by ratepayers. The value proposition for the customer is being evaluated through an active initiative with storage technology providers.

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<sup>41</sup> See Integrated Demand Response Portfolio Plan. Hawaiian Electric Companies. Docket No.2007-0134. July 28, 2014.

In order to provide certain grid services, distributed energy storage must be equipped with proper telemetry / communications to allow coordination with grid operations; the telemetry / communications design must provide for operation within specified performance time frames. Advances in communications utilizing Internet protocols (IP) and cloud-based aggregation technologies are now more prevalent in industry. With the addition at the distributed storage site of control hardware with communication backhaul to an aggregator/coordination point for the utility, near real-time storage asset status and the ability to control the storage asset, can be provided for customer sited storage. For essential grid services response, an aggregated response would be needed to manage local distribution conditions as well as provide some of the support services to manage ramping of locally sited distributed PV. The response time is a function of both communications latency and the ability of a distributed resource itself to respond in the time frames required by certain grid services. These response times are described in Appendix E, Essential Grid Services. For example, regulation reserves must immediately responsive to AGC (observable change within 2 seconds) signals, which requires an interface to the Energy Management System (EMS). Distributed energy storage used to provide grid services with fast response requirements and integration with the EMS must also be equipped with the proper telemetry and communications infrastructure. Depending on the business model, the cost of the communications infrastructure is in addition to the cost of the storage product. This cost may be incurred by the customer, or by aggregators who manage the telemetry devices. The cost/benefit must consider the interface costs and value benefit for the customer and utility. Without coordination and visibility by the utility the value of customer-sited storage is diminished.

The Companies are engaged in conversations with customer storage integrators and suppliers to develop and test advanced integration and management features for customer-sited energy storage systems.

## Energy Storage in the Preferred Plan

The Preferred Plans for the three operating companies include specific energy storage additions summarized below. These are additions on top of energy storage already installed in the respective systems, and could change as the Companies conduct further technical and economic analyses. Table 5-7 shows the energy storage additions that are in the preferred plan (demonstration projects are not shown in the tables).

| Year Installed  | Capacity                 | Type of Storage Device | Storage Duration | Purpose  |
|-----------------|--------------------------|------------------------|------------------|--|
| 2015 (Moloka'i) | 2 MW (committed project) | Battery                | 11 min           | Frequency regulation; DG-PV support  |
| 2018 (Lana'i)   | 10 MW                    | Battery                | 90 min           | Contingency reserves; DG-PV support  |
| 2018 (Moloka'i) | 10 MW                    | Battery                | 90 min           | Contingency reserves; DG-PV support  |
| 2019 (Maui)     | 20 MW                    | Battery                | 30 min           | Regulation reserves; reduce regulation reserves carried by thermal units                                     |
| 2019 (Maui)     | 20 MW                    | Battery                | 30 min           | Contingency reserves. Bridge until quick start RICE units can be installed for voltage support in South Maui |

Table 5-8. Maui Electric Preferred Plan Energy Storage Additions

## Utilization of Energy Storage on Maui and Lana'i

To varying degrees, existing battery energy storage systems on Maui and Lana'i have the potential to be repurposed to better serve the needs of the entire electrical system. In fact, one of the third-party owned existing batteries on Maui is already used to provide frequency regulation. Given their size in relation to their respective grids, it may be possible to utilize the other battery energy storage system on Maui, and the third-party owned battery energy storage system on Lana'i, for frequency regulation as well. However, in cases where the battery energy storage system is not owned by Maui Electric, the ability to repurpose the energy storage system will be contingent on negotiations of contract terms between the utility and each owner. Amendments to current contract terms would be as agreed upon by the parties and approved by the Commission.

### Existing Storage at Maui Electric

The Maui system currently contains two battery energy storage systems that are owned and operated by third parties. The Kaheawa Wind Power II, LLC (KWP2) facility couples a 21 MW wind farm with a 10 MW/20MWh battery energy storage system. The KWP2 battery provides system support in the form of frequency regulation and regulating

reserve. In addition, the KWP2 BESS provides ramp rate control of its wind power output to meet ramp rate limits required by the Power Purchase Agreement (PPA).

The Auwahi Wind Energy, LLC (AWE) facility couples a 21MW wind farm with an 11MW/4.4MWh battery energy storage system; the AWE battery was installed to allow facility to meet the performance standards of their PPA, primarily ramp rate control.

Additionally, Maui Electric owns and operates a 1MW/1MWh battery energy storage system located at the Wailea substation as part of the Department of Energy (DOE)-funded, HNEI-led Maui Smart Grid project. The Maui Smart Grid project battery provides peak circuit load reduction and voltage support. Operation of this battery is expected to continue through 2018.

Several smaller batteries are targeted for installation on Maui as part of the Japan U.S. Maui Smart Grid Project (JUMPSmart). This project, in collaboration with Maui Electric, Hitachi, Hitachi Advanced Clean Energy Corporation, and the New Energy and Industrial Technology Development Organization in Japan (NEDO), will evaluate the aggregation and management of distributed energy storage and other distributed resources through smart grid technology.

#### Existing Energy Storage on Lana'i

On Lana'i, the Lana'i Sustainability Research, LLC (LSR) 1.2 MW photovoltaic facility incorporates a 1.125MW/500 kWh battery energy storage system within their generation facility design. Similar to the AWE battery, the LSR battery is utilized to allow facility to meet the performance standards in their PPA, primarily ramp rate control.

#### Planned Energy Storage on Moloka'i

Maui Electric, in collaboration with HNEI, is currently pursuing a 2MW/375 kWh battery energy storage project on the island of Moloka'i to provide frequency regulation and PV integration support. Technical assessments on the optimal use of the battery are currently underway. Although a project schedule has not yet been developed, installation of the BESS is anticipated to occur in 2015.

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## GENERATION PORTFOLIO OF AN O'AHU–MAUI GRID INTERCONNECTION

Two independent analyses were developed to test the economics of constructing a 200 MW DC bi-directional transmission tie between the islands of Maui and O'ahu. The analysis was designed to identify the potential savings in power costs created by the cable. The forecast of savings then creates the benchmark, "the price to beat", for owning and operating the transmission cable. In our analysis we did not explicitly analyze

## 5. Preferred Plan

### Generation Portfolio of an O'ahu–Maui Grid Interconnection

additional system security costs that could be potentially incurred if the cable configuration was one 200 MW cable versus two 100 MW cables. A redundant connection (two 100 MW cables) has potential system benefits since the N-1 contingency is closer to the current system requirements versus the alternative of the largest outage potentially being 200 MW. The trade-off for the redundant cables is likely to be close to a doubling in the cost of constructing the transmission link.

The independent analyses were performed by Black & Veatch and PA Consulting, members of the modeling team assembled for the PSIP analyses. The production cost simulation models used by both firms in this analysis are described in Appendix C. The analyses used slightly different approaches. One approach is not considered preferred to the other, rather the different approaches provide different perspectives. The conclusion from the analysis of both companies indicates that the transmission cable is not a cost effective solution. The cable could not possibly be built for the estimated amount to be cost effective. Based upon the two analyses, the NPV of the estimated savings excluding the cost of the transmission cable are \$60 M–\$ 175 M, respectively. For the cable system to be cost effective, the NPV for the design, construction, operation, and maintenance of the cable system would have to be less these amounts.

A discussion of the analyses performed follows.

#### A. PA Consulting Analysis

PA developed an analysis of the transmission cable potential benefits using the AURORA hourly production simulation model. Six cases were developed where PA allowed the AURORA model to use its long-term expansion algorithm to develop the least cost generation expansion plan subject to constraints and certain assumptions. The major assumptions and constraints included:

- Starting with the existing generation assets on Maui and O'ahu.
- Assuming that LNG would be available on both islands starting in 2017.
- Assuming that distributed generation (that is, DG-PV) would be built out on both islands.
- Generator operating characteristics, operating costs, new unit costs, and fuel costs consistent with the assumptions documented in this document.

Six cases were modeled and in each case the Aurora model was allowed to identify the least cost generation mix. The six cases were combined to create four scenarios and create a range of estimated savings.

**I. Thermal Future with No Grid Tie.** In this scenario the model was not allowed to select new utility scale wind and solar projects beyond the projects that have already



been included in the Base Case for Maui. These scenarios roughly tied to the base case scenarios developed for each of the islands.

**2. Grid Tie–Thermal Future.** In this scenario the model selected the least cost generation expansion plan assuming the two islands were connected by a 200 MW transmission link. The two systems were modeled as one pool where they shared a reserve margin and the system was jointly dispatched subject to the transfer constraint between the islands. The model was constrained to not selecting new utility scale wind or solar beyond projects already included in the Base Case for Maui.

**3. Renewable Future with No Grid Tie.** In this scenario the model was allowed to select the least cost mix of resources including utility scale wind and solar.

**4. Grid Tie–Renewable Future.** In this scenario the model selected the least cost generation expansion plan assuming the two islands were connected by a 200 MW transmission link. The two systems were modeled as one pool where they shared a reserve margin and the system was jointly dispatched subject to the transfer constraint between the islands.

## B. Black & Veatch Analysis

The O'ahu-to-Maui transmission cable analysis was based on the assumption that each island would need to be able to meet both load and system security requirements independently; that is, each island could continue to provide energy and grid stability in the event that the transmission cable failed. Thus, the analysis uses a base case that allows each island to meet its own requirements independently; this system configuration was maintained across the alternate cases evaluated. This base case includes distributed generation build-out; additional utility-scale renewable projects; LNG; and improvements to thermal fleet flexibility, efficiency, and reliability through retirements and new generation additions.

The potential benefit to the transmission cable stems from the difference in production cost between O'ahu and Maui—particularly the potential for low-cost, higher-production wind generation. Thus, the Black & Veatch analysis considered additional wind installed on Maui and, via the transmission cable, energy was allowed to flow between Maui and O'ahu. Except for this additional wind on Maui, the remainder of the generating system remained consistent with the base case. Both the transmission cable and the additional Maui wind were modeled as on-line in 2022.

Since generation on the margin on Maui is cheaper than generation on O'ahu, given the presence of a transmission cable, Maui generation will be used to meet O'ahu demand. In absence of sufficient additional wind, Maui thermal units will run to assist in meeting O'ahu demand, and O'ahu thermal units will back down. As additional wind is installed

## 5. Preferred Plan

### Environmental Compliance

on Maui, O'ahu generation decreases, Maui thermal generation decreases, and Maui wind generation increases.

The optimum scenario evaluated by Black & Veatch incorporates an additional 300 MW of wind on Maui in 2022, coincident with the assumed on-line date of the transmission cable. This scenario saw significant (30%) decrease in non-renewable generation on O'ahu. On Maui, renewable generation more than doubled. The resulting system-wide generation savings, excluding the cost of the interconnection transmission cable, would have an NPV of \$80M.

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## ENVIRONMENTAL COMPLIANCE

Environmental legislation, regulations, and governmental rules have increased dramatically in recent years, especially regarding air (Clean Air Act) and water (Clean Water Act). Maui Electric must comply with all environmental requirements but the following discussion focuses on four main areas:

- National Ambient Air Quality Standards (NAAQS)
- Greenhouse Gas (GHG)
- Regional Haze Rule
- Reciprocating Internal Combustion Engines National Emission Standards for Hazardous Air Pollutants (RICE NESHAP) Rule
- Toxic Substances Control Act (TSCA)
- National Pollution Discharge Elimination System

Maui Electric focused their analysis on NAAQS compliance.

### Environmental Compliance Plan

The Hawaiian Electric Companies must comply with environmental laws and regulations that govern how existing facilities are operated, new facilities are constructed and operated, and hazardous waste and toxic substances are cleaned up and disposed.

Complying with air and water pollution regulations could require the Companies to commit significant capital and annual expenditures.

#### National Ambient Air Quality Standards (NAAQS)

In 2010, the EPA established two new, significantly more stringent, one-hour air quality standards for nitrogen dioxide (NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>). These standards apply to

all sources in the state, which includes all Hawaiian Electric, Hawaiian Electric Light, and Maui Electric generating stations.

Sulfur dioxide emissions can be controlled by either reducing the sulfur content in the fuel or by installing scrubbers coupled with ESPs to remove sulfur dioxide from exhaust gases. ESPs integrated with scrubbers can remove sub-micron droplets, acid mists, metals, and mercury particles. These controls also remove pollutants regulated by the MATS Rule and thus would provide for compliance with the MATS rule.

Nitrogen oxides (NO<sub>x</sub>) – nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) – emissions can be controlled by combustion hardware improvements such as low NO<sub>x</sub> burners and overfire air and by the installation of selective catalytic reduction (SCR) systems.

#### *EPA SO<sub>2</sub> NAAQS Implementation Strategy*

EPA's paper *Next Steps for Area Designations and Implementation of the Sulfur Dioxide National Ambient Air Quality Standard* (dated February 6, 2013) describes their updated one-hour SO<sub>2</sub> NAAQS implementation strategy. This strategy anticipates additional EPA rules and guidance, and addresses areas not currently proposed to be designated as nonattainment areas based on air monitoring data from 2009–2011.<sup>42</sup>

The EPA is not prepared to propose any designation action in Hawai'i at this time. The agency is deferring action to designate areas in Hawai'i while it continues to assess Hawai'i's request to exclude air quality monitoring data that exceeds the 2010 SO<sub>2</sub> standard under the Exceptional Events Rule due to SO<sub>2</sub> emissions from an active volcano.

On January 7, 2014, the EPA released two updated draft documents, SO<sub>2</sub> NAAQS Designations Modeling Technical Assistance Document and SO<sub>2</sub> NAAQS Designations Source-Oriented Monitoring Technical Assistance Document, which provide technical assistance for states implementing the 1-hour SO<sub>2</sub> standard. These updated draft documents provide technical advice on the use of modeling and monitoring to determine if an area meets the 1-hour SO<sub>2</sub> standard.

Air agencies will also work with sources by establishing and submitting to the EPA enforceable emission limitations that ensure that the SO<sub>2</sub> NAAQS can be attained before the date that final designations are issued. Based on the EPA's February 6, 2013 updated implementation strategy, depending on whether a modeling or monitoring path is followed, the 1-hour SO<sub>2</sub> attainment deadlines range from December 2022 to December 2025. The EPA has indicated that this implementation schedule does not reflect any final agency action nor impose any legally binding or enforceable requirements. The timeline and milestones are therefore subject to change.

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<sup>42</sup> EPA is not prepared to propose designation action in Hawai'i. The agency is deferring action to designate areas in Hawai'i while it continues to assess Hawai'i's request to exclude air quality monitoring data that exceeds the 2010 SO<sub>2</sub> standard under the Exceptional Events Rule due to SO<sub>2</sub> emissions from an active volcano (as stated in an EPA letter to Governor Neil Abercrombie, February 6, 2013).

## 5. Preferred Plan

### Environmental Compliance

#### *MECO NAAQS Compliance Strategy*

MECO analyzed:

- Switching to lower sulfur fuels such as Low Sulfur Industrial Fuel Oil (LSIFO), biofuels, or LNG only for the Ma'alaea combined cycle units.
- Installing AQC equipment on Kahului units 1 through 4.
- Retiring existing units and replacing them with new firm geothermal or biofuel generation.

#### Greenhouse Gas (GHG) Regulations

In 2012, the DOH issued a proposed state GHG rule to achieve the goals of State of Hawai'i Act 234, the Global Warming Solutions Act of 2007 (Act 234) which mandates that statewide GHG emissions be reduced to 1990 levels by 2020. DOH addressed public comments to the proposed rule in 2013. The GHG regulations were recently signed by Governor Abercrombie and became effective on June 30, 2014.

The regulations issued by the DOH requires entities that have the potential to emit GHGs of more than 100,000 tons per year of carbon dioxide equivalent (CO<sub>2</sub>e) to reduce GHG emissions by 16 percent below 2010 emission levels by January 1, 2020, and maintain those levels thereafter. Ten power plants operated by Hawaiian Electric Companies meet the applicability condition. Hawaiian Electric has one year to submit GHG emission reduction plans to DOH for its affected power plants. These plans will explain how each facility intends to meet its GHG reduction threshold by the 2020 target date, what technology will be employed, and how the reduction will be sustained going forward. For greater flexibility, the proposed rule allows affected facilities to "partner" among each other to meet GHG reduction targets. That is, one affected facility can agree to "transfer" some of their allowable GHG emissions to another facility to meet the reduction target for the second facility in cases where that facility might not be able to meet their target on their own.

On June 18, 2014, EPA published a proposed rule that would establish GHG performance standards for existing power plants under Clean Air Act Section 111(d).<sup>43</sup>

The Clean Air Act requires EPA to establish a procedure for each state to follow in implementing Section 111(d) that is similar to the state implementation plan procedures laid out in Section 110 of the Act. Section 111(d) delegates to the state primary responsibility for both developing and implementing the performance standards.

EPA is proposing state-specific GHG emission reduction targets and a two part-structure for states to achieve the targets. States would be required to meet an interim goal on

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<sup>43</sup> 79 Fed. Reg. 34830.

average over the ten year period from 2020-2029 and a final goal in 2030 and thereafter. EPA also identifies a number of potential options for states to meet the proposed targets. Using EPA's 2012 baseline, Hawai'i would have to reduce its statewide CO<sub>2</sub> emission rate by approximately 15% to meet EPA's proposed 2030 final goal.

EPA developed the proposal pursuant to a 2013 directive from President Obama. The directive requires EPA to finalize the proposal no later than June 1, 2015, which will start the one-year period for states to complete and submit state plans to EPA. Hawaiian Electric is studying EPA's proposal and will actively participate in the rulemaking.

Hawaiian Electric is committed to taking direct action to mitigate the contributions to global warming from electricity production. Such action has, and will, continue to include promoting aggressive energy conservation and transitioning to clean, efficient and eco-effective energy production in all markets that the Company serves. Hawaiian Electric is already taking active steps to mitigate contributions to global warming by investing in and committing to use biofuels, renewable generation, and energy conservation.

### Regional Haze

Regional haze is essentially impaired visibility caused by human emissions and natural processes spread over a wide geographic area. The Clean Air Act required EPA to issue regulations to restore visibility for national parks and wilderness areas to levels that would exist if there were no human-made emissions – natural visibility.

EPA issued a Regional Haze Rule requiring states to establish interim goals toward attaining the final goal of natural visibility by 2064. EPA worked closely with Hawai'i to develop a Regional Haze Federal Implementation Plan (FIP) which became effective on November 8, 2012.

The FIP establishes an annual SO<sub>2</sub> emissions cap from Hawai'i Electric Light's three steam boiler facilities at Shipman, Hill, and Puna. The FIP provides flexibility for the utility to meet this cap by implementing measures such as energy conservation, using renewable energy, retiring units, or changing the sulfur content of the boiler fuel. The FIP requires Hawai'i Electric Light to comply with the cap by December 31, 2018.

### Reciprocating Internal Combustion Engines National Emission Standards for Hazardous Air Pollutants (RICE NESHAP)

Hawai'i Electric Light and Maui Electric implemented steps to comply with the Reciprocating Internal Combustion Engines National Emission Standards for Hazardous Air Pollutants (RICE NESHAP) deadline of May 2013. The RICE NESHAP rule required retrofitting catalytic emission controls, crankcase ventilation filters, continuous

parameter monitoring systems, and in some units switching to ultra-low sulfur diesel (ULSD) fuel.

### Toxic Substance Control Act (TSCA)

#### *Former Moloka'i Electric Company Generation Site*

The Toxic Substances Control Act of 1976 provides EPA with authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics and pesticides. TSCA addresses the production, importation, use, and disposal of specific chemicals including polychlorinated biphenyls (PCBs), asbestos, radon and lead-based paint.

In 1989, Maui Electric acquired by merger Moloka'i Electric Company. Moloka'i Electric Company had sold its former generation site in 1983, but continued to operate under a lease until 1985. The EPA has since performed Brownfield assessments of the generation site that identified environmental impacts in the subsurface. Although operations there stopped four years before the merger in 1989, in discussions with the EPA and the State of Hawai'i Department of Health (DOH), Maui Electric agreed to conduct further investigations at the generation site and at an adjacent parcel that Moloka'i Electric Company had used for equipment storage to determine the extent of impacts of subsurface contaminants. A 2011 assessment by a Maui Electric contractor of the adjacent parcel identified environmental impacts, including elevated polychlorinated biphenyls (PCBs) in the subsurface soils. Maui Electric continues to investigate the generation site and the adjacent parcel to determine the extent of impacts of PCBs, fuel oils, and other subsurface contaminants. In March 2012, Maui Electric accrued an additional \$3.1 million (reserve balance of \$3.6 million as of March 31, 2013) for the additional investigation and estimated cleanup costs at the site and the adjacent parcel. Final costs of remediation, however, will depend on the results of the continued investigation.

### National Pollutant Discharge Elimination System (NPDES)

#### *Kahului Power Plant*

EPA implements many of the Federal Clean Water Act (CWA) requirements through National Pollutant Discharge Elimination System (NPDES) permits. For example, the §316(a) thermal discharge requirements, §316(b) cooling water intake structure standards, and the categorical effluent standards are regulated through the NPDES permitting program. EPA is actively working on revising two CWA regulations that could have a significant impact on the design and operation of electric generating units: (1) the §316(b) cooling water intake structure regulations and (2) the Part 423 steam electric effluent guidelines.

The Kahului Power Plant receives water from underground aquifers, which means that §316(b) cooling water intake structure standards do not apply to the facility. Wastewater from the facility is discharged into the Pacific Ocean, which means the facility is required to maintain and comply with standards identified in its NPDES permit. Maui Electric has been informed that its next NPDES permit for Kahului Power Plant (Permit No. HI 0000094, ZM-37) will impose, for the first time, effluent limits for nutrients. Maui Electric has made the decision to retire the Kahului Power Plant since it will not be able to meet the effluent limits, and therefore proposed a compliance schedule that is based upon ceasing regulated discharges.

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## 6. Financial Impacts

The PSIP presents a Preferred Plan for the transformation of the Maui, Lana'i, and Moloka'i power systems.<sup>44</sup> The analyses used in the development of the Preferred Plan were based on numerous assumptions (discussed in Chapter 4 and summarized in Appendix F).<sup>45</sup>

The transformation of the power system will require significant investments by both the company and third parties to build the necessary flexible, smart, and renewable energy infrastructure needed to reliably serve customers across Maui. The PSIP requires a reliable, well-maintained transmission and distribution (T&D) system, a thermal generation fleet to firm variable renewables, and related infrastructure to achieve this transformation.

A strong and resilient grid is foundational for meeting our customers' needs for safe and reliable electric service, serving new customers and new electric loads such as electrified transportation, and providing energy services more generally. Investments to maintain, and as necessary expand, this foundational infrastructure are termed "foundational investments". These foundational investments are essential and complementary to the transformational investments defined by the PSIP. The investment requirements of the PSIP, including both transformational and foundational investments, are presented in detail in Appendix K. The magnitude and impacts of these investments are analyzed and discussed in this chapter in terms of customer affordability as measured by full service residential customer bill impact in real dollars (that is, 2014 dollars).

By combining the transformational together with the foundational investments, including their impact on fuel and O&M expenses, we provide a comprehensive analysis

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<sup>44</sup> Throughout the remainder of this chapter the use of the term "Maui" refers to all three systems.

<sup>45</sup> We acknowledge that actual circumstances may vary from what was assumed in the analyses, and accordingly, the PSIP will need to be revised and/or actions will need to be reviewed and updated from time to time.

## 6. Financial Impacts

### Residential Customer Bill Impacts

of customer affordability. Implicit in these financial analyses is the Company's ability to maintain affordable and ready access to capital markets.

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## RESIDENTIAL CUSTOMER BILL IMPACTS

The rate reform proposed in the DGIP<sup>46</sup> provides a rate design that reduces average monthly bills in real terms for average<sup>47</sup> residential full service<sup>48</sup> customers to approximately 28% below 2014 levels by 2030 while more fairly allocating fixed grid costs across all customers. The residential customer bill impact with DG-PV reform is discussed in detail in the next section of this chapter. The discussion immediately below presents the customer bill impact under current rate design to facilitate the comparison with the customer impact under the proposed DG-PV reform.

If the current rate design continues, the projected monthly bill for an average<sup>49</sup> full service<sup>50</sup> residential customer is expected to decrease by approximately 24% from 2014 to 2030. This is in contrast to a potential 28% reduction in real terms of the monthly electricity bill for average full service residential customers under DG rate reform (see discussion in next section). The bill impact of investments made in the early years to transform the system is mitigated by the conversion of several assets to lower cost containerized liquefied natural gas (LNG) in 2017. Beginning in 2021, once future investments to transform the grid taper off, the average full service residential bill will decline throughout the remainder of the study period to approximately 24% below 2014 levels, in real terms, by 2030.

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<sup>46</sup> The Companies filed their *Distributed Generation Improvement Plan (DGIP)* on August 26, 2014.

<sup>47</sup> Average is defined by taking the total usage across all full service customers and dividing by the number of full service customers in a given year. The average bill is not meant to project an actual future customer bill, but is illustrative of the bill impacts anticipated for customers with an average amount of usage across full service residential customers.

<sup>48</sup> Full Service Customer is defined as any residential or commercial customer that imports the entirety of their energy demands from the grid, and does not self-consume or export any energy derived from distributed energy resources co-located with their load.

<sup>49</sup> Average is defined by taking the total usage across all full service customers and dividing by the number of full service customers in a given year. The average bill is not meant to project an actual future customer bill, but is illustrative of the bill impacts anticipated for customers with an average amount of usage across full service residential customers.

<sup>50</sup> Full Service Customer is defined as any residential or commercial customer that imports the entirety of their energy demands from the grid, and does not self-consume or export any energy derived from distributed energy resources co-located with their load.

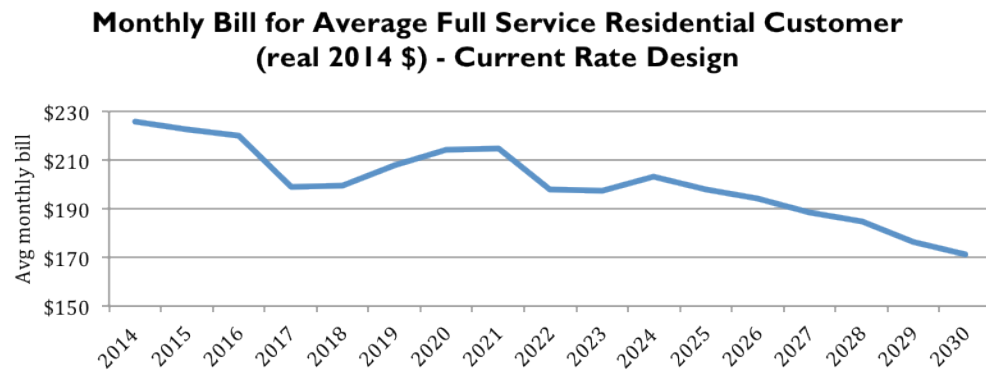


Figure 6-1. Average Full Service Residential Customer Bill Impact under Current Rate Design

These bill impact analyses assume that the residential customer class continues to be responsible for its current percentage of the total revenue requirement. This is a reasonable simplifying assumption, given that this class responsibility has been largely unchanged over the last 20 years or more.

## RESIDENTIAL CUSTOMER BILL IMPACTS WITH DG-PV REFORM

In this section, we estimate the average monthly bill for average, full service and DG residential customers assuming specific adjustments to rate design for all residential customers, including those with DG-PV, as described below. It is important to note that this is one potential approach to rate design among many other possibilities. Use of this approach for customer bill projections is not meant to advocate for or against this rate design versus any other, but instead is meant to demonstrate the relative impact to residential customer bills as a result of one possible set of rate design changes intended to address various challenges and concerns as discussed in the DGIP filing.<sup>51</sup>

The financial analysis utilizing this rate construct illustrates how such an alternative approach to DG-PV could result in average monthly bills for average full service residential customers that are, in real terms, 28% lower in 2030 as compared to 2014 (that is, an additional 4% lower than under the current rate design) and more fairly allocates fixed grid costs across all customers.

### Outline of Hypothetical DG-PV Reform (DG 2.0)

The Company's strategic vision for DG-PV encompasses reform of the rates governing DG-PV interconnections under an overall approach to distributed generation called

<sup>51</sup> Additional policy options are described further in the DGIP.

## 6. Financial Impacts

### Residential Customer Bill Impacts with DG-PV Reform

“DG 2.0”. As part of DG 2.0, the current NEM would be replaced with a tariff structure for DG systems that more fairly allocates fixed grid costs to DG customers and compensates customers for the value of their excess energy. For modeling purposes, DG 2.0 is assumed to begin for all new DG customers in 2017; customers who interconnect before 2017 will retain the tariff structures under which they applied.

As a party to Order No. 32269 issued by the Commission on August 21, 2014, the Companies view this as an opportunity to evaluate the precise nature and timing of the DG 2.0 rate reform. A preliminary set of assumptions regarding DG 2.0 has been made to facilitate the financial and capacity modeling performed in this PSIP and the DGIP, but these assumptions should not be interpreted as a policy recommendation.

These rate assumptions adhere to the underlying principles of the Company’s DG strategy and include the following:

- A fixed monthly charge applied to all customers, allocating fixed customer service and demand costs in a fair, equitable and revenue-neutral manner within customer classes.
- An additional fixed monthly charge applied only to new DG customers to account for additional standby generation and capacity requirements provided by the utility.
- A “Gross Export Purchase model” for export DG. Under this model, coincident self-generation from DG-PV and usage is not metered and customers sell excess electricity near wholesale rates and buy additional electricity at variable retail rates.

For the purposes of these projections, fixed monthly charges are assumed to comprise demand and customer service charge components.

The fixed demand charge has been estimated in two steps. First, a capacity requirement across all customers that would minimize cost shifts to low-usage customers was determined. Second, the fixed cost of meeting this capacity requirement for production, transmission, and distribution was calculated. An additional demand charge was also applied to DG 2.0 customers, due to the higher peak capacity requirements that DG customers have, on average, compared to the broad class of residential customers.

In addition to fixed capacity-based charges, monthly customer charges were estimated by allocating the fixed costs associated with servicing individual customers across all relevant households. These costs were assumed to be uniform within customer classes.

These fixed charge projections, along with assumed feed-in-tariff rates under the envisioned Gross Export Purchase model are shown in Table 6-1.

| ■ Residential Customer Groups | ■ Monthly Fixed Charge – All Residential Customers | ■ Monthly Fixed Charge – DG Only | ■ Feed-in-Tariff Purchase Price | ■ Tariff for Energy Consumed from Grid                          |
|-------------------------------|--|----------------------------------|---------------------------------|---|
| ■ Current NEM Customers       | ■ \$50   | ■ n/a                            | ■ n/a                           | ■ n/a, within NEM energy balance, retail rate for any shortfall |
| ■ DG 2.0 Customers            | ■ \$50   | ■ \$12                           | ■ \$0.20                        | ■ Retail rate   |
| ■ Full Service Customers      | ■ \$50   | ■ n/a                            | ■ n/a                           | ■ Retail rate   |

Table 6-1. Estimated Maui DG 2.0 Customer Charges and Feed in Tariff Rate

## OVERVIEW OF DG-PV FORECASTING

As customers respond to a revised set of market incentives such as DG 2.0, the rate of DG-PV installations will change. A market-driven forecast for DG-PV demand, assuming DG 2.0 is implemented in 2017, has been developed. At a high level, these forecasts estimate what DG-PV uptake will be as regulatory reform transitions away from existing DG programs (including NEM) over the next two years and implements DG 2.0 in the medium term. Accordingly, this PSIP has used DG-PV forecasts that were based on two distinct phases of DG uptake.

From 2014 to 2016, a set rate of interconnection under existing DG programs was assumed, based on simplifying assumptions about queue release and the pace of new applications.

From 2017 onward, the DG 2.0 tariff structure is assumed to apply across all customer classes.<sup>52</sup> Using benchmarked relationships between the payback period of PV systems and customer uptake rates, we projected market demand for new PV systems among all residential and commercial customer classes.

Based on this methodology, the projected number of residential customers on Maui with DG-PV would grow by about 200% from approximately 4,500 at the end of 2013 to approximately 13,500 in 2030. While this forecast will undoubtedly shift as more detailed policies are developed, it has been used as an essential input for all of the PSIP analyses.

<sup>52</sup> With the exception of grandfathered current NEM customers.

## 6. Financial Impacts

Overview of DG-PV forecasting

### Residential Customer Bill Impacts Under DG 2.0

The reform of DG related rates has a material impact on average monthly bills for full service residential customers. As shown in Figure 6-2, the projected average monthly bill for an average full service residential customer drops by 28% in real terms over the 2014 to 2030 period.

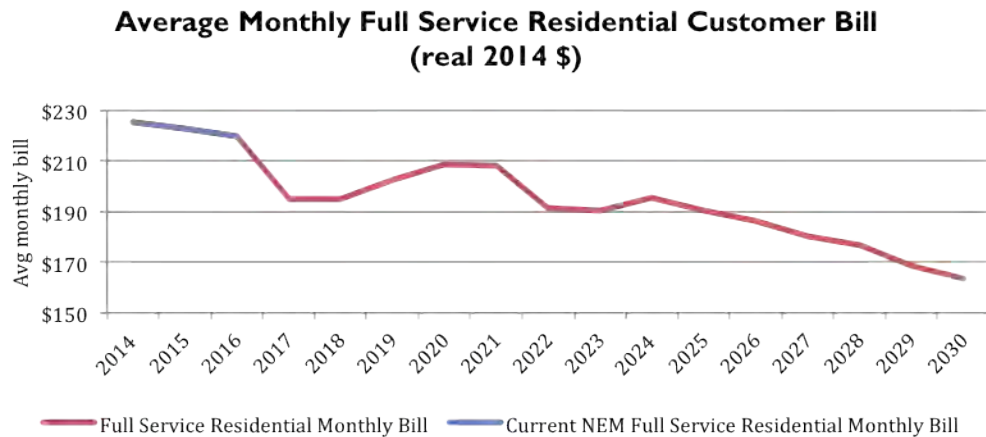


Figure 6-2. Average Full Service Residential Customer Bill Impact under DG 2.0

As discussed above, DG 2.0 is assumed to take effect in 2017. This results in a bill reduction for full service residential customers in 2017 that grows throughout the study period, as compared to the current rate design.

Under the DG 2.0 concept, current NEM customers would see an increased average monthly bill due to the increased fixed monthly demand and customer charges for all customers beginning in 2017, partially offset by the decrease in variable retail rates charged to all residential customers for electricity taken from the grid. The bill impact for new residential DG customers would include those charges, as well as the fixed charge for higher capacity and their net cost from the “Gross Export Purchase” model. Average full service customer average monthly bills would decrease under DG 2.0, despite the increase in fixed monthly demand and customers charges, as a result of the decrease in variable retail rates. Bill impacts for these customer groups, both under the current tariff structure as well as DG 2.0 are shown in Figure 6-3.

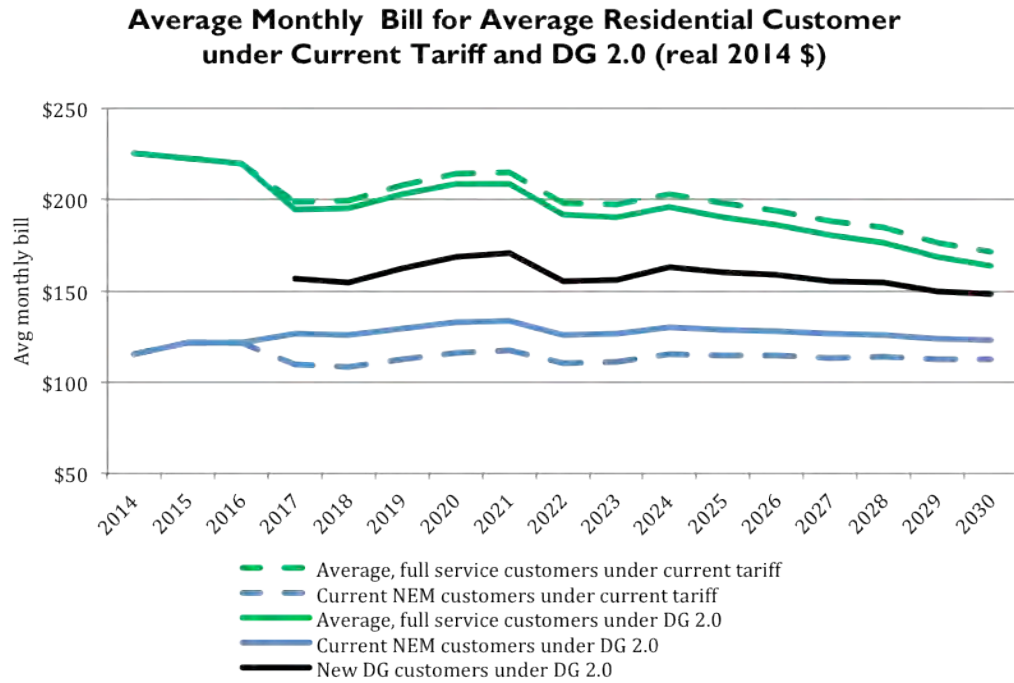


Figure 6-3. Average Residential Customer Bill Impact under Current Tariff and DG 2.0

## POTENTIAL POLICY TOOLS TO FURTHER SHAPE CUSTOMER BILL IMPACTS

This PSIP, coupled with the DGIP and the IDRPP, demonstrate a comprehensive path forward to achieve higher levels of renewable generation, lower long term costs, provide additional options for customers to manage their energy costs and more fairly allocate fixed grid costs across all customers while preserving an economic incentive for customers to opt for DG. To further mitigate these bill impacts, there are a range of policy tools that could be applied.

## 6. Financial Impacts

Potential Policy Tools to Further Shape Customer Bill Impacts

### Statewide Rates

As shown in the three PSIPs, the average monthly bill for an average full service residential customer for the three Companies vary under DG 2.0 in terms of both magnitude and timing, as shown in Figure 6-4, Figure 6-5, and Figure 6-6.

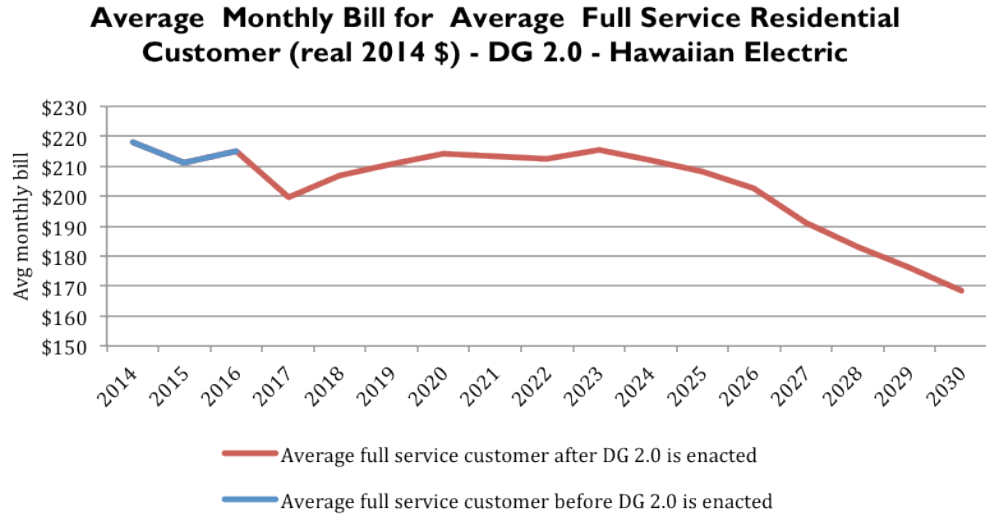


Figure 6-4. Average Monthly Bill for Average Full Service Residential Customer, Hawaiian Electric: DG 2.0

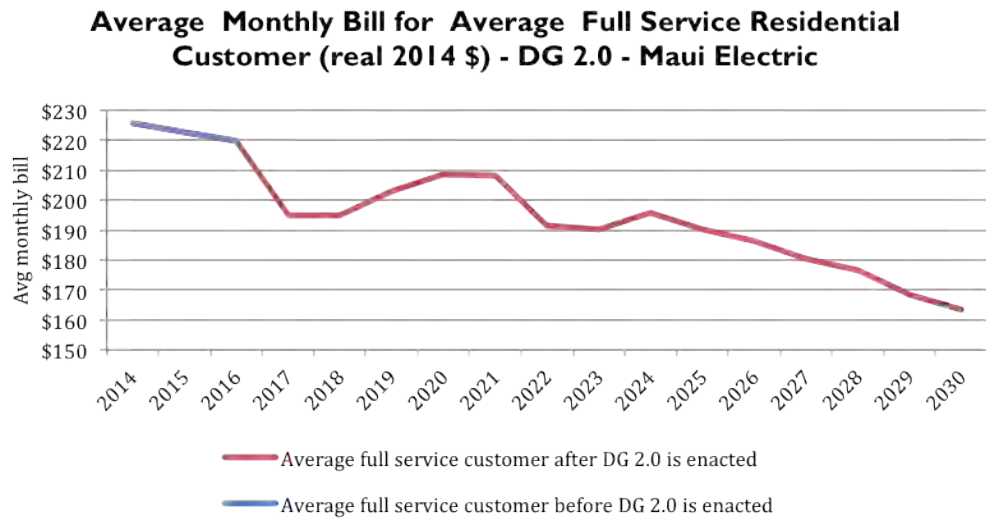


Figure 6-5. Average Monthly Bill for Average Full Service Residential Customer, Maui Electric: DG 2.0



### Average Monthly Bill for Average Full Service Residential Customer (real 2014 \$) - DG 2.0 - Hawai'i Electric Light

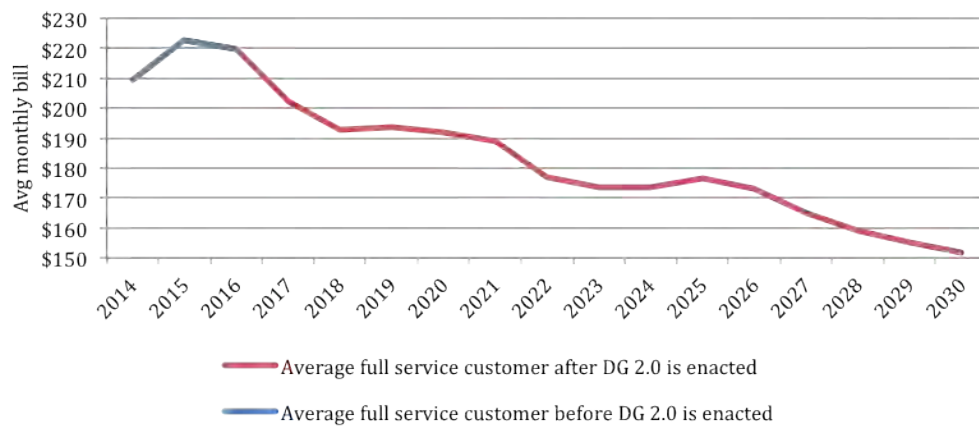


Figure 6-6. Average Monthly Bill for Average Full Service Residential Customer, Hawai'i Electric Light: DG 2.0

A shift toward a statewide rate approach, perhaps beginning with a statewide power supply rate component, would be a tool to smooth out changes impacting individual grids. This approach would also be logical given the “statewide” nature of the RPS goals.

In addition, moving to statewide rates would likely create regulatory efficiencies which would also serve to mitigate rates. For example, costs should be reduced by filing a single rate case every three years, rather than filing three rate cases in three years.

## Transportation Electrification Incentives

Accelerating the growth of the electric vehicle (EV) market in Hawai'i represents a significant opportunity to impact state emission policy goals, while having a positive impact on the cost of electricity by spreading the fixed costs of the grid over larger usage, and by developing a large load eligible for demand response. Electric vehicles can develop into a sizable, flexible, incremental load. Each of these attributes contributes to helping reduce long term energy costs. State policy adjustments, such as expanded incentives for purchasing EVs, could help further the reduction of long term energy costs.

As a new incremental load, EVs are unlikely to drive new, large investments in the grid. Thus, it is likely that the marginal T&D cost to serve EV load is very modest<sup>53</sup>, so energy sales for EVs would help lower the cost of the grid to other, non-EV customers.

<sup>53</sup> This would remain true as long as EV charging is done at times of high renewable generation, allowing excess generation to be used. The cost of an infrastructure and DR controls to achieve this end is not included in the PSIP analysis.

## 6. Financial Impacts

Projected Revenue Requirements for the Period 2015–2030

### State Tax Policy

There are a number of ways in which alternative State tax policy can potentially help mitigate electricity prices. Two potential opportunities are described below.

Today, approximately 9% of the average customer bill is comprised of taxes other than income taxes. The investment plans contained in this PSIP will result in the deployment of over \$1.2Bn in capital over the 2015 through 2030 time period. A limited duration excise tax exemption for certain types of investment, such as energy storage, would help reduce the impact on electric customers, while leaving state tax receipts at traditionally expected levels.

Another aspect of tax policy to be considered is the various revenue taxes the Company's customers pay. These taxes automatically increase with any increase in bills, such as the near term increases driven by the PSIP and DGIP transformational investments. However, any change in the Public Utilities fee component of revenue taxes must be made in light of the need for additional funds required for the Commission and Consumer Advocate to implement regulatory changes.

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## PROJECTED REVENUE REQUIREMENTS FOR THE PERIOD 2015–2030

The bill reductions discussed in the previous sections are made possible by projected changes in the underlying cost structures. These changes, discussed in terms of overall revenue requirements, are discussed below.

A utility's revenue requirement is the level of gross revenue that enables it to cover all of its prudently incurred expenses and allows it the opportunity to earn a fair return on its invested capital. The major cost elements that contribute to the total revenue requirement include:

- Fuel Expense
- Purchased Power Expense
- Operations & Maintenance Expense
- Depreciation Expense
- Taxes (Revenue and Income)
- Interest Expense
- Return on Equity Investment

### Projected Revenue Requirements

As illustrated in Figure 6-7, the total Maui revenue requirement remains unchanged from 2014 to 2021 in real terms (although the trend line reflects the introduction of LNG in the 2017 period), and then decreases significantly from 2021 forward, such that total revenue requirements are declining in real terms over the 2014 through 2030 period.

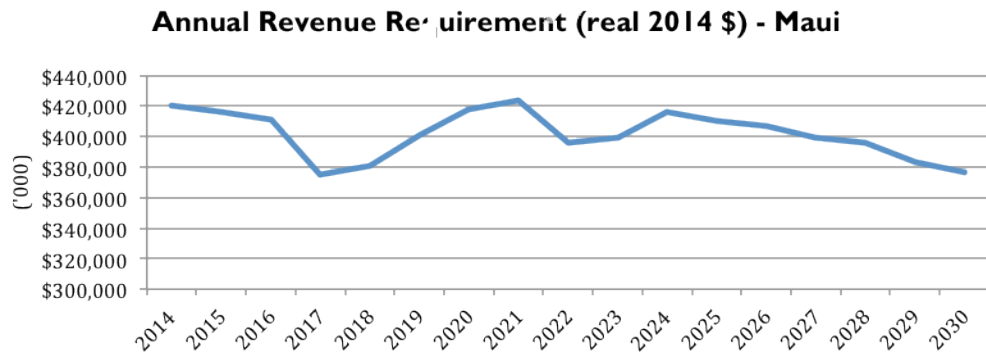


Figure 6-7. Maui Annual Revenue Requirement

The balance of this section explores the drivers of the changes in total revenue requirements.

To understand the drivers of the long term reductions in revenue requirements in real terms, Figure 6-8 provides a breakdown of the annual revenue requirement into its major components.

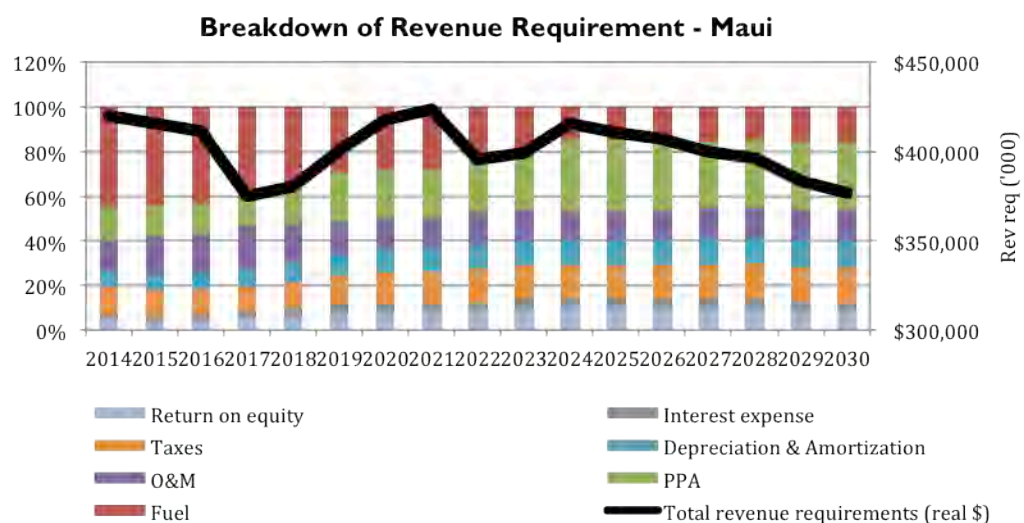


Figure 6-8. Maui Annual Revenue Requirement by Major Component

Fuel expense declines significantly over the period, driven by the continued shift toward renewable generation and the cost savings from the introduction of LNG, beginning in

## 6. Financial Impacts

Projected Revenue Requirements for the Period 2015–2030

2017. Power Purchase Agreement costs increase over the period, reflecting both the expanding purchases of renewables and the capacity costs for replacement dispatchable generation. O&M declines in real terms across the period, driven by the reductions in costs associated with Smart Grid and information technology investments.

Depreciation expense grows over the period, driven by both the transformational and foundational investments in the grid and the costs associated with retirement of most existing generating units. Interest expense grows over the period, driven primarily by higher levels of investment.

Tax expense, including revenue and income tax, increases over the period, driven in part by increased income tax expense associated with the increased equity investment. The excise taxes associated with the significant transformational and foundational investments to be made by the Company and others over the 2015–2025 period will be significantly higher than excise taxes associated with Company activities over the 2010–2014 period. The impact of this higher level of tax payments is reflected in the total cost of the new capital investments and is included in the PPA, depreciation, and return on capital cost elements in Figure 6-9. The corresponding state tax credit is amortized over 48 years and so the benefit is only partially realized in the forecast period.

The growth in return on equity investments and, as mentioned above, the interest expense, is driven by the capital investment profile of foundational and transformational investments, shown in Figure 6-9.



Figure 6-9. Maui Foundational and Transformational Capital Expenditures by Year

This profile reflects the basic fact that transformational investments need to be made in advance of each of major changes to the Maui, Lanai and Molokai grids. The LNG transportation, re-gasification and unit modification investments must be made to enable the LNG fuel savings. Rapid reacting contingency storage and other grid enhancements

are necessary to ensure system reliability with current levels of DG-PV, as well as being required to enable DG-PV growth over the next 5 to 7 years. Replacement dispatchable resources must be built or sourced in advance of any additional unit deactivations and retirements. Smart Grid capabilities must be built to enable dynamic pricing.

### Securitization

One tool that can help reduce the revenue requirement would be the use of a securitization mechanism to deal with retired generating units. This technique has been widely used elsewhere in the industry to deal with stranded costs.<sup>54</sup> One way it could be applied in Hawai'i to lower revenue requirements and lower costs to our customers would be to re-finance upon retirement the net book value of a generating unit, plus any un-accrued for removal costs, fully with securitized debt. The cash flow to repay the debt would come from a specially designated, non-bypassable customer charge. Figure 6-10 shows the revenue requirement reduction that can be achieved through securitization, assuming it was re-financed at 5% and repaid over 20 years, for each of the units planned to be retired through this PSIP.

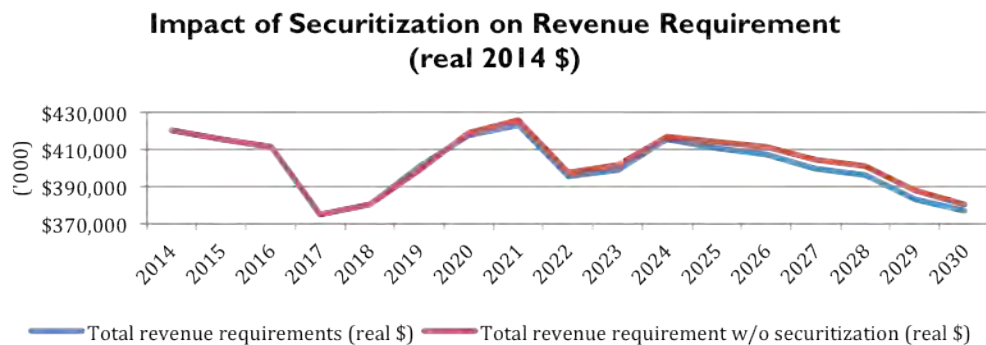


Figure 6-10. Impact of Securitization on Projected Maui Revenue Requirement

Given that retirement of existing generation is a key policy objective and that there has been acknowledgement of the need to deal with stranded costs by both the legislature and the Commission, the Company believes that planning for the availability of this tool is reasonable. Therefore, the customer bill impact analysis presented at the start of this chapter assumes that the projected revenue requirement has been reduced by securitization, as shown in Figure 6-10 above.

<sup>54</sup> Including states such as Texas, Pennsylvania, and New Jersey among many others.

## 6. Financial Impacts

### Conclusion

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## CONCLUSION

The PSIP identifies those transformational and foundational investments required to build the necessary flexible, smart and renewable energy needed to reliably serve customers across Maui, Lana'i and Moloka'i. Under the current rate design, electricity bills for average full service residential customers will be reduced by 24% in real terms from 2014 levels by 2030 under the current tariff structure and by 28% under DG 2.0.

# 7. Conclusions and Recommendations

Hawaiian Electric, Maui Electric, and Hawai'i Electric Light are pleased to present their Power Supply Improvement Plans (PSIP).

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## CONCLUSIONS

- 1. Renewable Portfolio Standard (RPS).** Hawai'i's policy goals will be achieved due to unprecedented levels of renewable energy on each island by 2030.
  - a. For the Hawaiian Electric Companies the consolidated renewable content of electricity increases to approximately 67%.
  - b. Hawai'i Electric Light's PSIP increases renewable content of electricity for Hawai'i Island to approximately 92%.
  - c. Maui Electric's PSIP increases renewable content of electricity for Maui County to approximately 72%.
  - d. Hawaiian Electric's PSIP increases renewable content of electricity for O'ahu to approximately 61%.
  
- 2. Customer Bill Impact Is Beneficial.** The Preferred Plan coupled with changes in rate design that more fairly allocates fixed grid costs across all customers (assumed effective in 2017) is expected to reduce monthly bills for average residential customers from 2014 to 2030 by:
  - a. 28% for Maui Electric
  - b. 27% for Hawai'i Electric Light
  - c. 23% for Hawaiian Electric

## 7. Conclusions and Recommendations

### Conclusions

3. **Distributed Solar PV.** For all three operating companies, the PSIP will result in a nearly three-fold increased in solar distributed generation (DG-PV).
4. **Demand Response.** The PSIP will utilize the demand response programs defined in the Companies recently issued *Integrated Demand Response Portfolio Plan (IDRPP)*<sup>55</sup> as integral tools for system operations, and to provide ways for customers to save money on their electric bills by reducing their usage at certain times.
5. **Energy Storage.** The Companies will utilize energy storage system for multiple purposes, and maximize the utilization of renewable energy that is available on the power systems. Storage will be used as “fast-responding” regulating and contingency reserves for system operation.
  - a. “Load-shifting” energy storage, including pumped storage hydro and flow batteries, are not currently be cost-effective and are not included in our Preferred Plan. In the future, this type of energy storage may prove to be cost effective and beneficial.
6. **Liquefied Natural Gas (LNG).** LNG play a critical role in the Preferred Plans for all three operating companies, providing for significant cost savings, environmental compliance, and enhanced operational flexibility.
7. **High Utilization of Renewable Energy Resources.** The available energy from renewable resources will be utilized at extremely high levels from 2015 through 2030. This is accomplished by installing energy storage to provide regulating and contingency reserves, using demand response as a tool for better managing system dispatch; selecting future thermal generation resources that have a high degree of operational flexibility; increasing the operational flexibility of existing thermal generation not slated for retirement during the study period; and reducing the “must-run” requirements of thermal generators. The following annual amounts of renewable energy will be utilized (not curtailed) annually:
  - a. Maui Electric achieves >95.8%
  - b. Hawai‘i Electric Light achieves >96.1%
  - c. Hawaiian Electric achieves >97.3%
8. **Diverse Generation Resource Mix.** Achieving unprecedented levels of renewable energy, reliable electric service, high utilization of available renewable energy depends on a diverse mix of generation resources and energy storage systems, and judicious use of demand response programs.

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<sup>55</sup> The Companies filed their IDRPP with the Commission on July 28, 2014.



- 9. Role of Thermal Generation.** Firm and dispatchable thermal generators provide a critical role complementing the renewable energy resources in the generation mix, including provision of critical grid services for system reliability, and back-up generation for when variable renewable resources are unavailable (for example, hours of darkness, extended cloudiness, or absence of wind).
- 10. Retirement of Existing Oil-fired Steam Generators.** During the PSIP planning period of 2015–2030, all of the existing oil-fired steam generators will be retired, or converted to LNG and then retired, including:
- a. Maui Electric: Kahului Units 1–4
  - b. Hawai'i Electric Light: Hill Units 5 & 6 and Puna Steam
  - c. Hawaiian Electric: Kahe Units 1–6 and Waiiau Units 3–8
- 11. O'ahu–Maui Grid Tie.** A grid tie connecting the electric grids of O'ahu and Maui would not be cost effective.

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## RECOMMENDATIONS

We recommend that the Commission, interveners, and participants in Docket 2014-0183, carefully consider the thoughtful and thorough analyses presented in this PSIP. We commit to an honest and thorough discussion of the matters discussed herein.

In the meantime, there are certain initiatives that are already underway that are integral parts of the Preferred Plan. In particular, we will continue to work with stakeholders to address distributed generation interconnection requirements in order to realize the aggressive DG-PV goals included in the Preferred Plan, and as outlined in the Distributed Generation Interconnection Plan filed concurrently with this PSIP. All of the ongoing initiatives are the subject of existing docketed proceedings before the Commission. We will continue to move forward with those initiatives as directed by the Commission.

We pledge to work collaboratively with key stakeholders during the regulatory review process so that together, we will achieve success in the transformation outlined in this PSIP.

**7. Conclusions and Recommendations**  
Recommendations

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## A. Commission Order Cross Reference

In Docket No. 2011-0092, Order No. 32055, the Hawai'i Public Utilities Commission ordered Maui Electric:

"to prepare and file with the commission a Power Supply Improvement Plan ("PSIP") within one hundred and twenty (120) days of the date of this Order, which shall include remedial analyses to supplement the SICR Plan, as well as a comprehensive evaluation of MECO's power supply system and a "detailed strategy and set of resulting action plans to implement changes to MECO's portfolio of generating units and current operating practices."<sup>56</sup>

The Order listed a number of component plans, each with a number of issues to consider. The Order also listed other stipulations – energy storage and ancillary services – to be analyzed and evaluated.

Presented here is a cross reference between the issues raised in the Commission's Order and the locations in this PSIP where they are addressed.

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<sup>56</sup> Docket No. 2011-0092, Order No. 32055, Section VII.; p86–87.

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## COMPONENT PLANS

| Component Plan  | PSIP Heading                  | Page |
|---|-------------------------------|------|
| Generation Fleet Adequacy Plan                                  | Roles of Generation Resources | 5-17 |
| Optimal Renewable Energy Portfolio Plan                         | Generation and Energy Mix     | 5-8  |
| Generation Commitment and Economic Dispatch Review              | Appendix N                    | N-1  |
| Additional Considerations: Non-transmission alternatives (NTAs) | Appendix O                    | O-1  |

Table A-1. Component Plan Cross Reference

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## FURTHER ACTION: ENERGY STORAGE

| Component Plan | PSIP Heading          | Page |
|----------------|-----------------------|------|
| Energy Storage | Energy Storage Design | 5-29 |

Table A-2. Further Action: Energy Storage Cross Reference

## B. Glossary and Acronyms

This Glossary and Acronym Appendix contains the terms used throughout the Power Supply Improvement Plan (PSIP), the Distributed Generation Interconnection Plan (DGIP), and the Integrated Interconnection Queue (IIQ). The Appendix clarifies the meaning of these terms, and helps you better understand the concepts described by these terms.

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### A

#### **Adequacy of Supply**

The ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

#### **Advanced DER Technology Utilization Plan (ADERTUP)**

A plan within the Distributed Generation Improvement Plan (DGIP) that sets forth the near, medium, and long-term plans by which customers would install, and utilities would utilize, advanced technologies to mitigate adverse grid impacts of distributed generation (DG) photovoltaics (PV).

#### **Advanced Distribution Management System (ADMS)**

A single system that includes an Outage Management System (OMS), Distribution Management System (DMS), and Distribution SCADA components and functionalities all in one platform, with a single user interface for the operator. ADMS will be used to help manage and integrate the new technologies and applications to be deployed as part of the utility's grid modernization program.

### **Advanced Inverter**

A smart inverter capable of being interconnected to the utility (via two-way communications) and controlled by it.

### **Advanced Metering Infrastructure (AMI)**

A primary component of a modern grid that provides two-way communications between the customer premises and the utility. An AMI is a necessary prerequisite to the interactions with advanced inverters, customer sited storage, demand response through direct load control, and EVs.

### **Alternating Current (AC)**

An electric current whose flow of electric charge periodically reverses direction. In Hawai'i, the mainland United States, and in many other developed countries, AC is the form in which electric power is delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave. In Hawai'i and the mainland United States, the usual power system frequency of 60 hertz (1 hertz (Hz) = 1 cycle per second).

### **Ancillary Services**

Services that supplement capacity as needed in order to meet demand or correct deviations in frequency. These include reserves, black start resources, and frequency response.

### **As-Available Renewable Energy**

See Variable Renewable Energy on page B-35.

### **Avoided Costs**

The costs that utility customers would avoid by having the utility purchase capacity and/or energy from another source (for example, energy storage or demand response) or from a third party, compared to having the utility generate the electricity itself. Avoided costs comprise two components:

- Avoided capacity costs, which includes avoided capital costs (for example, return on investment, depreciation, and income taxes) and avoided fixed operation and maintenance costs.
- Avoided energy costs, which includes avoided fuel costs and avoided variable operation and maintenance costs.

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**B****Baseload**

The minimum electric or thermal load that is supplied continuously over a period of time. See also Load, Electric on page B-19.

**Baseload Capacity**

See Capacity, Generating on page B-4.

**Baseload Generation**

The production of energy at a constant rate, to support the system's baseload.

**Battery Energy Storage Systems (BESS)**

Any battery storage system used for contingency or regulating reserves, load shifting, ancillary services, or other utility or customer functions. See also Storage on page B-31.

**Black Start**

The ability of a generating unit or station to go from a shutdown condition to an operating condition and start delivering power without assistance from the electric system.

**British Thermal Unit (Btu)**

A unit of energy equal to about 1055 joules that describes the energy content of fuels. A Btu is the amount of heat required to raise the temperature of 1 pound of water by 1°F at a constant atmospheric pressure. When measuring electricity, the proper unit would be Btu per hour (or Btu/h) although this is generally abbreviated to just Btu. The term MBtu means a thousand Btu; the term MMBtu means a million Btu.

**Buy-All/Sell-All**

Tariff structure for DER under which customers would sell their entire DG output to the utility and purchase all of their requirements from the utility. This structure requires a two-meter system, with one meter to monitor grid import/export and one to monitor generation from the PV system.

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C

**Capacitor**

A device that helps improve the efficiency of the flow of electricity through distribution lines by reducing energy losses. This is accomplished by the capacitor's ability to correct AC voltage so that the voltage is in phase with the AC current. Capacitors are typically installed in substations and on distribution system poles.

**Capacity Factor (cf)**

The ratio of the average operating load of an electric power generating unit for a period of time to the capacity rating of the unit during that period of time.

**Capacity, Generating**

The rated continuous load-carrying ability, expressed in megawatts (MW) or megavolt-amperes (MVA) of an electric generating plant. It is the maximum power that a machine or system can produce or carry under specified conditions, usually expressed in kilowatts or megawatts. Capacity is an attribute of an electric generating plant that does not depend on how much it is used. Types of capacity include:

**Baseload Capacity:** Those generating facilities within a utility system that are operated to the greatest extent possible to maximize system mechanical and thermal efficiency and minimize system operating costs. Baseload capacity typically operates at high annual capacity factors, for example greater than 60%.

**Firm Capacity:** Capacity that is intended to be available at all times during the period covered by a commitment, even under adverse conditions.

**Installed Capacity (ICAP):** The total capacity of all generators able to serve load in a given power system. Also called ICAP, the total wattage of all generation resources to serve a given service or control area.

**Intermediate Capacity:** Flexible generators able to efficiently vary their output across a wide band of loading conditions. Also known as Cycling Capacity. Typically annual capacity factors for intermediate duty generating units range from 20% to 60%.

**Net Capacity:** The maximum capacity (or effective rating), modified for ambient limitations, that a generating unit, power plant, or electric system can sustain over a specified period, less the capacity used to supply the demand of station service or auxiliary needs.



**Peaking Capacity:** Generators typically called on for short periods of time during system peak load conditions. Annual capacity factors for peaking generation are typically less than 20%.

### **Capital Expenditures**

Funds expended by a utility to construct, acquire or upgrade physical assets (generating plants, energy storage devices, transmission plant, distribution plant, general plant, major software systems, or IT infrastructure). Capital expenditures for a given asset include funds expended for the acquisition and development of land related to the asset, obtaining permits and approvals related to the asset, environmental and engineering studies specifically related to construction of the asset, engineering design of the asset, procurement of materials for the asset, construction of the asset, and startup activities related to the asset. Capital expenditures may be associated with a new asset or an existing asset (that is, renovations, additions, upgrades, and replacement of major components).

### **Carbon Dioxide (CO<sub>2</sub>)**

A greenhouse gas produced when carbon-based fossil fuels are combusted.

### **Combined Cycle (CC)**

A combination of combustion turbine- and steam turbine-driven electrical generators, where the combustion turbine exhaust is passed through a heat recovery waste heat boiler which, in turn, produces steam which drives the steam turbine.

**2x1 Combined Cycle:** A configuration in which there are two combustion turbines, one heat recovery waste heat boiler, and one steam turbine. The combustion turbines produce heat for the single waste heat boiler, which in turn produces steam that is directed to the single steam turbine.

**Dual-Train Combined Cycle (DTCC):** A configuration in which there are two combustion turbines, two heat recovery waste heat boilers and one steam turbine. Each combustion turbine/waste heat boiler combination produces steam that is directed to the single steam turbine.

**Single-Train Combined Cycle (STCC):** A configuration in which there is one combustion turbine, one heat recovery waste heat boiler, and one steam turbine.

### **Combined Heat and Power (CHP)**

The simultaneous production of electric energy and useful thermal energy for industrial or commercial heating or cooling purposes. The Energy Information Administration (EIA) has adopted this term in place of cogeneration.

**Combustion Turbine (CT)**

Any of several types of high-speed generators using principles and designs of jet engines to produce low cost, high efficiency power. Combustion turbines typically use natural gas or liquid petroleum fuels to operate.

**Commercial and Industrial Direct Load Control (CIDLC)**

A demand response program that provides financial incentives to qualified businesses for participating in demand control events. Such a program is designed for large commercial and industrial customers.

**Commercial and Industrial Dynamic Pricing (CIDP)**

A demand response program that provides tariff-based dynamic pricing options for electrical power to commercial and industrial customers. CIDP encourages customers to reduce demand when the overall load is high.

**Conductor Sag**

The distance between the connection point of a conductor (transmission/distribution line) and the lowest point of the line.

**Connected Load**

See Load, Electric on page B-19.

**Contingency Reserve**

The reserve deployed to meet contingency disturbance requirements, the largest single resource contingency on each island.

**Curtailement**

Cutting back on variable resources during off-peak periods of low electricity use in order to keep generation and consumption of electricity in balance.

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D

**Daytime Minimum Load (DML)**

The absolute minimum demand for electricity between 9 AM and 5 PM on one or more circuits each day.

**Demand**

The rate at which electricity is used at any one given time (or averaged over any designated interval of time). Demand differs from energy use, which reflects the total amount of electricity consumed over a period of time. Demand is often measured in Kilowatts (kW = 1 Kilowatt = 1000 watts), while energy use is usually measured in Kilowatt-hours (kWh = Kilowatts x hours of use = Kilowatt-hours). Load is considered synonymous with demand. (See also Load, Electric on page B-19.)

**Demand Charge**

A customer charge intended to allocate fixed grid costs to customers based on each customer's consumption demand.

**Demand Response (DR)**

Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. The underlying objective of demand response is to actively engage customers in modifying the demand for electricity, in lieu of a generating plant supplying the demand.

**Load Control:** Includes direct control by the utility or other authorized third party of customer end-uses such as air conditioners, lighting, and motors. Load control may entail partial or load reductions or complete load interruptions. Customers usually receive financial consideration for participation in load control programs.

**Price Response:** Refers to programs that provide pricing incentives to encourage customers to change their electricity usage profile. Price response programs include real-time pricing, dynamic pricing, coincident peak pricing, time-of-use rates, and demand bidding or buyback programs.

**Demand-Side Management (DSM)**

The planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. It refers only to energy and load-shape modifying activities that are undertaken in response to utility or third party-administered programs. It does not refer to energy and load-shape changes arising from the normal operation of the marketplace or from government-mandated energy efficiency standards. Demand--Side Management (DSM) covers the complete range of load-shape objectives, including strategic conservation and load management, as well as strategic load growth.

#### **Department of Business, Economic Development, & Tourism (DBEDT)**

Hawai'i's resource center for economic and statistical data, business development opportunities, energy and conservation information, and foreign trade advantages. DBEDT's mission is to achieve a Hawai'i economy that embraces innovation and is globally competitive, dynamic and productive, providing opportunities for all Hawai'i's citizens. Through our attached agencies, we also foster planned community development, create affordable workforce housing units in high-quality living environments, and promote innovation sector job growth.

#### **Department of Land and Natural Resources (DLNR)**

A department within the Hawai'i state government responsible for managing state parks and other natural resources.

#### **Direct Current (DC)**

A department within the Hawai'i state government responsible for managing Hawai'i's unique natural and cultural resources. Also oversees state-owned and state conservation lands.

#### **Distributed Energy Resources Technical Working Group (DER-TWG)**

A working group to be formed as a review committee for DER-related technical assessments.

#### **DG 2.0**

A generic term used to describe revised tariff structures governing export and non-export models, based on fair allocation of costs among distributed generation (DG) customers and traditional retail customers, and fair compensation of DG customers for energy provided to the grid.

#### **Direct Current (DC)**

An electric current whose flow of electric charge remains constant. Certain renewable power generators (such as solar PV) deliver DC electricity, which must be converted to AC electricity, using an inverter, for use in the power system.

#### **Direct Load Control (DLC)**

This Demand-Side Management category represents the consumer load that can be interrupted by direct control of the utility system operator. For example, the utility may install a device such as a radio-controlled device on a customer's air-conditioning equipment or water heater. During periods of system need, the utility will send a radio signal to the appliance with this device and control the appliance for a set period of time.

**Direct Transfer Trip**

A protection mechanism that originates from station relays in response to a substation event.

**Dispatchable Generation**

A generation source that is controlled by a system operator or dispatcher who can increase or decrease the amount of power from that source as the system requirements change.

**Distributed Circuit Improvement Implementation Plan (DCIIP)**

A plan within the Distributed Generation Interconnection Plan (DGIP) that summarizes the specific strategies and action plans, including associated costs and schedules, to implement circuit upgrades and other mitigation measures to increase capacity of electrical grids to interconnect additional distributed generation.

**Distributed Energy Resources (DER)**

Non-centralized generating and storage systems that are co-located with energy load.

**Distributed Energy Storage**

Energy storage systems sited on the distribution circuit, including substation-sited and customer-sited storage.

**Distributed Generation (DG)**

A term referring to a small generator, typically 10 megawatts or smaller, that is sited at or near load, and that is attached to the distribution grid. Distributed generation can serve as a primary or backup energy source and can use various technologies, including combustion turbines, reciprocating engines, fuel cells, wind generators, and photovoltaics. Also known as a Distributed Energy Resource (see page B-9).

**Distributed Generation Interconnection Capacity Analysis (DGICA)**

A plan within DGIP to proactively identify distribution circuit capacity constraints to the safe and reliable interconnection of distributed generation resources. Includes system upgrade requirements necessary to increase circuit interconnection capability in major capacity increments.

**Distribution Automation (DA)**

Programs to allow monitoring and control of all distribution level sources, as well as the automation of feeders to provide downstream monitoring and control.

#### **Distribution Circuit Monitoring Program (DCMP)**

A document filed by the Companies on June 27, 2014, outlining three broad goals. First, to measure circuit parameters to determine the extent to which distributed solar photovoltaic (PV) generation is causing safety, reliability, or power quality issues. Second, to ensure that distributed generation circuit voltages are within tariff and applicable standards. Third, to increase the Companies' knowledge of what is occurring on high PV penetration circuits to determine boundaries and thresholds and further future renewable DG integration work.

#### **Distribution Circuit**

The physical elements of the grid involved in carrying electricity from the transmission system to end users.

#### **Distribution Transformer**

A transformer used to step down voltage from the distribution circuit to levels appropriate for customer use.

#### **Disturbance Ride-Through**

The capability of DG systems to remain connected to the grid under non-standard voltage levels.

#### **Droop**

The amount of speed (or frequency) change that is necessary to cause the main prime mover control mechanism to move from fully closed to fully open. In general, the percent movement of the main prime mover control mechanism can be calculated as the speed change (in percent) divided by the per unit droop.

#### **Dual-Train Combined Cycle (DTCC)**

See Combined Cycle on page B-5.

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### E

#### **Economic Dispatch**

The start-up, shutdown, and allocation of load to individual generating units to effect the most economical production of electricity for customers.

#### **Electric Power Research Institute (EPRI)**

A nonprofit research and development organization that conducts research, development and demonstration relating to the generation, delivery, and use of electricity.

**Electric Vehicle (EV)**

A vehicle that uses one or more electric motors or traction motors for propulsion.

**Electricity**

The set of physical phenomena associated with the presence and flow of electric charge.

**Energy**

The ability to produce work, heat, light, or other forms of energy. It is measured in watt-hours. Energy can be computed as capacity or demand (measured in watts), multiplied by time (measured in hours). For example, a 1 megawatt (one million watts) power plant running at full output for 1 hour will produce 1 megawatt-hour (one million watt-hours or 1000 kilowatt-hours) of electrical energy.

**Emissions**

An electric power plant that combusts fuels releases pollutants to the atmosphere (for example, emissions of sulfur dioxide) during normal operation. These pollutants may be classified as primary (emitted directly from the plant) or secondary (formed in the atmosphere from primary pollutants). The pollutants emitted will vary based on the type of fuel used.

**Energy Efficiency DSM**

Programs designed to encourage the reduction of energy used by end-use devices and systems. Savings are generally achieved by substituting more technologically advanced equipment to produce the same level of energy services (for example, lighting, water heating, motor drive) with less electricity. Examples include programs that promote the adoption of high-efficiency appliances and lighting retrofit programs through the offering of incentives or direct install services.

**Energy Efficiency Portfolio Standard (EEPS)**

A goal for reducing the demand for electricity in Hawai'i through the use of energy efficiency and displacement or offset technologies set by state law. The EEPS goes into effect in January 2015. Until then, energy savings from these technologies are included in the calculations for Hawai'i's RPS. The EEPS for Hawai'i provides for a total energy efficiency target of 4,300,000 megawatt-hours per year by the year 2030. To the extent that this target is achieved, this quantity of electric energy will not be served by Hawai'i's electric utilities. Therefore, the projected amount of energy reductions due to energy efficiency are removed from the system energy requirement forecasts used in this PSIP.

#### **Energy Excelerator**

A program of the Pacific International Center for High Technology Research that funds seed-stage and growth-stage startups with compelling energy solutions and immediate applications in Hawai'i, helping them succeed by providing funding, strategic relationships, and a vibrant ecosystem.

#### **Energy Management System (EMS)**

A computer system, including data-gathering tools used to monitor and control electrical generation and transmission.

#### **Expense**

An outflow of cash or other consideration (for example, incurring a commercial credit obligation) from a utility to another person or company in return for products or services (fuel expense, operating expense, maintenance expense, sales expense, customer service expense, interest expense.). An expense might also be a non-cash accounting entry where an asset (created as a result of a Capital Expenditure) is used up (for example, depreciation expense) or a liability is incurred.

#### **Export Model**

A model for DG PV interconnection in which co-incident self-generation and usage is not metered, excess energy is exported to the grid, and energy is imported to meet additional customer needs.

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### F

#### **Feeder**

A circuit carrying power from a major conductor to a one or more distribution circuits.

#### **Firm Capacity**

See Capacity, Generating on page B-4.

#### **Feed-In-Tariff (FIT) Program**

A FIT program specific to Hawaiian Electric, under guidelines issued by the Hawai'i Public Utilities Commission, which provides for customers to sell all the electric energy produced to the electric company.

#### **Feed-In-Tariff (FIT)**

The generic term for the rate at which exported DG PV is compensated by the utility.



**First-In-First-Out (FiFo)**

The policy for clearing the DG interconnection queues, under which applications are processed in the order in which they were received.

**Flicker**

An impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

**Flywheel**

See Storage one page B-31.

**Forced Outage**

See Outage on page B-23.

**Forced Outage Rate**

See Outage on page B-23.

**Fossil Fuel**

Any naturally occurring fuel formed from the decomposition of buried organic matter, essentially coal, petroleum (oil), and natural gas. Fossil fuels take millions of years to form, and thus are non-renewable resources. Because of their high percentages of carbon, burning fossil fuels produces about twice as much carbon dioxide (a greenhouse gas) as can be absorbed by natural processes.

**Frequency**

The number of cycles per second through which an alternating current passes. Frequency has been generally standardized in the United States electric utility industry at 60 cycles per second (60 Hz). The power system operator strives to maintain the system frequency as close as possible to 60 Hz at all times by varying the output of dispatchable generators, typically through automatic means. In general, if demand exceeds supply, the frequency will drop below 60 Hz; if supply exceeds demand, the frequency will rise above 60 Hz. If the system frequency drops to an unacceptable level (under-frequency), or rises to an unacceptable level (over-frequency), a system failure can occur. Accordingly, system frequency is an important indicator of the power system's condition at any given point in time.

**Frequency Regulation**

The effort to keep an alternating current at a consistent 60 Hz per second (or other fixed standard).

**Full-Forced Outage**

See Outage on page B-23.

#### **Full Service Customer**

Any residential or commercial customer that imports the entirety of their energy demands from the grid, and does not self-consume or export any energy derived from distributed energy resources co-located with their load.

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## G

#### **Generating Capacity**

See Capacity, Generating on page B-4.

#### **Generation (Electricity)**

The process of producing electrical energy from other forms of energy; also, the amount of electric energy produced, usually expressed in kilowatt-hours (kWh) or megawatt hours (MWh).

**Nameplate Generation (Gross Generation):** The electrical output at the terminals of the generator, usually expressed in megawatts (MW).

**Net Generation:** Gross generation minus station service or unit service power requirements, usually expressed in megawatts (MW). The energy required for pumping at a pumped storage plant is regarded as plant use and must be deducted from the gross generation.

#### **Generator (Electric)**

A machine that transforms mechanical, chemical, or thermal energy into electric energy. Includes wind generators, solar PV generators, and other systems that convert energy of one form into electric energy. See also Capacity, Generating on page B-4.

#### **Geographic Information System (GIS)**

A computer system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.

#### **Gigawatt (GW)**

A unit of power, capacity, or demand equal to one billion watts.

#### **Gigawatt-hour (GWh)**

A unit of electric energy equal to one billion watt-hours.

#### **Grandfather**

To exempt a class of customers from changes to the laws or regulations under which they operate.

**Greenhouse Gases (GHG)**

Any gas whose absorption of solar radiation is responsible for the greenhouse effect, including carbon dioxide, methane, ozone, and the fluorocarbons.

**Grid (Electric)**

An interconnected network of electric transmission lines and related facilities.

**Grid Modernization**

The full suite of technologies and capabilities—including the data acquisition capabilities, controlling devices, telecommunications, and control systems—necessary to operate the utility’s modernized electric grid. This includes Advanced Metering Infrastructure (AMI) with two-way communications and all the components to implement an Advanced Distribution Management System/Energy Management System. Additional components might include Volt-VAR Optimization (VVO); demand response; control of DG (curtailment and other); adaptive relaying (dynamic load shed); transformer monitoring; and potentially other advanced analytics, reporting, and monitoring capabilities.

**Gross Generation**

See Generation (Electricity) on page B-14.

**Ground Fault Overvoltage**

A transient overvoltage issue that occurs when the neutral of a wye grounded system shifts, causing a temporary overvoltage on the unfaulted phase.

**Grounding Transformer**

A transformer that provides a safe path to ground.

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## H

**Hawai'i Public Utilities Commission (PUC)**

A state agency that regulates all franchised or certificated public service companies operating in Hawai'i. The PUC prescribes rates, tariffs, charges and fees; determines the allowable rate of earnings in establishing rates; issues guidelines concerning the general management of franchised or certificated utility businesses; and acts on requests for the acquisition, sale, disposition or other exchange of utility properties, including mergers and consolidations.

### **Hawai'i Revised Statute (HRS)**

The codified laws of the State of Hawai'i. The entire body of state laws is referred to the Hawai'i Revised Statutes; the abbreviation HRS is normally used when citing a particular law.

### **Heat Rate**

A measure of generating station thermal efficiency, generally expressed in Btu per net kilowatt-hour. It is computed by dividing the total Btu content of fuel burned for electric generation by the resulting net kilowatt-hour generation.

### **High Voltage Direct Current (HVDC)**

An electric power transmission system that uses direct current, rather than alternating current, for bulk transmission.

### **Impacts**

The positive or negative consequences of an activity. For example, there may be negative consequences associated with the operation of power plants from the emission discharge or release of a material to the environment (for example, health effects). There may also be positive consequences resulting from the construction and siting of power plants which could affect society and culture.

### **Impedance**

A measure of the opposition to the flow of power in an AC circuit.

### **Independent Power Producer (IPP)**

Any entity that owns or operates an electricity generating facility that is not included in an electric utility's rate base. This term includes, but is not limited to, co-generators (or combined heat and power generators) and small power producers (including net metered and feed-in-tariff systems) and all other non-utility electricity producers, such as exempt wholesale generators, who sell electricity or exchange electricity with the utility. IPPs are also sometimes referred to as non-utility generators (NUGs).

### **Installed Capacity**

See Capacity, Generating on page B-4.

### **Integrated Demand Response Portfolio Plan (IDRPP)**

A Comprehensive Demand Response program proposal filed by the Companies with the Hawai'i Public Utilities Commission on July 28, 2014.

**Integrated Interconnection Queue (IIQ)**

Recommendations and plan for implementing and organizing an Integrated Interconnection Queue across all DG programs as directed by the Hawai'i Public Utilities Commission in Order 32053, to be filed on August 26, 2014.

**Integrated Resource Plan (IRP)**

The plan by which electric utilities identify the resources or the mix of resources for meeting near- and long-term consumer energy needs. An IRP conveys the results from a planning, analysis, and decision-making process that examines and determines how a utility will meet future demands. Developed in the 1980s, the IRP process integrates efficiency and load management programs, considered on par with supply resources; broadly framed societal concerns, considered in addition to direct dollar costs to the utility and its customers; and public participation into the utility planning process.

**Interconnection Charge**

A one-off charge to DG customers reflecting costs of studies and any potential upgrades (such as transformer upgrades) associated with distributed generation.

**Interconnection Requirements Study (IRS)**

Studies conducted by the Hawaiian Electric Companies on specific DG interconnection requests that may require mitigation measures to ensure circuit stability.

**Intermediate Capacity**

See Capacity, Generating on page B-4.

**Intermittent Renewable Energy**

See Variable Renewable Energy on page B-35.

**Inverter**

A device that converts direct current (DC) electricity to alternating current (AC) either for stand-alone systems or to supply power to an electricity grid. An appropriately designed inverter can provide dynamic reactive power as well as real power and low voltage ride-through capability. A solar PV system uses inverters to convert DC electricity to AC electricity for use in the grid, or directly by a customer.

**Islanding**

A condition in which a circuit remains powered by non-utility generation (that is, distributed generation resources) even when the circuit has been disconnected from the wider utility power network.

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K

**Kilowatt (KW)**

A unit of power, capacity, or demand equal to one thousand watts. The Companies sometimes express the demand for an individual electric customer, or the capacity of a distributed generator in kilowatts. The standard billing unit for electric tariffs with a demand charge component is the kilowatt.

**Kilowatt-hour (KWh)**

A unit of electric energy equal to one thousand watt-hours. The standard billing unit for electric energy sold to retail consumers is the kilowatt-hour.

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L

**Laterals**

Lines branching off the primary feeder on a distribution circuit.

**Levelized Cost of Energy (LCOE)**

The price per kilowatt-hour in order for an energy project to break even; it does not include risk or return on investment.

**Life-Cycle Costs**

The total cost impact over the life of a program or the life of an asset. Life-cycle costs include Capital Expenditures, operation, maintenance and administrative expenses, and the costs of decommissioning.

**Liquefied Natural Gas (LNG)**

Natural gas that has been cooled until it turns liquid, in order to make storage and transport easier.

**Live-Line Block Closing**

Restrictions on the re-closing of feeders with interconnected DG PV systems based on line voltage levels.

**Load, Electric**

The term load is considered synonymous with demand. Load may also be defined as an end-use device or an end-use customer that consumes power. Using this definition of load, demand is the measure of power that a load receives or requires.

**Baseload:** The minimum load over a given period of time.

**Connected Load:** The sum of the capacities or ratings of the electric power consuming apparatus connected to a supplying system, or any part of the system under consideration.

**Load Balancing**

The efforts of the system operator to ensure that the load is equal to the generation. During normal operating conditions the system operator utilizes load following and frequency regulation for load balancing.

**Load Control Program**

A program in which the utility company offers some form of compensation (for example, a bill credit) in return for having permission to control a customer's air conditioner or water heater for short periods of time by remote control.

**Load Forecast**

An estimate of the level of future energy needs of customers in an electric system. Bottom-up forecasting uses utility revenue meters to develop system-wide loads; used often in projecting loads of specific customer classes. Top-down forecasting uses utility meters at generation and transmission sites to develop aggregate control area loads; useful in determining reliability planning requirements, especially where retail choice programs are not in effect.

**Load Management DSM**

Electric utility or third party marketing programs designed to encourage the utility's customers to adjust the timing of their energy consumption. By coordinating the timing of its customers' consumption, the utility can achieve a variety of goals, including reducing the utility's peak system load, increasing the utility's minimum system load, and meeting unusual, transient, or critical system operating conditions.

**Load Profile**

Measurements of a customer's electricity usage over a period of time which shows how much and when a customer uses electricity. Load profiles can be used by suppliers and transmission system operators to forecast electricity supply requirements and to determine the cost of serving a customer.

**Load Shedding**

A purposeful, immediate response to curtail electric service. Load shedding is typically used to curtail large blocks of customer load (for example, particular distribution feeders) during an under frequency event when demand for electricity exceeds supply (for example, during the sudden loss of a generating unit).

**Load Tap Changer (LTC)**

A substation controller used to regulate the voltage output of a transformer.

**Low Sulfur Fuel Oil (LSFO)**

A fuel oil that contains less than 500 parts per million of sulfur; about 0.5% sulfur content.

**Low Sulfur Industrial Fuel Oil (LSIFO)**

A fuel oil that contains up to 7,500 parts per million of sulfur; about 0.75% sulfur content. LSIFO is used by Maui Electric and Hawai'i Electric Light if a fuel with lower sulfur content than MSFO is needed.

**Low Voltages**

Voltages above 0.9 per unit that are of concern because these voltages can become an under voltage violation in the future.

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**M****Maalaea Power Plant (MPP)**

The largest power plant on Maui, with 15 diesel units, a combined cycle gas turbine, and a combined/simple cycle gas turbine totaling 208.42 MW (net) of firm capacity.

**Maintenance Outage**

See Outage on page B-23.

**MBtu**

A thousand Btu. See also British Thermal Unit on page B-3.

**Medium Sulfur Fuel Oil (MSFO)**

A fuel oil that contains between 1,000 and 5,000 parts per million of sulfur; between 1% and 3.5% sulfur content.



**Megawatt (MW)**

A unit of power, capacity, or demand equal to one million watts. The Companies typically express their generating capacities and system demand in Megawatts.

**Megawatt-hour (MWh)**

A unit of electric energy equal to one million watt-hours. The Companies from time to time express the energy output of their generators or the amount of energy purchased from Independent Power Producers in megawatt-hours.

**MMBtu**

One million Btu. See also British Thermal Unit on page B-3.

**Modern Grid**

An umbrella term used to describe transformed grid, including communications, AMI, ADMS, and DA.

**Must Run Unit**

A baseload generation facility that must run continually due to operational constraints or system requirements to maintain system reliability; typically a large thermal power plant.

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**N****N-1 Contingency**

A condition that happens when a planned or unplanned outage of a transmission facility occurs while all other transmission facilities are in service. Also known as an N-1 condition.

**Nameplate Generation**

See Generation (Electricity) on page B-14.

**Net Capacity**

See Capacity, Generating on page B-4.

#### **Net Energy Metering (NEM)**

A financial arrangement between a customer with a renewable distributed generator and the utility, where the customer only pays for the net amount of electricity taken from the grid, regardless of the time periods when the customer imported from or exported to the grid. Under a NEM arrangement, the customer is allowed to remain connected to the power grid, so that the customer can take advantage of the grid's reliability infrastructure (such as ancillary services provided by generators, energy storage devices, and demand response programs), use the grid as a "bank" for power generated by the customer in excess of the customer's needs, and use the grid as a backup resource for times when the power generated by the customer is less than the customer's needs.

#### **Net Generation**

See Generation (Electricity) on page B-14.

#### **Nitrogen Oxide (NO<sub>x</sub>)**

A pollutant and strong greenhouse gas emitted by combusting fuels.

#### **Nominal Value (Nominal Dollars)**

While a complex topic, at its most basic, value is based on a measure of money over a period of time. Generally expressed in terms of US dollars, nominal value represents a money cost in a given year, usually the current year. As such, nominal dollars can also be referred to as current dollars.

#### **Non-Export Model**

A tariff structure governing the interconnection of non-export DG systems.

#### **Non-transmission alternatives**

Programs and technologies that complement and improve operation of existing transmission systems that individually or in combination defer or eliminate the need for upgrades to the transmission system.

#### **North American Electric Reliability Corporation (NERC)**

An international regulatory authority whose mission is to ensure the reliability of the bulk power system in North America.

## O

**Off-Peak Energy**

Electric energy supplied during periods of relatively low system demands as specified by the supplier. In general, this term is associated with electric water heating and pertains to the use of electricity during that period when the overall demand for electricity from our system is below normal.

**On-Peak Energy**

Electric energy supplied during periods of relatively high system demand as specified by the supplier.

**Operation and Maintenance (O&M) Expense**

The recurring costs of operating, supporting, and maintaining authorized programs, including costs for labor, fuel, materials, and supplies, and other current expenses.

**Operating Reliability**

The ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components.

**Operating Reserves**

There are two types of operating reserves that enable an immediate or near immediate response to an increase in demand. (See also Reserve on page B-28.)

**Spinning Reserve Service:** Provides additional capacity from electricity generators that are on-line, loaded to less than their maximum output, and available to serve customer demand immediately should a contingency occur.

**Supplemental Reserve Service:** Provides additional capacity from electricity generators that can be used to respond to a contingency within a short period, usually ten minutes.

**Outage**

The period during which a generating unit, transmission line, or other facility is out of service. The following six terms are types of outages or outage-related terms:

**Forced Outage:** The removal from service availability of a generating unit, transmission line, or other facility for emergency reasons or a condition in which the equipment is unavailable due to unanticipated failure.

**Forced Outage Rate:** The hours a generating unit, transmission line, or other facility is removed from service, divided by the sum of the hours it is removed from service, plus the total number of hours the facility was connected to the electricity system expressed as a percent.

**Full-Forced Outage:** The net capability of main generating units that is unavailable for load for emergency reasons.

**Maintenance Outage:** The removal of equipment from service availability to perform work on specific components that can be deferred beyond the end of the next weekend, but requires the equipment be removed from service before the next planned outage. Typically, a Maintenance Outage may occur anytime during the year, have a flexible start date, and may or may not have a predetermined duration.

**Partial Outage:** The outage of a unit or plant auxiliary equipment that reduces the capability of the unit or plant without causing a complete shutdown. It may also include the outage of boilers in common header installations.

**Planned (or Scheduled) Outage:** The shutdown of a generating unit, transmission line, or other facility, for inspection or maintenance, in accordance with an advance schedule.

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## P

### **Partial Outage**

See Outage on page B-23.

### **Peak Demand**

The maximum amount of power necessary to supply customers; in other words, the highest electric requirement occurring in a given period (for example, an hour, a day, month, season, or year). For an electric system, it is equal to the sum of the metered net outputs of all generators within a system and the metered line flows into the system, less the metered line flows out of the system. From a customer's perspective, peak demand is the maximum power used during a specific period of time.

### **Peaker**

A generation resource that generally runs to meet peak demand, usually during the late afternoon and early evening when the demand for electricity during the day is highest. It is also referred to as a peaker plant or a peaking power plant.

**Peaking Capacity**

See Capacity, Generating on page B-4.

**Phase imbalance**

A condition in which there is a voltage imbalance across two or more phases of a multi-phase system.

**Photovoltaic (PV)**

Electricity from solar radiation typically produced with photovoltaic cells (also called solar cells): semiconductors that absorb photons and then emit electrons.

**Planned Outage**

See Outage on page B-23.

**Planning Reserve**

See Reserve on page B-28.

**Plug-in Electric Vehicle (PEV)**

An umbrella term encompassing all electric or hybrid electric vehicles that can be recharged through an external electricity source.

**Power**

The rate at which energy is supplied to a load (consumed), usually measured in watts (W), kilowatts (kW), or megawatts (MW).

**Power Factor**

A dimensionless quantity that measures the extent to which the current and voltage sine waves in an AC power system are synchronized. If the voltage and current sine waves perfectly match, the power factor is 1.0. Power factors not equal to 1.0 result in dissipation of electric energy into losses.

**Power Generating Technology**

The myriad ways in which electric power is produced, including both commercially available technologies and emerging technologies, as well as hypothetical technologies.

**Power Purchase Agreement (PPA)**

A contract for the Hawaiian Electric Companies to purchase energy and or capacity from a commercial source (for example, an Independent Power Producer) at a predetermined price or based on pre-determined pricing formulas.

#### **Present Value**

The value of an asset, taking into account the time value of money – a future dollar is worth less today. Present value dollars are expressed in a constant year dollars (usually the current year). Future dollars are converted to present dollars using a discount rate. For example, if someone borrows money from you today, and agrees to pay you back in one year in the amount of \$1.00, and the discount rate is 10%, you would be only be willing to loan the other person \$0.90 today. Utility planners use present value as a way to directly compare the economic value of multi-year plans with different future expenditure profiles. Net Present Value is the difference between the present value of all future benefits, less the present value of all future costs.

#### **Primary Lines**

The main high-voltage lines of the transmission and distribution network.

#### **Proactive Approach**

A forward-looking process governing the forecasting of penetration of DER on distribution circuits, analysis of operational constraints, and pre-emptive mitigation of these constraints.

#### **Public Benefits Fee Administrator (PBFA)**

A third-party agent that handles energy efficiency rebates and incentives for the Hawaiian Electric Companies.

#### **Pumped Storage Hydro**

See Storage on page B-31.

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### Q

#### **Qualitative**

Consideration of externalities which assigns relative values or rankings to the costs and benefits. This approach allows expert assessments to be derived when actual data from conclusive scientific investigation of impacts are not available.

#### **Quantitative**

Consideration of externalities which provides value based on available information on impacts. This approach allows for the quantification of impacts without assigning a monetary value to those impacts (for example, tons of crop loss).

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R

**Ramping Capability**

A measure of the speed at which a generating unit can increase or decrease output.

**Rate Base**

The value of property upon which a utility is permitted to earn a specified rate of return as established by a regulatory authority. The rate base generally represents the book value of property used by the utility in providing service and may be calculated by any one or a combination of the following accounting methods: fair value, prudent investment, reproduction cost, or original cost. Depending on which method is used, the rate base includes net cost of plant in service, working cash, materials and supplies, and deductions for accumulated provisions for depreciation, contributions in aid of construction, customer advances for construction, accumulated deferred income taxes, and accumulated deferred investment tax credits.

**Reactive Power**

The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment.

**Real Dollars**

While a complex topic, at its most basic, value is a measure of money over a period of time. Generally expressed in terms of units of US dollars, real dollars represents the true cost inclusive of inflationary adjustments (such as simple price changes which, of course, are usually price increases). Over time, real dollars are a measure of purchasing power. As such, real dollars can also be referred to as constant dollars.

**Recloser**

A circuit breaker with the ability to reclose after a fault-induced circuit break.

**Reconductoring**

The process of replacing the cable or wiring on a distribution or transmission line.

**Regulating Reserves**

The capacity required to maintain system frequency through fast balancing.

**Reliability**

The degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply. Electric system reliability can be addressed by

considering two basic and functional aspects of the electric system, Adequacy of Supply and System Security. See also System Reliability on page B-33.

#### **Renewable Energy Resources**

Energy resources that are naturally replenished, but limited in their constant availability (or flow). They are virtually inexhaustible but are limited in the amount of energy that is available over a given period of time. The amount of some renewable resources (such as geothermal and biomass) might be limited over the short term as stocks are depleted by use, but on a time scale of decades or perhaps centuries, they can likely be replenished.

Renewable energy resources include photovoltaics, biomass, hydroelectric, geothermal, solar, and wind. In the future, they could also include the use of ocean thermal, wave, and tidal action technologies. Utility renewable resource applications include bulk electricity generation, on-site electricity generation, distributed electricity generation, non-grid-connected generation, and demand-reduction (energy efficiency) technologies.

Unlike fossil fuel generation plants (which can be sited where most convenient because the fuel is transported to the plant), renewable energy generation plants must be sited where the energy is available; that is, a wind farm must be sited where a sufficient and relatively constant supply of wind is available. In other words, fossil fuels can be brought to their generation plants whereas renewable energy generating plants must be brought to the renewable energy source.

#### **Renewable Portfolio Standard (RPS)**

A goal for the percentage of electricity sales in Hawai'i to be derived from renewable energy sources. The RPS is set by state law. Savings from energy efficiency and displacement or offset technologies are part of the RPS until January 2015, when they will instead be counted toward the new EEPS. The current RPS calls for 10% of net electricity sales by December 31, 2010; 15% of net electricity sales by December 31, 2015; 25% of net electricity sales by December 31, 2020; and 40% of net electricity sales by December 31, 2030.

#### **Repowering**

A means of permanently increasing the output and/or the efficiency of conventional thermal generating facilities.

#### **Reserve**

There are two types of reserves:

**Operating Reserve:** That capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages, and local area protection. See also Operating Reserves on page B-23.



**Planning Reserve:** The difference between a control area's expected annual peak capability and its expected annual peak demand expressed as a percentage of the annual peak demand.

**Reserve Margin (Planning)**

The amount of unused available capability of an electric power system at peak load for a utility system as a percentage of total capability. Such capacity may be maintained for the purpose of providing operational flexibility and for preserving system reliability.

**Residential Direct Load Control (RDLC)**

A demand response program that offers incentives to customers who allow the Hawaiian Electric Companies to install a load control switch on residential electric water heater, so that the load can be curtailed remotely by the utility during times of system need.

**Resiliency**

The ability to quickly locate faults and automatically restore service after a fault, using FLISR (Fault Location, Isolation, & Service Restoration).

**Retail Rate**

The rate at which specific classes of customers compensate the utility for grid electricity.

**Reverse Flow**

The flow of electricity from the customer site onto the distribution circuit or from the distribution circuit through the substation to higher voltage lines. Also called backfeed.

**Rule 14H**

The Hawaiian Electric Company rules governing service connections and facilities on a customer's premises.

**Rule 18**

The Hawaiian Electric Company rules governing Net Energy Metering.

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S

**Schedule Q**

The tariff structure that governs Hawaiian Electric purchases from qualifying facilities 100kW or less

**Scheduled Outage**

See Outage on page B-23.

**Secondary Lines**

Low voltage distribution lines directly serving customers.

**Service Charge**

A fixed customer charge intended to allocate the cost of servicing the grid to all customers, regardless of capacity needs.

**Service Level Issue**

Any issue arising at the point of service provision to customers, including traditional utility service and grounding transformer overloads caused by DG PV.

**Service Transformer**

A transformer that performs the final voltage step-down from the distribution circuit to levels usable by customers.

**Simple-Cycle Combustion Turbine (SCCT)**

A generating unit in which the combustion turbine operates in a stand-alone mode, without waste heat recovery.

**Single-Train Combined Cycle (STCC)**

See Combined Cycle on page B-5.

**Small Business Direct Load Control (SBDLC)**

A demand response programs that allows the electric utility to curtail load without intervention of an operator at the end user's (customer's) premises. For example, the utility may install a load control switch on an electric water heater or air-conditioning unit, so that the load can be controlled remotely by the utility during times of system need.

**Smart Grid**

A platform connecting grid hardware devices to smart grid applications, including VVO, AMI, Direct Load Control, and Electric Vehicle Charging.

**Smart Inverter Working Group (SIWG)**

A working group created by the California Public Utilities Commission to propose updates to the technical requirements of inverters.

**Spinning Reserve Service**

See Operating Reserves on page B-23.

**Standard Interconnection Agreement (SIA)**

Rules governing interconnection of distributed generation systems.

**Standby Charge**

A fixed charge intended to recover significant backup generation facilities the utility must maintain to ensure grid reliability in the event of widespread DG outages.

**Static VAR Compensator**

A device used provide reactive power in order to smooth voltage swings.

**Steady-State Conditions**

Conditions governing normal grid operations; contrasted with transient conditions.

**Steam Turbine (ST)**

A turbine that is powered by pressurized steam and provides rotary power for an electrical generator.

**Storage**

A system or a device capable of storing electrical energy to serve as an ancillary service resource on the utility system and/or to provide other energy services. Three major types of energy storage are relevant for consideration in Hawai'i:

**Battery:** An energy storage device composed of one or more electrolyte cells that stores chemical energy. A large-scale battery can provide a number of ancillary services, including frequency regulation, voltage support (dynamic reactive power supply), load following, and black start as well as providing energy services such as peak shaving, valley filling, and potentially energy arbitrage. Also referred to as Battery Energy Storage System (BESS).

**Flywheel:** A cylinder that spins at very high speeds, storing rotational kinetic energy. A flywheel can be combined with a device that operates either as an electric motor that accelerates the flywheel to store energy or as a generator that produces electricity from the energy stored in the flywheel. The faster the flywheel spins, the more energy it retains. Energy can be drawn off as needed by slowing the flywheel. A large flywheel plant can provide a number of ancillary services including frequency regulation, voltage support (dynamic reactive power supply), and potentially spinning reserve.

**Pumped Storage Hydro:** Pumped storage hydro facilities typically use off-peak electricity to pump water from a lower reservoir into one at a higher elevation storing potential energy. When the water stored in the upper reservoir is released, it is passed through hydraulic turbines to generate electricity. The off-peak electrical energy used to pump the water uphill can be stored indefinitely as gravitational energy in the upper reservoir. Thus, two reservoirs in combination can be used to store electrical energy for a long period of time, and in large quantities. A modern

pumped-storage facility can provide a number of ancillary services, such as frequency regulation, voltage support (dynamic reactive power), spinning and non-spinning reserve, load following and black start as well as energy services such as peak shaving and energy arbitrage.

**Sulfur Oxide (SO<sub>x</sub>)**

A precursor to sulfates and acidic depositions formed when fuel (oil or coal) containing sulfur is combusted. It is a regulated pollutant.

**Substation**

A small building or fenced in yard containing switches, transformers, and other equipment and structures for the purpose of stepping up or stepping down voltage, switching and monitoring transmission and distribution circuits, and other service functions. As electricity gets closer to where it is to be used, it goes through a substation where the voltage is lowered so it can be used by customers such as homes, schools, and factories.

**Substation Transformer**

Substation-sited transformers used to change voltage levels between transmission lines, or between transmission lines and distribution lines.

**Supervisory Control and Data Acquisition (SCADA)**

A system used for monitoring and control of remote equipment using communications networks.

**Supplemental Reserve Service**

See Operating Reserves on page B-23.

**Supply-Side Management**

Actions taken to ensure the generation, transmission, and distribution of energy are conducted efficiently. Supply-side generation includes generating plants that supply power into the electric grid.

**Switching Station**

An electrical substation, with a single voltage level, whose only functions are switching actions.

**Synchronous Condensers**

Devices used to modulate the voltage or power factor of transmission lines. Synchronous condensers typically provide dynamic reactive power support, and are deployed only where dynamic reactive power support needs to be maintained at a particular location.

**System**

The utility grid: a combination of generation, transmission, and distribution components.

**System Average Interruption Duration Index (SAIDI)**

The average outage duration for each customer served. A reliability indicator.

**System Average Interruption Frequency Index (SAIFI)**

The average number of interruptions that a utility customer would experience. A reliability indicator.

**System Reliability**

Broadly defined as the ability of the utility system to meet the demand of its customers while maintaining system stability. Reliability can be measured in terms of the number of hours that the system demand is met.

**System Security**

The ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

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**T****Tariff**

A published volume of rate schedules and general terms and conditions under which a product or service will be supplied.

**Thermal Loading**

The maximum current that a conductor can transfer without overheating.

**Time-of-Use (TOU) Rates**

The pricing of electricity based on the estimated cost of electricity during a particular time block. Time-of-use rates are usually divided into three or four time blocks per twenty-four hour period (on-peak, mid-peak, off-peak and sometimes super off-peak) and by seasons of the year (summer and winter). Real-time pricing differs from TOU rates in that it is based on actual (as opposed to forecasted) prices which may fluctuate many times a day and are weather-sensitive, rather than varying with a fixed schedule.

**Total Resource Cost (TRC)**

A method for measuring the net costs of a conservation, load management, or fuel substitution program as a resource option, based on the total costs of the program, including both the participants' and the utility's costs.

#### **Transformer**

A device used to change voltage levels to facilitate the transfer of power from the generating plant to the customer. A step-up transformer increases the voltage (power) of electricity while a step-down transformer decreases it.

#### **Transient Condition**

An aberrant grid condition that begins with an adverse event and ends with the return to steady-state conditions (stable voltage, connection of all loads).

#### **Transient Over Voltage (TrOV)**

A transient issue characterized by a sudden spike in voltage above steady-state conditions on a circuit, or on a subset or component of a circuit.

#### **Transmission and Distribution (T&D)**

Transmission lines are used for the bulk transfer of electric power across the power system, typically from generators to load centers. Distribution lines are used for transfer of electric power from the bulk power level to end-users and from distributed generators into the bulk power system. In the Hawaiian Electric Companies, standard transmission voltages are 138,000 volts (Hawaiian Electric system only) and 69,000 volts (Hawaiian Electric, Maui Electric, Hawai'i Electric Light). Distribution voltage is 23,000 volts (Maui Electric) and 13,200 volts (all systems).

#### **Transmission System**

The portion of the electric grid that transports bulk energy from generators to the distribution circuits.

#### **Two-Way Communications**

The platform and capabilities that are required to allow bi-directional communication between the utility and elements of the grid (including customer-sited advanced inverters), and control over key functions of those elements. The platform must contain monitor and control functions, be TCP/IP addressable, be compliant with IEC 61850, and provide cyber security at the transport and application layers as well as user and device authentication.

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### U

#### **Ultra Low Sulfur Diesel (ULSD)**

A diesel fuel that contains less than 15 parts per million of sulfur.

**Under Frequency Load Shedding (UFLS)**

A system protection scheme used during transient adverse conditions to balance load and generation.

**Under Voltage Load Shedding (UVLS)**

A system protection scheme used during low voltage conditions to avoid a voltage collapse.

**Under Voltage Violation**

Bus voltage less than 0.9 per unit.

**United States Department of Defense (DOD)**

An executive department of the U.S. government responsible for coordinating and supervising all agencies and functions of the Federal government that are concerned directly with national security and the armed forces.

**United States Department of Energy (DOE)**

An executive department of the U.S. government that is concerned with the United States' policies regarding energy, environmental, and nuclear challenges.

**United States Environmental Protection Agency (EPA)**

An executive department of the U.S. government whose mission is to protect human health and the environment.

**University of Hawai'i Economic Research Organization (UHERO)**

The economic research organization at the University of Hawai'i, which is a source for information about the people, environment, and Hawai'i and the Asia-Pacific economies, including energy issues.

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**V****Variable Renewable Energy**

A generator whose output varies with the availability of its primary energy resource, such as wind, the sun, and flowing water. The primary energy source cannot be controlled in the same manner as firm, conventional, fossil-fuel generators. Specifically, while a variable generator (without storage) can be dispatched down, its output cannot be guaranteed 100% of the time when needed. However, the primary energy source may be stored for future use, such as with solar thermal storage, or when converted into electricity via storage technologies. Also referred to as intermittent and as-available renewable energy.

## B. Glossary and Acronyms

### W

#### **Voltage**

Voltage is a measure of the electromotive force or electric pressure for moving electricity.

#### **Voltage Collapse**

The sudden and large decrease in the voltage that precipitates shutdown of the electrical system.

#### **Voltage Regulation**

A measure of change in the voltage magnitude between the sending and receiving end of a component, such as a transmission or distribution line.

#### **Voltage Regulator Controller**

A device used to monitor and regulate voltage levels.

#### **Volt/VAR control**

Control over voltage and reactive power levels.

#### **Volt/VAR Optimization (VVO)**

The process of monitoring voltages at customer premises through an AMI system, and optimizing them using reactive power control and voltage control capabilities.

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### W

#### **Watt**

The basic unit of measure of electric power, capacity, or demand. It is a derived unit of power in the International System of Units (SI), named after the Scottish engineer James Watt (1736–1819).



## C. Modeling Analyses Methods

Three teams conducted independent modeling analysis for produce the results presented in the PSIP. The teams included Hawaiian Electric Company generation planning, Black & Veatch, and PA Consulting. Each team employed a different modeling analysis method. In addition, Electric Power Systems employed a grid simulation model to conduct its system security studies.

Each of these four modeling methods are presented.

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### GRID SIMULATION MODEL FOR SYSTEM SECURITY ANALYSIS

The Transmission Planning Division of Hawaiian Electric Company uses the Siemens PSSE (Version 33) Power-Flow and Transient Stability program for transmission grid modeling and for system security analysis. This program is one of three most commonly used grid simulation programs in United States utilities. The program supports the IEEE (Institute of Electric and Electronic Engineer) generic models for generators and inverters. When available, custom models can preclude generic models.

PSSE is high-performance transmission planning software that has supported the power community with meticulous and comprehensive modeling capabilities for more than 40 years. The probabilistic analyses and advanced dynamics modeling capabilities included in PSSE provide transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks. PSSE is used for power system transmission analysis in over 115 countries worldwide.

The program has two distinct program models: (1) power flow to represent steady state conditions and (2) stability to represent transients caused by faults and rapid changes in

### **C. Modeling Analyses Methods**

Grid Simulation Model for System Security Analysis

generation. The transient conditions are modeled to about 10 seconds after which most system will stabilize or fail.

After major system disturbances, we use this program to verify the system events as well as to verify the modeling assumptions.

Input to this program includes impedances for all the transmission lines, transformers, and capacitors; detailed information of the electrical characteristics of all generators and inverters (including PV panels and wind turbines); and energy storage devices (such as batteries). The model includes relays for fault clearing and under-frequency load shedding (UFLS).

Electric Power Systems used the PSSE model to conduct its robust and detailed system security studies because the model allows rapid and consistent sharing of data.

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## HAWAIIAN ELECTRIC: P-MONTH MODELING ANALYSIS METHODS

The Companies used computer models for the PSIP analyses. Production costs of the operating the system is simulated using the P-Month hourly production simulation model. The model is populated with unit data to characterize the resources operating on the system at all hours so that the performance and cost of the system can be evaluated for various future cases. The data from the hourly production simulation model is processed using other internally developed tools to evaluate the results of the simulations.

### P-MONTH Hourly Production Simulation Model

#### Thermal Generation Modeling

The model, P-MONTH, is an hourly production simulation program supplied by the P Plus Corporation (PPC). This model simulates the chronological, hour-by-hour operation of the generation system by dispatching (mathematically allocating) the forecasted hourly load among the generating units in operation. Unit commitment and dispatch levels are based on fuel cost, transmission loss (or “penalty”) factors, and transmission system requirements. The load is dispatched by the model such that the overall fuel expense of the system is minimized (that is, “economic dispatch”) within the constraints of the system. The model calculates the fuel consumed using the unit dispatch described above, based on the load carried by each unit and the unit’s efficiency characteristics. The total fuel consumed is the summation of each unit’s hourly fuel consumption.

#### Variable Generation Modeling

The model calculates the energy produced by renewable resources and other variables using an 8760 hourly profile. This profile is constructed based on historical observed output from in service variable generation or from solar irradiance profiles and measured wind potential for future variable generation. Generation that is produced according to this hourly profile that cannot be accommodated on the system in any one hour will be curtailed per the curtailment order. The curtailment order follows a last in, first out rule whereby the last installed variable renewable resource will be curtailed first, that is, reverse chronological order.

#### Unit Forced Outage Modeling

The production simulation model can be used by applying one of two techniques: probabilistic or Monte Carlo. Using the probabilistic technique, the model will assume

## C. Modeling Analyses Methods

Hawaiian Electric: P-MONTH Modeling Analysis Methods

generating units are available to operate (when they are not on overhaul) at some given load that is determined by their normal top load rating and forced outage rate. By this methodology, the units will nearly always be available at a derated capacity that has been reduced to account for the forced outage rate.

PMONTH has a Monte Carlo Simulation option in which random draws are used to create multiple scenarios (iterations) to model the effect of random forced outages of generating units. Each scenario is simulated individually; the averages of the results for all the scenarios represent the expected system results. This Option provides the most accurate simulation of the power system operations if sufficient number of scenarios are used. However, the computer run time can be long if many scenarios are run. The number of scenarios needed to establish a certain level of confidence in the results depends on the objectives of the user and the size of the system. Normally, the system production cost will converge sufficiently between 20 and 30 iterations.

Using the Monte Carlo, or deterministic, technique, forced outages for generating units are treated as random, discrete outages in one week increments. The model will randomly take a generating unit out of service (during periods when it is available) up to a total forced outage time of 5%. By this methodology, the unit can operate at normal top load for 95% of the time when it is not on overhaul but will not be able to operate (that is, will have a zero output) for 5% of the time when it is not on overhaul. For the PSIP, the modeling will use the Monte Carlo methodology to capture the forced outages of all thermal units.

### Demand Response Modeling

Demand response programs were modeled to provide several benefits including capacity deferral and regulating reserve. Programs that provide capacity were included in the capacity planning criteria analysis assessment. Programs that provide regulating reserve ancillary services were included in the modeling.

### Energy Storage Modeling

The benefits of energy storage for system contingencies are captured in the system security modeling. Regulating reserves were provided by a combination of energy storage and thermal generation. Load shifting was modeled as a scheduled energy storage resource. The roundtrip efficiency was accounted for in the charging of this resource. The charging schedule was optimized to coincide with the hours in which curtailment occurred or the profile of PV energy during the day to minimize day time curtailment. The discharging schedule coincided with the evening peak.

## System Security Requirements

The system security requirements were met by including the regulating and contingency reserve capabilities of demand response, energy storage, and thermal generation in the modeling. The system security requirements depend on the levels of PV and wind on the system. The regulating reserve requirements were changed hourly in the model to reflect the dynamic changes in levels of PV and wind throughout the day. Curtailed energy from controllable PV and future wind resources contributed to meeting the regulating reserve requirement. The contingency reserve requirements were changed annually to reflect the largest unit contingency on the system.

## Sub-Hourly Model

The P-Month model is an hourly chronological model. Sub-hourly modeling cannot be done using this model. The Companies developed a limited sub-hourly model to assess the any value that the hourly model was not able to capture compared to the modeling sub-hourly when batteries, and other resources that operate like batteries, are on the system.

## Key Model Inputs

In addition to the system changes described in the Base Plan, there are several key assumptions that are required for modeling:

1. Energy and hourly load to be served by firm and non-firm generating units
2. Load carrying capability of each firm generating unit
3. Efficiency characteristics of each firm generating unit
4. Variable O&M costs
5. Operating constraints such as must-run units or minimum energy purchases from purchased power producers
6. Overhaul maintenance schedules for the generating units
7. Estimated forced outage rates and maintenance outage rates
8. Regulating reserve requirements
9. Demand response and energy storage resources
10. Fuel price forecasts for fuels used by generating units

### Methodology for Post-Processing of Production Simulation Results

#### Key Outputs

Some of the key outputs from the model are as follows:

1. Generation produced by each firm generation units
2. Generation accepted into the system by non-firm generating units
3. Excess energy not accepted into the system (curtailed energy)
4. Fuel consumption and fuel costs
5. Variable and fixed O&M costs
6. Start-up costs

#### Post-Processing

The outputs from the model are post-processed using Excel to incorporate the following:

1. Capital costs for new generating units, renewable and energy storage resources, allocated based on capital expenditure profiles
2. Capital costs for utility projects such as fuel conversions or the retirement of existing utility generating units
3. Payments to Independent Power Producers (IPP) for purchased power, including Feed in Tariff projects
4. Fixed O&M for future energy storage resources

All costs are post-processed into annual and total dollars to be used in the Financial Model. All annual, total, and present value (2015\$) revenue requirements are also post-processed for use in evaluating the different plans but are not meant to be the “all-in costs” that the Financial Model will be doing. Revenue requirements are characterized as utility and IPP. Utility revenue requirements are categorized into fuel, fixed O&M, variable O&M, and capital. IPP revenue requirements are categorized into capacity and energy payments. Using the revenue requirements from post-processing, plans can be analyzed according to several key metrics.

## Key Metrics

The key metrics analyzed through post processing of the model data are as follows:

1. Differential accumulated present value of annual revenue requirements
2. Differential rate impact
3. Monthly bill impact
4. Total system curtailment
5. Renewable Portfolio Standards (RPS)
6. Gas consumption
7. Utility CO<sub>2</sub> emissions
8. Annual Generation Mix
9. Daily Generation Mix by Hour

## Lana'i & Moloka'i Modeling

The model used in the analysis for Lana'i and Moloka'i is an Excel based model focusing on meeting the total sales (energy) forecasted for each year. In this way the amount of energy produced from each resource was assumed to be taken regardless of any profiles. This simplified model shows results that are directionally correct.

The model calculations are broken up into three pieces: existing power purchase agreements, future renewable resources, and utility generation. First, it is assumed that the utility generation will provide a minimum amount of generation for system reliability. Second, the existing power purchase agreements fill in additional energy based on historical purchases. Lastly, future resources can be added to get as close to the total sales as possible. If the total energy provided by the three pieces is less than forecasted sales for a particular year, the utility generation will increase to make up the difference. If the total energy is greater than forecasted sales then the excess is curtailed from newly added resources.

The model will track all costs associated with fuel expense, O&M, capital, and power purchased payments to give annual revenue requirements and total net present value (NPV) consistent with the analysis for the other islands. Similarly, the model will also calculate the Renewable Portfolio Standards (RPS) percent for each year of the plan.

The utility generation component allows for different fuels to be assigned to the units as well as splitting the fuel types as necessary. Fuel usage and associated costs are calculated for each year.

### **C. Modeling Analyses Methods**

Hawaiian Electric: P-MONTH Modeling Analysis Methods

Future renewable resources are identified by the year of installation as well as ownership (for example, utility or IPP). Resource ownership determines the capital expenditures patterns. Either a levelized profile or a declining profile to match company revenue requirements is used in the analysis. Costs for O&M and applicable fuel costs for each year are calculated for the new resources.





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## PA CONSULTING: PRODUCTION COST MODELING

PA Consulting Group (PA) performed hourly and sub-hourly production cost modeling to support the Hawaiian Electric Companies' development of the PSIPs. The production cost modeling was conducted using the EPIS AURORA<sup>xmp</sup> software. AURORA is an hourly chronological dispatch model used to model electricity markets. The model has broad capabilities. The primary forecasting capabilities that we used in the model are least cost dispatch and long-term capacity expansion modeling.

The capacity expansion model is an optimization model that determines the most cost effective long-term generation expansion and retirement schedules, based upon assumptions regarding capital costs, operating costs, and operational constraints, as well as system constraints such as reserve margins and spin requirements. The most cost effective plan is based upon the solution with the lowest net present value.

The chronological dispatch model determines the least-cost solution for dispatching resources, including demand side resources, to meet load and reserve margin requirements. The dispatch solution honors individual generator constraints and factors in marginal dispatch costs, including fuel and O&M. Each resource is modeled individually, taking into account the unit-specific cost and operating characteristics. Units are dispatched in the simulation in the order of economic merit (according to dispatch cost) until adequate generation is brought on line to meet the load. The model factors in out-of-merit dispatch due to must-run and must-take requirements. The model also curtails resources if the constrained generation exceeds demand.

The sub-hourly modeling was structured to address the Commission's interest in utilizing sub-hourly modeling to more fully investigate issues raised in the April 28th D&Os. These issues include evaluation of the value of DR and DG in the context of the Company's vision for the future of the utility, and consideration of resources required to support the integration of more intermittent renewable generation resources, and to reduce curtailments where it is economic to do so.

Specifically, PA used the sub-hourly modeling to identify any periods with unserved energy or periods with significant potential for renewable energy curtailment. We evaluated whether changing the resource mix can cost effectively address these issues. This assessment was conducted using iterative analyses to identify whether changing the available resource mix will reduce curtailment or dispatch costs.

AURORA was used to both evaluate a least-cost capacity expansion and retirement plan, and also to model scenarios of alternative resource plans in order to identify the incremental costs associated with alternative policies.

## C. Modeling Analyses Methods

PA Consulting: Production Cost Modeling

### Key Inputs

PA worked with Hawaiian Electric Resource Planning and Black & Veatch to develop a common set of assumptions for the modeling initiative. These assumptions include:

- Resource characteristics (such as capacity, heat rates, ramp rates, minimum-up times, and minimum-down times)
- Characteristics of demand response programs
- Fuel costs
- Types of fuel that each fossil generator will use
- Identification of timing and generators that would be converted to burn LNG
- Fixed and variable operating costs
- Capital costs necessary to extend the life of existing generation
- Costs for new generation technologies (capital and operating)
- Availability of new generation resources (timing and capacities)
- System load forecasts
- Production profiles for variable energy resources.

### Hourly Production Cost Modeling

Generation and demand side resources are dispatched to serve the system load. The base case simulations reflect the current configuration in which each island is a stand-alone system.<sup>1</sup> Units with low operating costs relative to other facilities are dispatched often; units with high costs are dispatched less frequently. The hourly dispatch logic is based upon short-run marginal generation costs, which include: fuel costs, variable operating costs, start-up costs, and emission costs. In contrast, the long-term retirement and expansion plan considers all costs rather than just marginal costs. The additional costs in the long run optimization include fixed O&M costs and capital costs.

The hour-by-hour interaction of supply and demand determines how frequently plants are dispatched within a market. The model incorporates logic for a variety of constraints that are incorporated into the least-cost dispatch logic. These constraints include: must-run requirements, minimum load requirements, ramp times, minimum uptimes, and minimum downtimes. The model also includes planned maintenance schedules and forced outage rates. The determination of the least-cost dispatch, subject to constraints, is based upon the model, assuming perfect information about future hourly loads.

PA used an iterative process to develop the preferred PSIP for each island. Our first step was to represent the existing systems within the model and develop simulations for the

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<sup>1</sup> A case was run with a 200 MW DC transmission cable connecting the islands of O'ahu and Maui.

first two years. We used these simulations to calibrate the models to reasonably represent how the current power systems dispatch and to capture the current generation operating costs, fuel costs, and purchase power agreements. We then used the optimization model to develop a least cost base case that factored in constraints related to committed generation retirements, assumptions about future levels of distributed generation, and availability of new generation resources. In the third stage of our analysis we tested alternative scenarios to examine the incremental costs of alternative power supply plans. The analysis in the third stage was based upon modeling specific scenarios over the 2015–2030 time horizon and did not use the long-term resource optimization feature.

## Sub-Hourly Production Cost Modeling

The purpose of the sub-hourly modeling was to gain insights regarding ramp constraints, identify potential issues with large amounts of variable supply resources, and identify the potential value of fast response resources, including demand response resources. We use sub-hourly modeling to identify any periods with unserved energy or high frequency, and amounts of renewable energy curtailment. We then assess whether changing the resource mix can cost effectively address these issues.

The sub-hourly modeling was conducted with the previously described production cost model. In order to develop the sub-hourly analysis, it was necessary to convert all the hourly generation and variable supply resource profiles into five-minute profiles. We did not change any assumptions about fuel costs or generator constraints. A brief description of the process for developing the five-minute profiles follows.

We started with available one-minute historic net load profiles, wind production profiles, and solar production profiles. We developed a one-minute gross load profile from the one-minute profiles into five-minute profiles using averages of the five-minute periods. In instances where we did not have sub-hourly data, such as for hydro generation, we assumed that the generation was constant over the one hour period.

PA modeled four days per month at the five-minute level, rather than every day, due to the large amounts of data associated with five-minute modeling. The four representative days included a mid-week weekday (Monday–Thursday), a Friday, and each week-end day.

An overview of PA’s sub-hourly modeling methodology follows. This modeling will be conducted at the five-minute intervals.

### I. Development of Sub-Hour Modeling Assumptions and Data Inputs

We based inputs to the sub-hourly model on the assumptions agreed upon for the hourly model (fuel costs, generator characteristics, and load forecast) and on one-minute data.

## C. Modeling Analyses Methods

PA Consulting: Production Cost Modeling

The one-minute data include historic net load profiles, wind production profiles, and solar production profiles. In addition, PA incorporated input from parallel tasks related to development of DG and DR unit characteristics and cost options, as well as how that analysis should be integrated into the sub-hourly chronological dispatch modeling. PA closely coordinated these efforts with the company to ensure that the modeling assumptions and scenarios modeled are consistent with the Company's strategic vision.

### 2. Translation of Hourly Model Assumptions/Inputs to Five-minute Data

The vast majority of assumptions and inputs used for hourly modeling were used directly in the 5-minute modeling. These include fuel costs, resource capacities and efficiencies, and resource variable operating costs, as well as system operating reserve requirements. In some cases, dynamic information such as resource ramp rates and other time dependent assumptions were adjusted to correspond to the five-minute modeling interval, so that the inputs were correctly incorporated in to the model's economic dispatch algorithms.

### 3. Development of Five-minute Profiles for Modeling Inputs

We converted renewable generation production profiles from one-minute to five-minute data, and converted the hourly load forecasts to five-minute profiles using the historic one minute load profiles. The conversion ensured consistency between the hourly, one-minute, and five-minute data sets.

**Renewable Generation Profiles.** Five-minute profiles for wind and solar were constructed from available one-minute data. PA analyzed the one-minute data to develop representative five-minute shapes for typical days in each month. The representative five-minute shapes were not limited to simple averages of one-minute renewable output levels across days, but were structured to represent the extent of variation that exists at the one minute level. There was only one one-minute wind and solar profile per island so all solar and wind resources on each island used the common wind / solar profile. The capacity of the individual units were adjusted so that over a year the total production matched each unit's characteristics.

**Load Shape and Distributed Generation Profiles.** The derivation of the five-minute load shape profiles required a different analysis, since existing load data reflect behind-the-meter generation. Given time limitations, PA utilize an Excel-based model to construct five-minute load shapes for future years. Future load shapes were based on the current five-minute system load shape and the hourly load forecasts. PA used the five-minute PV production shape and penetration estimates for behind-the-meter solar to allocate the hourly loads into five-minute blocks representing gross system loads (without behind-the-meter generation) and net system loads for future years.

#### 4. Sub-Hourly Model Development and Calibration

PA modeled four days per month at the five-minute level. We did not model all days due to the large amount of data at the five-minute level, and array limitations in the AURORAxmp software. The four representative days included a mid-week weekday (Monday–Thursday), a Friday, and each week-end day. Depending on model run-times and post processing efforts, PA either weighted the midweek day to represent four days, or performed additional simulations to capture a typical week per month to facilitate developing aggregate annual results.

PA developed and validated sub-hourly generation dispatch models for the Maui, O’ahu, and Hawai’i Island systems. Since AURORAxmp is currently configured for hourly modeling, PA had to adjust input parameters to facilitate five-minute modeling. PA adjusted input parameters so that each standard Aurora model hour is interpreted as a five-minute period. Hence, each representative day consisted of 288 standard Aurora model hours. Each representative day was modeled independently, and the standard Aurora model hourly output was aggregated through post processing to produce results for the day.

PA conducted a calibration exercise to verify that the model results made sense in the context of the sub-hourly modeling. We also verified that the sub-hourly modeling results are logical and reasonable, based upon PA’s expertise and based upon consultation with generation planning and generation operations staff expertise within the Company. After the results were validated for each system, PA executed simulations of the representative, P5, and P95 cases for each system. Annual system costs and performance metrics were calculated for each set of system conditions.

The simulations provided insights into the resource requirements necessary to meet load requirements with a mix of intermittent and non-intermittent resources. PA used the hourly simulations to capture the full capital and fixed operating costs for the purposes of estimating the total generation system operating costs at the annual level.

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### BLACK & VEATCH: ADAPTIVE PLANNING MODEL

Black & Veatch is applying its Adaptive Planning Framework to support the PSIP. Adaptive planning provides a framework for modeling complex systems, exploring options (and impacts of constraints), and comparing such options across varying metrics. Key metrics or outcomes would be costs, annual capital commitment required, degree of renewable penetration (capacity, energy served), and system reliability.

The Adaptive Planning Framework manages the overall calculation and cost accounting process. PSIP-specific requirements will be directly addressed by configuring the model:

- Dispatch methodology defined by collective Hawaiian Electric team, based on legal mandates, operational protocols, and defined reserve margins.
- Dispatch models and algorithms tailored to address system constraints (safety, security), loading or ramping criteria defined by Hawaiian Electric by asset class, battery charge, and discharge protocols by size and class of battery, among others.
- Repair times by asset class for projected failures and scheduled outages.
- Full cost accounting of all power supply elements by asset class, nature of cost, and other factors.

Different solution approaches can be applied in adaptive planning. As configured for this plan, the dispatch and economic models do not optimize capacity additions directly, as we believe that there are number of factors and complexities that dictate technology strategies and paths that need to be “engineered”. We have, rather, focused on leveraging the model to evaluate alternate technology and capacity plans, including the adequacy of these plans to meet reserve margin or cause curtailment.

For this particular problem, given the complexity, the number of constraints, and the need to consider system security and reliability thresholds in each period, we have elected to apply the following:

- In concert with Hawaiian Electric and PA Consulting, define the general characteristics of base “path” based on central strategy and glide-path analysis. This will define some key initial assumptions regarding technology choice, timing, and retirements.
- Based on this analysis, the B&V team will then define alternative technology mixes or paths that need to be investigated; the focus would be to improve economics, flexibility, grid resiliency, or other factors based on our assessment of year-to-year unit commitment and dispatch data; this effort will also directly explore roles and penetration of battery assets over time.

- The team will generate sensitivities for each path (base and alternative) to stress test results; key variables that can be considered would be aggregate demand by system, the amount of spinning reserves over time (by year coincident with asset mix and by hour to address night-time or off-peak versus peak requirements), timing of capital investments, technology flips (battery versus pumped storage, battery versus thermal for contingency, etc.), timing of retirements, etc.

We believe that this approach maximizes our ability to provide visibility into results and key assumptions, as needed to define optimal PSIP path. It will also allow for direct comparison of decisions and timing that will be critical for Hawaiian Electric in subsequent steps to refine financial engineering of overall rates. Given the short time frame of this study, we do not plan on directly integrating a regulatory or rate model with AP framework, but would work with Hawaiian Electric to apply results of our work within existing spreadsheet models to enable analysis of investment requirements and the nature of investments over the evaluation period.

Economic results will be driven, in part, by market forecasts for fuel (oil, LNG, etc.). The Black & Veatch framework provides robust scenario analysis that will be applied in this case to evaluate:

- Mix and timing of renewable and energy storage assets
- Timing of retirements
- Timing and nature of new generation additions
- Timing and nature of participation from IPPs
- System characteristics
- Reliability risk based on level of investment and intensity of asset type
- Alternate views of costs including market price of fuel, the cost of implementing technology, etc., as needed to address increasingly higher degree of renewable penetration over time.

Economics can be applied in different forms within the model. We can consider:

- Direct capital investment in year of investments driven by project S-curves.
- Levelized costs based on spread of CAPEX and other related costs into an equivalent annual annuity.
- RRF schedule. Capital can be spread and factors can be assigned based on RRF input schedules.
- Third-party contract (IPP, DR, etc.) where the energy or service can be contracted on \$/MWh, \$/MW, or combination.

### C. Modeling Analyses Methods

Black & Veatch: Adaptive Planning Model

Model outputs will be populated within spreadsheets and data viewers to enable direct analysis and comparison (between cases) of:

- Period values by asset; periods can be either 1-hour or 5-minute for PSIP. We will also consider a smaller segment of 1-minute data to test impacts on wind and solar dispatch and spin. Detailed results would include dispatch MW, costs (capital, VOM, FOM), contribution to renewable, and role (contingency, regulation, energy, etc.)
- Aggregated results by asset; basically the same output as available for the period would be available for the asset by year and overall.
- Typical “daily” or 24-hour view; this view would analyze data for each asset by hour in day resulting from dispatch by asset by year. This will allow us to validate the overall dispatch approach, as well as better characterize roles of units. Values calculated would include average, min, max, and standard deviation. This will provide insights into rationale for IPP energy supply schedules for assets that are not anticipated to be owned by Hawaiian Electric.

#### Time Slice Model within Adaptive Planning Framework.

At the heart of the Adaptive Planning framework is a direct solution mathematical framework that enables direct analysis and “integration” of asset performance and aggregate match of resources to demand (as depicted in the figure below) contribution by asset, aggregate reliability, and costs.

#### “CORE” MATH/PLANNING FRAMEWORK

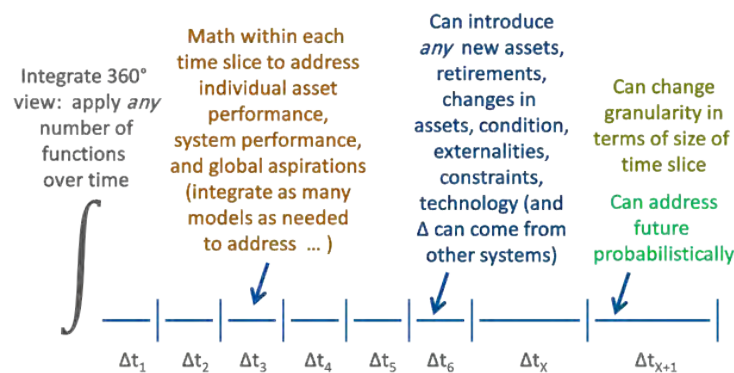


Figure C-1. Black & Veatch Mathematical Modeling Framework

Within the framework, each time slice affords the opportunity for us to:

- Introduce new assets, retire assets, change characteristics (simulate planned outages, etc.).
- Commit assets based on availability, renewable and non-renewable, and economics.



- Incorporate assumptions for wind and solar variability for that particular time slice based on perturbations of the historical wind and solar patterns.
- Incorporate rules for utilizing DG as must-take resource versus curtailable resource.
- Dispatch assets based on protocol and security, and economics including use of DR and energy storage to address ramping or smoothing, forced outages of committed assets, etc.
- Identify boundary conditions (from time slice to time slice) that serve as the basis for evaluating the next time slice; there are a number of instances where actions (such as a start of a 10-minute or 30-minute reserve resource within a particular time slice) will require forward commitment across time slices.

The time slice model works in conjunction with the economic dispatch model to evaluate the situation in the current period and translate this information to subsequent affected time slices. Each time slice considers (takes as input) for each power source:

- Status (available, scheduled outage, forced outage, retired, etc.)
- Operating efficiency
- Fuel characteristics (if applicable)
- Consumable unit costs
- Revenue requirements for capital expenditure

Each time slice also considers demand, adjusted for DR load shaping programs and, as applicable, DG PV. With this information, the time slice model determines:

- Status applicable to next time slice
- Consumable requirements
- Operating costs

The information generated is available at the time-slice or less granular resolution, for example, hourly, monthly, or annually. In addition, the asset hierarchy allows data to be viewed for each power source or aggregated across sources. Capital costs and other outputs associated with those investments would be tabulated by calendar year or other time domain, as required.

## Generation Dispatch Methodology

The dispatch model will be used to set the electrical generation outputs to satisfy the electrical demand at the lowest cost while also satisfying system constraints (constrained optimization). These constraints will include system stability (must-run units), minimum downtime and uptime constraints, spinning and non-spinning reserve margin

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requirements, and non-dispatchable renewable generation. The model will use the following data:

- Variable costs and start-up costs for electrical generation assets
- Ramp rates, minimum downtime, and minimum uptime for electrical generation assets
- Historical reliability and maintainability (MTBF, MTTR) data for all generation assets
- Solar and wind penetration forecast (by time step resolution)
- Solar and wind forecasts (by time step resolution)
- Demand forecasts (by time step resolution)
- System losses

Demand response will be factored into this model via two forms: 1) change in overall “demand” curve as influenced by time-of-day pricing and 2) modeling of specific DR programs.

Energy storage is applied as a resource to supply capacity, regulation, contingency, and other ancillary services associated with frequency response and security. Energy storage added to supply capacity, regulation, or contingency will be modeled via the dispatch model; energy storage added to frequency response will be considered as a cost component of the overall system.

### Sub-Hourly Model

Traditional hourly modeling does not expose the operational transients that must be managed during real-time operation of the electric grid. Hence, traditional hourly modeling also does not expose potential value (economic and risk mitigation value, for example) that one set of assets may have over another set of assets, as all transients are softened. Sub-hourly modeling will expose some of this value to support the optimum resource selection that does not violate policy considerations (risk tolerance, renewable goals, budget constraints, fuel diversity, etc.)

Similar to an hourly modeling approach, the sub-hourly model will calculate both commitment (what units are generating power) and dispatch (MW contribution of each asset to the target load) but now at a sub-hourly time step. Maximum daily rate of change will be greater and ramp rate constraints will be hit more often, thereby potentially changing the economic outcome of the simulation as compared to the hourly model. The hourly model assumes dispatch and commitment set points that do not violate any constraints when the time step is one hour, but when the truer transient nature is exposed at the sub-hourly time step, some otherwise masked constraints will likely become controlling.

The sub-hourly model (5 minute time step) will perform a constrained optimization for both asset commitment and asset dispatch against a sub-hourly desired load that utilizes both near term (next few time steps ahead) and intermediate term (out to the largest minimum down time of committed assets) load forecasts. The assets considered include generation (dispatchable and non-dispatchable), demand response, and energy storage. Each asset will have two primary states: available or unavailable. Each unavailable state may have sub-states—for example, scheduled versus unscheduled outage. Each asset will also have a series of constraints or attributes:

- Maximum output (or curtailment)
- Minimum output (or curtailment)
- Ramp up constraint
- Ramp down constraint
- Minimum run time
- Minimum down time
- Maximum run time curve as a function of operating state (energy storage, demand response, emission limits, fuel availability, etc.)
- Time between failures
- Time to restore
- Planned outages
- Startup cost
- Variable cost curve as a function of MW (input/output curve, heat rate curve, O&M, fuel forecast)
- Fixed costs (for annual cost calculations)

There are also system constraints that must be met. These include:

- Spinning reserve requirements (incorporating energy storage and demand response options)
- Grid stability requirements, including must-run units (constraints will be rules-based, as power flow modeling is not envisioned as feasible within the project time constraints)
- Policy constraints (power quality, reliability targets, risk tolerance)

The sub-hourly model will change the state of each asset to optimize the economics within the bounds of the model constraints. Accounting routines will keep track of asset performance (\$, MWh, number of starts) and system performance (unserved load, curtailed generation, \$, MWh). We envision sensitivities where selected constraints are

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relaxed and where the load forecast is modified. This will help test the robustness of the plan.

The modeling approach defined above is ideally suited to evaluating, comparing, and contrasting differing strategies regarding the mix of fossil generation, utility renewables versus energy storage, distributed generation versus energy storage, and demand response options. Based on the supply options provided, the model will determine the low-cost means for meeting the required load and base constraints. These constraints can be modified to evaluate other policy considerations (such as greater renewable penetration) that may move the solution away from optimal.

## D. System Security Standards

The Hawaiian Electric Company contracted with Electric Power Systems and its two senior project engineers, David A Meyer and David W Burlingame, to conduct a system security and stability study and analysis of the Maui Electric power grid.

Herewith is a discussion of the study and its resultant effects for system security on the Maui Electric power grid.

Boundary conditions were established for the expected generation scenarios for the years 2015, 2016, 2017, 2023, and 2030. These years were chosen due to the large changes that occur during this time period, including additions of renewable energy (2015, 2016, 2017), peak load (2023), and additions of new generation units and changes in system loads (2030). The boundary conditions were identified by configuring the generation dispatches to stress the system to determine the stability and contingency reserve requirements for the system.

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## METHODOLOGY

The reduction in system inertia and system response due to displacement of conventional generation units by variable energy will result in a less robust power system. This can potentially increase the amount of stages of the Under Frequency Load Shed system (UFLS) that will activate for unit trips and result in lower critical clearing times for all transmission and subtransmission faults.

### System Improvement Assumptions

It is assumed that dual primary, communications assisted relaying is installed on all Maui Electric 69 kV and 23 kV circuits and all N-1 faults are cleared in less than 9 cycles.

The extreme variation in feeder loading during daytime and nighttime conditions require an adaptive relaying scheme for the under frequency load shedding system. This system is assumed to be in service in 2017. Due to the requirements of the under frequency load shed scheme, SCADA control of all distribution circuits will be required for the new system. It is assumed that SCADA control will be establish to all substations by 2017.

Control of all distributed generation (DG) PV is assumed in 2017. Control of DG would allow the curtailed PV to provide 10-minute reserves to replace regulation reserves used to counter ramping of the variable generation.

### PV Assumptions

It was assumed that only 10 MW of the total DG installed would utilize legacy trip settings for voltage and frequency. The remaining PV was assumed to have extended ride through characteristics allowing the PV to remain online during system contingencies. The settings used for the legacy and extended PV capability are shown below in Table D-1.

| PV Type  | Protection Type |       | Settings 1          |               | Settings 2          |               |
|----------|-----------------|-------|---------------------|---------------|---------------------|---------------|
|          |                 |       | Set Point<br>(Hz or | Time<br>(sec) | Set Point<br>(Hz or | Time<br>(sec) |
| Legacy   | Voltage         | Over  | 1.10                | 0.99          | 1.2                 | 0.157         |
|          |                 | Under | 0.88                | 1.99          | 0.5                 | 0.157         |
|          | Frequency       | Over  | 60.5                | 0.157         | -                   | -             |
|          |                 | Under | 59.3                | 0.157         | -                   | -             |
| Extended | Voltage         | Over  | 1.10                | 0.99          | 1.2                 | 0.157         |
|          |                 | Under | 0.88                | 1.99          | 0.5                 | 0.49          |
|          | Frequency       | Over  | 63                  | 19.99         | -                   | -             |
|          |                 | Under | 57                  | 19.99         | -                   | -             |

Table D-1. PV Settings

## D. System Security Standards

### Methodology

It is important to note that the legacy PV has an under frequency trip setting of 59.3 Hz and a relay time of 0.157 seconds. Based on these settings, an under frequency event is likely to result in tripping of the legacy PV, further depressing system frequency following its tripping. The legacy PV also trips on over frequency at 60.5 Hz also in 0.157 seconds. The loss of legacy PV following a transmission fault will decrease system security. The extended PV settings have an under frequency set point of 57.0 Hz and a relay time of 20 seconds, resulting in minimal PV tripping during under frequency events.

## Criteria

The criteria for the system security studies are based on Maui Electric's adopted planning document TPL-001. The planning document outlines the transmission and generation contingencies and the acceptable performance of the system.

The generation planning criteria BAL-502 also contains required characteristics of future energy resources that were used in the system studies.

The overriding criteria used for the analysis was that the system should not activate more than the Stage 1 of the UFLS system during single unit outages, loss of a wind farm or PV source. Stage 1 currently results in the loss of customers that is acceptable to the planning criteria in TPL-001. The settings used for the existing UFLS system are shown below in Table D-2.

| UFLS Stage | Set Point (Hz) | Intentional Delay (Sec) | Breaker Time (sec) |
|------------|----------------|-------------------------|--------------------|
| Stage 1    | 58.7           | 0.000                   | 0.083              |
| Stage 2    | 58.5           | 0.000                   | 0.083              |
| Stage 3    | 58             | 0.000                   | 0.083              |

Table D-2. UFLS Settings

## Contingency Reserves Analysis

The replacement of traditional generation with variable generation will require additional contingency reserves. Energy Storage Systems (ESS) were added to the system provide system stability and meet the performance requirements of TPL-001.

During analysis, if the simulation resulted in a frequency below 58.7 Hz for a single contingency event, the contingency reserves were increased in 5 MW increments until the frequency stayed above 58.7 Hz. The amount of contingency reserves that just prevented the Stage 2 of UFLS is defined as the minimum level of contingency reserves for the system.

## Contingencies

Contingencies of major 69 kV lines with 5 cycle clearing times were utilized to verify system stability for each generation configuration. Unit outages consisted of the larger Maui Electric units or a single contingency wind farm line or transformer. These contingencies were used to identify the level of contingency reserves required to meet the reliability standards set forth in TPL-001. A list of contingencies used for the study is shown below in Table D-3.

|            | Disturbance      | From Bus | To Bus | 'ID' | Clearing Time (Cycles) |
|------------|------------------|----------|--------|------|------------------------|
| Unit Trips | MPP 14           | 301      | -      | 1    | -                      |
|            | MPP 10           | 108      | -      | 0    | -                      |
|            | MPP 16           | 302      | -      | 2    | -                      |
|            | HC&S             | 804      | -      | 4    | -                      |
|            | MPP 15           | 303      | -      | 3    | -                      |
|            | AWF              | 90991    | -      | S3   | -                      |
|            | KWP              | 90971    | -      | 1    | -                      |
| Faults     | Kanaha_6923      | 602      | 202    | 4    | 7                      |
|            | Puunene_6923     | 4002     | 4      | 1    | 7                      |
|            | Waiinu_6923      | 636      | 236    | 1    | 7                      |
|            | Maa-Lahaluna     | 39       | 97     | 2    | 5                      |
|            | Maa-KWP          | 39       | 636    | 1    | 5                      |
|            | Maa-Kihei        | 39       | 35     | 1    | 5                      |
|            | Kanaha-Puunene   | 602      | 401    | 1    | 5                      |
|            | Lahaina-Lahaluna | 34       | 84     | 1    | 5                      |

Table D-3. Contingencies

## Load and PV Levels

The forecast load growth increases from current peak load levels near 200 MW to 218 MW in 2023, and decreasing through 2030 to 206 MW. DG connected to the system is projected to increase through the years with 130 MW projected in 2030. Table D-4 shows the projected load and DG levels for this study.

|                  | Minimum | Day Minimum | Day Peak | Evening Peak |
|------------------|---------|-------------|----------|--------------|
| 2015 Load Levels | 86.3    | 135.3       | 183.6    | 195.4        |
| 2016 Load Levels | 87.3    | 138.7       | 186.1    | 197.7        |
| 2017 Load Levels | 90.7    | 142.7       | 191.3    | 203.7        |
| 2023 Load Levels | 97.2    | 154.0       | 205.6    | 218.5        |
| 2030 Load Levels | 91.8    | 148.5       | 195.1    | 206.3        |

|             | Nameplate Capacity | Sunny (MW) | Cloudy (MW) |
|-------------|--------------------|------------|-------------|
| 2015 PV Gen | 75.0               | 63.8       | 7.5         |
| 2016 PV Gen | 90.0               | 76.5       | 9.0         |
| 2017 PV Gen | 96.0               | 81.6       | 9.6         |
| 2023 PV Gen | 116.0              | 98.6       | 11.6        |
| 2030 PV Gen | 130.0              | 110.5      | 13.0        |

Table D-4. Maui Electric Load and PV Levels

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## YEAR 2015 ANALYSIS

Power flow cases were created for the day minimum and day peak load times. The day minimum cases assumed a load of 135 MW, with renewable generation resources consisting of 75 MW of distributed PV (12 MW legacy PV) and 72 MW of wind. The day peak cases assumed a load of 183 MW.

The assumptions used for the 2015 cases are listed below:

- These cases assume that 12 MW of PV has legacy trip settings (59.3 Hz/ 60.5 Hz), all other PV has extended ride through
- KPP 3, KPP 4, DTCC1 are baseloaded. Sensitivity cases were run with ½ DTCC2 baseloaded
- Existing protection clearing times were used
- No curtailment of DG resources

### 2015 Generation Dispatches

Prior to the correction of the PV trip settings, the loss of 12 MW of PV during an under frequency event results in the worst case scenario for the system. Consequently, only the daytime cases were run for the 2015. For line fault contingencies, it is critical that only 12 MW of PV utilize the 60.5 Hz trip setting. With DTCC1, KPP 3, KPP 4 online, the wind must be curtailed for the daytime minimum cases. Details of the generation dispatches for the 2015 study year are shown in Table D-5.

| 2015            |                            |       |       |       |                         |       |       |       |
|-----------------|----------------------------|-------|-------|-------|-------------------------|-------|-------|-------|
|                 | Daytime Minimum Load Level |       |       |       | Daytime Peak Load Level |       |       |       |
| Wind Level      | Windy                      | Windy | Calm  | Calm  | Windy                   | Windy | Calm  | Calm  |
| Solar Gen (Cap) | 75.0                       | 75.0  | 75.0  | 75.0  | 75.0                    | 75.0  | 75.0  | 75.0  |
| Curtailed Solar | 0.0                        | 0.0   | 0.0   | 0.0   | 0.0                     | 0.0   | 0.0   | 0.0   |
| Solar Gen (MW)  | 63.8                       | 7.5   | 63.8  | 7.5   | 63.8                    | 7.5   | 63.8  | 7.5   |
| KPP 1           |                            |       |       |       |                         |       |       |       |
| KPP 2           |                            |       |       |       |                         |       |       |       |
| KPP 3           | 7.0                        | 8.0   | 8.0   | 11.0  | 7.5                     | 8.0   | 10.0  | 11.0  |
| KPP 4           | 7.0                        | 8.0   | 8.0   | 11.0  | 7.5                     | 8.0   | 10.0  | 11.0  |
| MPP 14          | 18.0                       | 17.5  | 17.0  | 16.5  | 17.0                    | 18.0  | 16.0  | 19.8  |
| MPP 15          | 8.0                        | 7.7   | 8.0   | 11.5  | 7.5                     | 8.0   | 8.0   | 13.0  |
| MPP 16          | 18.0                       | 17.5  | 17.0  | 16.8  | 17.0                    | 18.0  | 16.2  | 20.0  |
| MPP 17          |                            |       |       | 18.0  |                         | 17.0  | 19.0  | 19.5  |
| MPP 18          |                            |       |       | 11.5  |                         | 6.0   | 9.0   | 10.5  |
| MPP 19          |                            |       |       | 18.0  |                         |       | 19.0  | 19.5  |
| HC&S            | 11.0                       | 9.0   | 11.0  | 12.0  | 11.0                    | 11.0  | 10.0  | 11.0  |
| MPP 10          |                            |       |       |       |                         | 10.0  |       | 12.0  |
| MPP 11          |                            |       |       |       |                         |       |       | 11.5  |
| MPP 12          |                            |       |       |       |                         |       |       | 11.0  |
| MPP 13          |                            |       |       |       |                         |       |       |       |
| Wind Total      | 0.0                        | 60.0  | 0.0   | 0.0   | 51.0                    | 72.0  | 0.0   | 0.0   |
| Load            | 132.8                      | 135.2 | 132.8 | 133.8 | 182.3                   | 183.5 | 181.0 | 182.8 |
| Reg Up          | 19.0                       | 20.3  | 19.0  | 17.5  | 20.5                    | 23.6  | 23.6  | 8.0   |
| Reg Down        | 21.0                       | 19.7  | 21.0  | 36.5  | 19.5                    | 29.6  | 24.4  | 60.1  |

Table D-5. 2015 Dispatch Cases KPP 3, KPP 4, DTCCI Baseloaded

## 2015 Results

The minimum frequency results are shown in Table D-6 for the 2015 cases.

|                  | Day Min |         |         |         | Day Peak |         |         |         |
|------------------|---------|---------|---------|---------|----------|---------|---------|---------|
|                  | wnd_sun | wnd_cld | clm_sun | clm_cld | wnd_sun  | wnd_cld | clm_sun | clm_cld |
| Outage           | Min     | Min     | Min     | Min     | Min      | Min     | Min     | Min     |
| M14              | 58.3    | 59.4    | 59.4    | 59.5    | 59.4     | 59.5    | 59.6    | 59.6    |
| MGS10            |         |         |         |         |          | 59.7    |         | 59.7    |
| M16              | 58.4    | 59.4    | 59.4    | 59.5    | 59.5     | 59.5    | 59.5    | 59.5    |
| HC&S             | 59.6    | 59.7    | 59.6    | 59.6    | 59.6     | 59.7    | 59.7    | 59.7    |
| M15              | 59.7    | 59.8    | 59.7    | 59.7    | 59.8     | 59.8    | 59.8    | 59.7    |
| AWF              |         | 59.6    |         |         | 59.6     | 59.7    |         |         |
| KWP              |         | 58.6    |         |         | 58.3     | 59.0    |         |         |
| Kanaha_6923      | 59.8    | 59.8    | 59.7    | 59.7    | 59.9     | 59.9    | 59.7    | 59.8    |
| Puunene_6923     | 59.8    | 59.9    | 59.8    | 59.8    | 59.9     | 59.9    | 59.8    | 59.8    |
| Waiinu_6923      | 59.8    | 59.6    | 59.8    | 59.7    | 59.7     | 59.7    | 59.8    | 59.7    |
| Maa-Lahaluna     | 59.8    | 59.8    | 59.8    | 59.6    | 59.9     | 59.8    | 59.7    | 59.5    |
| Maa-KWP          | 59.6    | 59.6    | 59.6    | 59.4    | 59.8     | 59.8    | 59.3    | 59.4    |
| Maa-Puunene      | 59.0    | 59.9    | 58.6    | 59.2    | 59.6     | 59.8    | 58.9    | 59.1    |
| Maa-Kihe         | 59.8    | 59.9    | 59.8    | 59.7    | 60.0     | 59.9    | 59.7    | 59.6    |
| Kanaha-Puunene   | 59.8    | 59.8    | 59.8    | 59.8    | 59.9     | 59.9    | 59.8    | 59.9    |
| Lahaina-Lahaluna | 58.9    | 59.5    | 59.0    | 59.3    | 59.6     | 59.8    | 59.2    | 59.3    |
|                  | Stage 1 | Stage 2 | Stage 3 |         |          |         |         |         |

Table D-6. 2015 Stability Results 12 MW PV that Trips at 59.3 Hz

The M14, M16, and KWP unit trip simulations resulted in stage 2 of load shedding. It should be noted that these results assume only 12 MW of PV trip at the current over frequency setting of 60.5 Hz. Following a line fault, it is critical that no additional PV trip

## D. System Security Standards

Year 2015 Analysis

for the high frequency condition. If additional PV is retrofitted such that only 10 MW of PV capacity has the 59.3/60.5 Hz trip settings, the results are slightly improved. Table D-7 shows the contingency results when this retrofit is completed.

| Outage           | Day Min        |                |                |                | Day Peak       |                |                |                |
|------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                  | wnd_sun<br>Min | wnd_cld<br>Min | clm_sun<br>Min | clm_cld<br>Min | wnd_sun<br>Min | wnd_cld<br>Min | clm_sun<br>Min | clm_cld<br>Min |
| M14              | 58.5           | 59.4           | 59.4           | 59.5           | 59.4           | 59.5           | 59.6           | 59.6           |
| MGS10            |                |                |                |                |                | 59.7           |                | 59.7           |
| M16              | 58.5           | 59.4           | 59.4           | 59.5           | 59.5           | 59.5           | 59.5           | 59.5           |
| HC&S             | 59.6           | 59.7           | 59.6           | 59.6           | 59.6           | 59.7           | 59.7           | 59.7           |
| M15              | 59.7           | 59.8           | 59.7           | 59.7           | 59.8           | 59.8           | 59.8           | 59.7           |
| AWF              |                | 59.6           |                |                | 59.6           | 59.7           |                |                |
| KWP              |                | 58.6           |                |                | 58.3           | 59.0           |                |                |
| Kanaha_6923      | 59.8           | 59.8           | 59.7           | 59.7           | 59.9           | 59.9           | 59.7           | 59.8           |
| Puunene_6923     | 59.8           | 59.9           | 59.8           | 59.8           | 59.9           | 59.9           | 59.8           | 59.8           |
| Waiinu_6923      | 59.8           | 59.6           | 59.8           | 59.7           | 59.7           | 59.7           | 59.8           | 59.7           |
| Maa-Lahaluna     | 59.8           | 59.8           | 59.8           | 59.6           | 59.9           | 59.8           | 59.8           | 59.5           |
| Maa-KWP          | 59.6           | 59.6           | 59.6           | 59.4           | 59.8           | 59.8           | 59.5           | 59.4           |
| Maa-Puunene      | 59.1           | 59.9           | 58.9           | 59.2           | 59.6           | 59.8           | 59.2           | 59.1           |
| Maa-Kihei        | 59.8           | 59.9           | 59.8           | 59.7           | 60.0           | 59.9           | 59.7           | 59.6           |
| Kanaha-Puunene   | 59.8           | 59.8           | 59.8           | 59.8           | 59.9           | 59.9           | 59.8           | 59.9           |
| Lahaina-Lahaluna | 59.1           | 59.5           | 59.1           | 59.3           | 59.6           | 59.8           | 59.3           | 59.3           |
|                  | Stage 1        | Stage 2        | Stage 3        |                |                |                |                |                |

Table D-7. 2015 Stability Results: 10 MW PV that Trips at 59.3 Hz

The minimum frequency improved with the lower PV levels, but was not enough to prevent the second stage of load shedding.

We studied the impact that a direct transfer trip would have on the minimum system frequency in 2015. In this scenario, the unit breaker was used to directly trip the first stage of UFLS instead of relying on frequency decay to initiate the trip. The results of these simulations are shown below in Table D-8.

| Outage | Day Min        |                |                |                | Day Peak       |                |                |                |
|--------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|        | wnd_sun<br>Min | wnd_cld<br>Min | clm_sun<br>Min | clm_cld<br>Min | wnd_sun<br>Min | wnd_cld<br>Min | clm_sun<br>Min | clm_cld<br>Min |
| M14    | 59.5           | 59.7           | 59.5           | 59.7           | 59.6           | 59.7           | 59.7           | 59.8           |
| MGS10  |                |                |                |                |                | 59.8           |                | 59.8           |
| M16    | 59.5           | 59.7           | 59.5           | 59.7           | 59.7           | 59.7           | 59.7           | 59.8           |
| HC&S   | 59.7           | 59.8           | 59.7           | 59.8           | 59.7           | 59.8           | 59.8           | 59.8           |
| M15    | 59.8           | 59.8           | 59.8           | 59.8           | 59.8           | 59.9           | 59.8           | 59.8           |
| AWF    |                | 59.8           |                |                | 59.8           | 59.8           |                |                |
| KWP    |                | 59.2           |                |                | 58.5           | 59.5           |                |                |
|        | Stage 1        | Stage 2        | Stage 3        |                |                |                |                |                |

Table D-8. 2015 Stability Results: 12 MW PV that Trips at 59.3 Hz; Transfer Trip Stage I

With the transfer trip of stage 1, the second stage of load shedding can be avoided. If the transfer trip could be enabled for the loss of any of the combustion turbines, or the KWP plant, the system would meet the reliability criteria.

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## YEAR 2016 ANALYSIS

Power flow cases were created for the day minimum and day peak load times. The day minimum cases used a load of 138 MW, with renewable generation resources consisting of 90 MW of distributed PV (12 MW legacy PV) and 72 MW of wind. The day peak cases used a load of 186 MW.

The assumptions used for the 2016 cases are listed below:

- These cases assume that 12 MW of PV has legacy trip settings (59.3 60.5 Hz), all other PV has extended ride through. Sensitivity cases run with 10 MW
- KPP 3, KPP 4, and DTCC1 are baseloaded
- Existing protection clearing times were used
- No curtailment of DG resources

### 2016 Generation Dispatches

As for the 2015 cases, only the daytime cases were run for 2016. The loss of legacy PV due to under-frequency trip settings will worsen the unit trip scenarios, and the PV will also reduce the net load on each stage of load shed. For line fault conditions, it is critical that the legacy PV be limited to only 12 MW of PV for over frequency conditions. With DTCC1, KPP 3, KPP 4 online, the wind must be curtailed for the daytime minimum cases. Details of the generation dispatches for the 2016 study year are shown in Table D-9.

## D. System Security Standards

Year 2016 Analysis

| 2016            |                            |       |       |       |                         |       |       |       |
|-----------------|----------------------------|-------|-------|-------|-------------------------|-------|-------|-------|
|                 | Daytime Minimum Load Level |       |       |       | Daytime Peak Load Level |       |       |       |
| Wind Level      | Windy                      | Windy | Calm  | Calm  | Windy                   | Windy | Calm  | Calm  |
| Solar Gen (Cap) | 90.0                       | 90.0  | 90.0  | 90.0  | 90.0                    | 90.0  | 90.0  | 90.0  |
| Curtailed Solar | 0.0                        | 0.0   | 0.0   | 0.0   | 0.0                     | 0.0   | 0.0   | 0.0   |
| Solar Gen (MW)  | 76.5                       | 9.0   | 76.5  | 9.0   | 76.5                    | 9.0   | 76.5  | 9.0   |
| KPP 1           |                            |       |       |       |                         |       |       |       |
| KPP 2           |                            |       |       |       |                         |       |       |       |
| KPP 3           | 3.5                        | 7.0   | 7.5   | 10.0  | 5.0                     | 9.0   | 11.0  | 10.5  |
| KPP 4           | 3.5                        | 7.0   | 7.5   | 10.0  | 5.0                     | 9.0   | 11.0  | 10.5  |
| MPP 14          | 8.4                        | 14.7  | 15.0  | 16.2  | 10.0                    | 17.0  | 13.6  | 18.8  |
| MPP 15          | 4.0                        | 6.0   | 6.0   | 12.0  | 5.0                     | 7.5   | 7.0   | 13.0  |
| MPP 16          | 8.4                        | 14.8  | 15.0  | 18.0  | 10.0                    | 17.0  | 15.0  | 19.5  |
| MPP 17          |                            |       |       | 19.0  |                         | 17.0  | 17.0  | 19.5  |
| MPP 18          |                            |       |       | 12.0  |                         | 6.0   | 8.0   | 12.0  |
| MPP 19          |                            |       |       | 19.0  |                         |       |       | 19.0  |
| HC&S            | 8.0                        | 8.0   | 8.4   | 12.0  | 8.5                     | 11.0  | 12.0  | 12.0  |
| MPP 10          |                            |       |       |       |                         | 11.5  | 12.0  | 12.0  |
| MPP 11          |                            |       |       |       |                         |       |       | 12.0  |
| MPP 12          |                            |       |       |       |                         |       |       | 12.0  |
| MPP 13          |                            |       |       |       |                         |       |       |       |
| MPP 4           |                            |       |       |       |                         |       |       | 5.5   |
| MPP 6           |                            |       |       |       |                         |       |       |       |
| MPP 8           |                            |       |       |       |                         |       |       |       |
| MPP 9           |                            |       |       |       |                         |       |       |       |
| Wind Total      | 23.0                       | 72.0  | 0.0   | 0.0   | 64.5                    | 72.0  | 0.0   | 0.0   |
| Load            | 135.3                      | 138.5 | 135.9 | 137.2 | 184.5                   | 186.0 | 183.1 | 185.3 |
| Reg Up          | 52.2                       | 30.5  | 28.6  | 15.6  | 44.5                    | 22.6  | 21.0  | 7.0   |
| Reg Down        | 4.8                        | 26.5  | 28.4  | 55.4  | 12.5                    | 47.6  | 46.2  | 78.0  |

Table D-9. 2016 Dispatch Cases

The minimum frequency results for 2016 are shown below in Table D-10.

## 2016 Results

|                  | Day Min |         |         |         | Day Peak |         |         |         |
|------------------|---------|---------|---------|---------|----------|---------|---------|---------|
|                  | wnd_sun | wnd_cld | clm_sun | clm_cld | wnd_sun  | wnd_cld | clm_sun | clm_cld |
| Outage           | Min     | Min     | Min     | Min     | Min      | Min     | Min     | Min     |
| M14              | 59.7    | 59.5    | 59.5    | 59.6    | 59.7     | 59.5    | 59.6    | 59.6    |
| MGS10            |         |         |         |         |          | 59.7    | 59.6    | 59.7    |
| M16              | 59.7    | 59.5    | 59.5    | 59.5    | 59.7     | 59.5    | 59.6    | 59.6    |
| HC&S             | 59.7    | 59.7    | 59.7    | 59.6    | 59.7     | 59.7    | 59.6    | 59.7    |
| M15              | 59.8    | 59.8    | 59.8    | 59.7    | 59.8     | 59.8    | 59.8    | 59.7    |
| AWF              |         | 59.7    |         |         | 59.7     | 59.7    |         |         |
| KWP              | 58.7    | 58.6    |         |         | 58.5     | 59.0    |         |         |
| Kanaha_6923      | 59.8    | 59.7    | 59.8    | 59.7    | 59.8     | 59.9    | 59.8    | 59.8    |
| Puunene_6923     | 59.9    | 59.9    | 59.9    | 59.8    | 59.9     | 59.9    | 59.8    | 59.8    |
| Waiinu_6923      | 59.7    | 59.4    | 59.8    | 59.7    | 59.6     | 59.7    | 59.8    | 59.7    |
| Maa-Lahaluna     | 60.0    | 59.7    | 59.8    | 59.6    | 59.8     | 59.9    | 59.7    | 59.6    |
| Maa-KWP          | 60.0    | 59.5    | 59.7    | 59.4    | 59.8     | 59.9    | 59.4    | 59.4    |
| Maa-Puunene      | 59.9    | 59.8    | 59.5    | 59.2    | 59.8     | 59.8    | 59.1    | 59.1    |
| Maa-Kihei        | 60.0    | 59.7    | 59.8    | 59.7    | 59.9     | 60.0    | 59.8    | 59.6    |
| Kanaha-Puunene   | 59.8    | 59.6    | 59.9    | 59.8    | 59.7     | 59.9    | 59.8    | 59.9    |
| Lahaina-Lahaluna | 59.6    | 59.6    | 59.3    | 59.2    | 59.6     | 59.8    | 59.3    | 59.3    |
|                  | Stage 1 | Stage 2 | Stage 3 |         |          |         |         |         |

Table D-10. 2016 Stability Results - 12 MW PV that Trips at 59.3 Hz



The loss of the KWP plant can result in stage 2 load shedding for the high PV/ minimum daytime load condition.

The impact of reducing the legacy PV to only 10 MW is shown in Table D-11.

|                  | Day Min |         |         |         | Day Peak |         |         |         |
|------------------|---------|---------|---------|---------|----------|---------|---------|---------|
|                  | wnd_sun | wnd_cld | clm_sun | clm_cld | wnd_sun  | wnd_cld | clm_sun | clm_cld |
| Outage           | Min     | Min     | Min     | Min     | Min      | Min     | Min     | Min     |
| M14              | 59.7    | 59.5    | 59.5    | 59.6    | 59.7     | 59.5    | 59.6    | 59.6    |
| MGS10            |         |         |         |         |          | 59.7    | 59.6    | 59.7    |
| M16              | 59.7    | 59.5    | 59.5    | 59.5    | 59.7     | 59.5    | 59.6    | 59.6    |
| HC&S             | 59.7    | 59.7    | 59.7    | 59.6    | 59.7     | 59.7    | 59.6    | 59.7    |
| M15              | 59.8    | 59.8    | 59.8    | 59.7    | 59.8     | 59.8    | 59.8    | 59.7    |
| AWF              |         | 59.7    |         |         | 59.7     | 59.7    |         |         |
| KWP              | 58.7    | 58.6    |         |         | 58.5     | 59.0    |         |         |
| Kanaha_6923      | 59.8    | 59.7    | 59.8    | 59.7    | 59.8     | 59.9    | 59.8    | 59.8    |
| Puunene_6923     | 59.9    | 59.9    | 59.9    | 59.8    | 59.9     | 59.9    | 59.8    | 59.8    |
| Waiinu_6923      | 59.7    | 59.4    | 59.8    | 59.7    | 59.6     | 59.7    | 59.8    | 59.7    |
| Maa-Lahaluna     | 60.0    | 59.7    | 59.8    | 59.6    | 59.8     | 59.9    | 59.7    | 59.6    |
| Maa-KWP          | 60.0    | 59.5    | 59.7    | 59.4    | 59.8     | 59.9    | 59.4    | 59.4    |
| Maa-Puunene      | 59.9    | 59.8    | 59.5    | 59.2    | 59.8     | 59.8    | 59.1    | 59.2    |
| Maa-Kihei        | 60.0    | 59.7    | 59.8    | 59.7    | 59.9     | 60.0    | 59.8    | 59.6    |
| Kanaha-Puunene   | 59.8    | 59.6    | 59.9    | 59.8    | 59.7     | 59.9    | 59.8    | 59.9    |
| Lahaina-Lahaluna | 59.6    | 59.6    | 59.3    | 59.2    | 59.6     | 59.8    | 59.3    | 59.3    |
|                  | Stage 1 | Stage 2 | Stage 3 |         |          |         |         |         |

Table D-11. 2016 Stability Results: 10 MW PV that Trips at 59.3 Hz

The minimum frequency did improve with the lower PV and was able to prevent the second stage of load shedding.

In order to prevent the second stage of load shedding for the loss of a generation unit, we studied the impact that a direct transfer trip would have on the minimum system frequency in 2016. The results of these simulations are shown below in Table D-12.

|        | Day Min |         |         |         | Day Peak |         |         |         |
|--------|---------|---------|---------|---------|----------|---------|---------|---------|
|        | wnd_sun | wnd_cld | clm_sun | clm_cld | wnd_sun  | wnd_cld | clm_sun | clm_cld |
| Outage | Min     | Min     | Min     | Min     | Min      | Min     | Min     | Min     |
| M14    | 59.5    | 59.7    | 59.5    | 59.7    | 59.6     | 59.7    | 59.7    | 59.8    |
| MGS10  |         |         |         |         |          | 59.8    |         | 59.8    |
| M16    | 59.5    | 59.7    | 59.5    | 59.7    | 59.7     | 59.7    | 59.7    | 59.8    |
| HC&S   | 59.7    | 59.8    | 59.7    | 59.8    | 59.7     | 59.8    | 59.8    | 59.8    |
| M15    | 59.8    | 59.8    | 59.8    | 59.8    | 59.8     | 59.9    | 59.8    | 59.8    |
| AWF    |         | 59.8    |         |         | 59.8     | 59.8    |         |         |
| KWP    |         | 59.2    |         |         | 58.7     | 59.5    |         |         |
|        | Stage 1 | Stage 2 | Stage 3 |         |          |         |         |         |

Table D-12. 2016 Stability Results: 12 MW PV that Trips at 59.3 Hz; Transfer Trip Stage I

With the transfer trip the second stage of load shedding can be avoided with 12 MW PV that trips at 59.3 Hz. The transfer trip should be enabled for the loss of any of the combustion turbines, or the KWP plant.

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## YEAR 2017 ANALYSIS

Power flow cases were created for the minimum, day minimum, day peak, and peak load times. Renewable generation resources consist of 96 MW of distributed PV (10 MW legacy PV) and 72 MW of wind.

The year 2017 was selected for analysis due to the large jump in PV between 2015 and 2017, without additional security reserves or dispatchable generation added to counter the increase.

The assumptions used for the 2017 cases are listed below:

- These cases assume that 10 MW of PV has legacy trip settings, all other PV has extended ride through.
  - Sensitivity cases run with 10 MW
- KPP 3, KPP 4, DTCC1, and ½ DTCC2 are baseloaded
  - Sensitivity cases were run without ½ DTCC2 baseloaded
  - Sensitivity cases were run without KPP 3 and KPP 4 baseloaded (mimics 2019 case)
  - Sensitivity cases were run with only DTCC1 baseloaded
- Upgraded protection times were used such that all faults are cleared in 5 cycles
- PV installed after the beginning of 2015 can be curtailed
- DTCC1 minimum generation is reduced to allow more renewable generation

## 2017 Generation Dispatches

With KPP 3, KPP 4, DTCC1, and ½ DTCC2 online, the wind must be curtailed for the daytime minimum cases. Details of the generation dispatches for the 2017 study year are shown in Table D-13.

| 2017            |         |      |                      |       |       |       |                         |       |       |       |           |       |
|-----------------|---------|------|----------------------|-------|-------|-------|-------------------------|-------|-------|-------|-----------|-------|
| Wind Level      | Minimum |      | Daytime Minimum Load |       |       |       | Daytime Peak Load Level |       |       |       | Peak Load |       |
|                 | Windy   | Calm | Windy                | Windy | Calm  | Calm  | Windy                   | Windy | Calm  | Calm  | Windy     | Calm  |
| Solar Gen (Cap) | 0.0     | 0.0  | 81.6                 | 9.6   | 81.6  | 9.6   | 81.6                    | 9.6   | 81.6  | 9.6   | 0.0       | 0.0   |
| Curtailed Solar |         |      | 34.0                 | 4.0   |       |       | 11.5                    |       |       |       |           |       |
| Solar Gen (MW)  |         |      | 47.6                 | 5.6   | 81.6  | 9.6   | 70.1                    | 9.6   | 81.6  | 9.6   |           |       |
| KPP 1           |         |      |                      |       |       |       |                         |       |       |       |           |       |
| KPP 2           |         |      |                      |       |       |       |                         |       |       |       |           |       |
| KPP 3           | 3.5     | 8.0  | 3.5                  | 3.5   | 7.0   | 11.0  | 3.5                     | 9.0   | 10.0  | 11.0  | 11.0      | 11.5  |
| KPP 4           | 3.5     | 8.0  | 3.5                  | 3.5   | 7.0   | 11.0  | 3.5                     | 9.0   | 10.0  | 11.0  | 11.0      | 11.5  |
| MPP 14          | 9.0     | 18.3 | 8.9                  | 13.1  | 8.7   | 17.7  | 8.7                     | 16.5  | 13.9  | 18.8  | 17.5      | 19.7  |
| MPP 15          | 4.0     | 12.0 | 4.0                  | 6.5   | 5.0   | 12.0  | 4.0                     | 8.0   | 7.0   | 12.0  | 8.0       | 12.0  |
| MPP 16          | 9.0     | 18.2 | 9.0                  | 13.0  | 9.5   | 18.0  | 9.0                     | 16.5  | 13.9  | 18.5  | 17.5      | 20.0  |
| MPP 17          | 14.4    | 18.0 | 14.5                 | 16.0  | 16.0  | 19.0  | 14.5                    | 17.0  | 17.0  | 19.0  | 18.0      | 20.0  |
| MPP 18          | 4.5     | 7.0  | 4.1                  | 5.0   | 5.0   | 12.0  | 4.5                     | 8.0   | 8.0   | 10.5  | 9.0       | 12.0  |
| MPP 19          |         |      |                      |       |       | 19.0  |                         | 17.0  | 17.0  | 19.0  | 18.0      | 20.0  |
| HC&S            |         |      |                      |       |       |       |                         |       |       |       |           |       |
| MPP 10          |         |      |                      | 12.0  |       | 12.0  |                         | 9.0   | 10.0  | 12.0  | 10.0      | 12.0  |
| MPP 11          |         |      |                      |       |       |       |                         |       |       | 12.0  | 10.0      | 12.0  |
| MPP 12          |         |      |                      |       |       |       |                         |       |       | 12.0  |           | 12.0  |
| MPP 13          |         |      |                      |       |       |       |                         |       |       | 12.0  |           | 12.0  |
| MPP 4           |         |      |                      |       |       |       |                         |       |       | 5.5   |           | 5.5   |
| MPP 6           |         |      |                      |       |       |       |                         |       |       | 5.5   |           | 5.5   |
| MPP 8           |         |      |                      |       |       |       |                         |       |       |       |           | 5.4   |
| MPP 9           |         |      |                      |       |       |       |                         |       |       |       |           | 5.4   |
| MPP 1           |         |      |                      |       |       |       |                         |       |       | 2.5   | 2.5       | 2.5   |
| MPP 2           |         |      |                      |       |       |       |                         |       |       |       |           | 2.5   |
| MPP 3           |         |      |                      |       |       |       |                         |       |       |       |           | 2.5   |
| Wind Total      | 42.0    | 0.0  | 46.0                 | 64.5  | 0.0   | 0.0   | 72.0                    | 72.0  | 0.0   | 0.0   | 72.0      | 0.0   |
| Load            | 89.9    | 89.5 | 141.1                | 142.7 | 139.8 | 141.3 | 189.8                   | 191.6 | 188.4 | 190.9 | 204.5     | 204.0 |
| Reg Up          | 57.4    | 15.8 | 55.8                 | 43.0  | 45.1  | 12.4  | 55.6                    | 31.1  | 34.3  | 10.4  | 26.5      | 6.6   |
| Reg Down        | 6.4     | 48.0 | 6.0                  | 23.2  | 16.7  | 59.0  | 6.2                     | 37.3  | 31.1  | 78.8  | 47.5      | 90.5  |

Table D-13. 2017 Dispatch Cases

With KPP 3, KPP 4, DTCC1, and ½ DTCC2 online, the wind and solar must be curtailed for the daytime minimum cases.

We also created some sensitivity dispatch cases that did not have KPP 3 and KPP 4 online. These cases were created to mimic the 2017 system response to the loss of a generating unit. It is noted that the 2017 cases do not have the transmission upgrades necessary to deal with the steady state overload and voltage concerns related to the loss of a transmission line. The cases were only created for the minimum and daytime minimum cases when the baseload assumption changes the dispatch scenarios. These sensitivity case dispatches are shown below in Table D-14 through D-16.

## D. System Security Standards

Year 2017 Analysis

| 2017 - KPP Not Baseloaded |                    |      |                            |       |       |       |
|---------------------------|--------------------|------|----------------------------|-------|-------|-------|
| Wind Level                | Minimum Load Level |      | Daytime Minimum Load Level |       |       |       |
|                           | Windy              | Calm | Windy                      | Windy | Calm  | Calm  |
| Solar Gen (Cap)           | 0.0                | 0.0  | 81.6                       | 9.6   | 81.6  | 9.6   |
| Curtailed Solar           |                    |      | 34.0                       |       |       |       |
| Solar Gen (MW)            |                    |      | 47.6                       | 9.6   | 81.6  | 9.6   |
| MPP 14                    | 8.9                | 19.4 | 9.4                        | 13.2  | 15.3  | 18.3  |
| MPP 15                    | 4.0                | 12.0 | 4.0                        | 6.5   | 7.0   | 12.0  |
| MPP 16                    | 8.0                | 19.5 | 9.0                        | 13.0  | 15.0  | 18.0  |
| MPP 17                    | 14.4               | 19.0 | 14.5                       | 16.0  | 16.0  | 19.0  |
| MPP 18                    | 4.5                | 7.5  | 4.1                        | 5.0   | 5.0   | 12.0  |
| MPP 19                    |                    |      |                            |       |       | 19.0  |
| HC&S                      |                    |      |                            |       |       |       |
| MPP 10                    |                    | 12.3 |                            | 12.0  |       | 12.0  |
| MPP 11                    |                    |      |                            |       |       | 11.0  |
| MPP 12                    |                    |      |                            |       |       | 11.0  |
| MPP 13                    |                    |      |                            |       |       |       |
| Wind Total                | 51.0               | 0.0  | 53.0                       | 67.5  | 0.0   | 0.0   |
| Load                      | 90.8               | 89.7 | 141.6                      | 142.8 | 139.9 | 141.9 |
| Reg Up                    | 42.5               | 5.9  | 39.3                       | 26.9  | 28.0  | 13.5  |

Table D-14. 2017 Dispatch Cases - KPP Not Baseloaded

| 2017 - DTCC2 Not Baseloaded |                    |      |                            |       |       |       |
|-----------------------------|--------------------|------|----------------------------|-------|-------|-------|
| Wind Level                  | Minimum Load Level |      | Daytime Minimum Load Level |       |       |       |
|                             | Windy              | Calm | Windy                      | Windy | Calm  | Calm  |
| Solar Gen (Cap)             | 0.0                | 0.0  | 81.6                       | 9.6   | 81.6  | 9.6   |
| Curtailed Solar             |                    |      | 34.0                       | 4.0   |       |       |
| Solar Gen (MW)              |                    |      | 47.6                       | 5.6   | 81.6  | 9.6   |
| KPP 1                       |                    |      |                            |       |       |       |
| KPP 2                       |                    |      |                            |       |       |       |
| KPP 3                       | 3.5                | 8.0  | 3.5                        | 3.5   | 9.0   | 11.0  |
| KPP 4                       | 3.5                | 8.0  | 3.5                        | 3.5   | 9.0   | 11.0  |
| MPP 14                      | 8.6                | 18.3 | 9.5                        | 13.1  | 11.4  | 17.7  |
| MPP 15                      | 3.7                | 12.0 | 4.0                        | 6.5   | 5.5   | 12.0  |
| MPP 16                      | 8.5                | 18.2 | 9.0                        | 13.0  | 11.4  | 18.0  |
| MPP 17                      |                    | 18.0 |                            | 16.0  |       | 19.0  |
| MPP 18                      |                    | 7.0  |                            | 5.0   |       | 12.0  |
| MPP 19                      |                    |      |                            |       |       | 19.0  |
| HC&S                        |                    |      |                            |       | 12.0  |       |
| MPP 10                      |                    |      |                            | 12.0  |       | 12.0  |
| MPP 11                      |                    |      |                            |       |       |       |
| MPP 12                      |                    |      |                            |       |       |       |
| MPP 13                      |                    |      |                            |       |       |       |
| Wind Total                  | 63.0               | 0.0  | 64.5                       | 64.5  | 0.0   | 0.0   |
| Load                        | 90.8               | 89.5 | 141.6                      | 142.7 | 139.9 | 141.3 |
| Reg Up                      | 50.2               | 15.8 | 46.5                       | 43.0  | 29.7  | 12.4  |
| Reg Down                    | 4.8                | 48.0 | 6.5                        | 23.2  | 27.3  | 59.0  |

Table D-15. 2017 Dispatch Cases: DTCC2 Not Baseloaded

| 2017 - DTCC1 Only Baseloaded Unit |                    |      |                            |       |       |       |
|-----------------------------------|--------------------|------|----------------------------|-------|-------|-------|
|                                   | Minimum Load Level |      | Daytime Minimum Load Level |       |       |       |
| Wind Level                        | Windy              | Calm | Windy                      | Windy | Calm  | Calm  |
| Solar Gen (Cap)                   | 0.0                | 0.0  | 81.6                       | 9.6   | 81.6  | 9.6   |
| Curtailed Solar                   |                    |      | 21.7                       |       |       |       |
| Solar Gen (MW)                    |                    |      | 59.9                       | 9.6   | 81.6  | 9.6   |
| KPP 1                             |                    |      |                            |       |       |       |
| KPP 2                             |                    |      |                            |       |       |       |
| KPP 3                             |                    |      |                            |       |       |       |
| KPP 4                             |                    |      |                            |       |       |       |
| MPP 14                            | 9.1                | 19.4 | 8.6                        | 13.2  | 15.3  | 18.3  |
| MPP 15                            | 3.5                | 12.0 | 3.5                        | 6.5   | 7.0   | 12.0  |
| MPP 16                            | 8.0                | 19.5 | 8.0                        | 13.0  | 15.0  | 18.0  |
| MPP 17                            |                    | 19.0 |                            | 16.0  | 16.0  | 19.0  |
| MPP 18                            |                    | 7.5  |                            | 5.0   | 5.0   | 12.0  |
| MPP 19                            |                    |      |                            |       |       | 19.0  |
| HC&S                              |                    |      |                            |       |       |       |
| MPP 10                            |                    | 12.3 |                            | 12.0  |       | 12.0  |
| MPP 11                            |                    |      |                            |       |       | 11.0  |
| MPP 12                            |                    |      |                            |       |       | 11.0  |
| MPP 13                            |                    |      |                            |       |       |       |
| Wind Total                        | 70.5               | 0.0  | 61.5                       | 67.5  | 0.0   | 0.0   |
| Load                              | 91.1               | 89.7 | 141.5                      | 142.8 | 139.9 | 141.9 |
| Reg Up                            | 34.4               | 5.9  | 32.9                       | 26.9  | 28.0  | 13.5  |
| Reg Down                          | 4.6                | 47.3 | 4.1                        | 23.3  | 23.8  | 50.9  |

Table D-16. 2017 Dispatch Cases: Only DTCC1 Baseloaded

In order to define the boundary conditions an additional dispatch case was created for each of the sensitivity cases listed above based on the baseloaded units. These dispatch cases are shown below in Table D-17.

| 2017 - Boundary Definition Cases |          |                        |       |       |
|----------------------------------|----------|------------------------|-------|-------|
|                                  | Day Peak | Day Minimum Load Level |       |       |
| Wind Level                       | Windy    | Windy                  | Windy | Windy |
| Solar Gen (Cap)                  | 81.6     | 81.6                   | 81.6  | 81.6  |
| Curtailed Solar                  | 34.0     | 34.0                   | 34.0  | 23.0  |
| Solar Gen (MW)                   | 47.6     | 47.6                   | 47.6  | 58.6  |
| KPP 1                            |          |                        |       |       |
| KPP 2                            |          |                        |       |       |
| KPP 3                            | 11.5     | 9.0                    |       |       |
| KPP 4                            | 11.5     | 9.0                    |       |       |
| MPP 14                           | 18.4     | 16.5                   | 16.2  | 19.0  |
| MPP 15                           | 13.0     | 11.0                   | 8.0   | 13.0  |
| MPP 16                           | 20.0     | 17.5                   | 17.0  | 20.0  |
| MPP 17                           | 20.0     |                        | 17.0  |       |
| MPP 18                           | 7.1      |                        | 5.0   |       |
| MPP 19                           |          |                        |       |       |
| HC&S                             |          |                        |       |       |
| Wind Total                       | 40.3     | 30.0                   | 30.0  | 30.0  |
| Load                             | 189.4    | 140.6                  | 140.8 | 140.6 |
| Reg Up                           | 1.8      | 13.0                   | 17.0  | 1.0   |
| Reg Down                         | 60.0     | 40.0                   | 28.7  | 36.0  |

Table D-17. 2017 Dispatch Cases: Boundary Definition

## D. System Security Standards

Year 2017 Analysis

The first column of Table D-17 shows the boundary case with KPP3, KPP4, DTCC1, and ½ DTCC2 baseloaded. The second column shows the boundary case without DTCC2. The third column lists the boundary case without KPP, and the last column has only DTCC1. These boundary cases were setup to determine the contingency reserves required to prevent stage 2 load shedding without relying on thermal generation.

## 2017 Results

The contingencies were simulated for each of the dispatch cases listed in Table D-13 through Table D-17. Table D-18 shows the simulation results with KPP3, KPP4, DTCC1, and ½ DTCC2 baseloaded.

|           | Minimum |        | Daytime Minimum |       |      |      | Daytime Peak |       |      |      | Peak  |      |
|-----------|---------|--------|-----------------|-------|------|------|--------------|-------|------|------|-------|------|
|           | Windy   | Calm   | Windy           | Windy | Calm | Calm | Windy        | Windy | Calm | Calm | Windy | Calm |
|           |         |        | Sun             | Cld   | Sun  | Cld  | Sun          | Cld   | Sun  | Cld  | Min   | Min  |
| Outage    | Min     | Min    | Min             | Min   | Min  | Min  | Min          | Min   | Min  | Min  | Min   | Min  |
| M14       | 59.7    | 59.3   | 59.7            | 59.6  | 59.7 | 59.5 | 59.7         | 59.6  | 59.6 | 59.6 | 59.6  | 59.6 |
| MGS10     |         |        |                 | 59.6  |      | 59.7 |              | 59.7  | 59.7 | 59.7 | 59.7  | 59.7 |
| M16       | 59.7    | 59.3   | 59.7            | 59.6  | 59.7 | 59.5 | 59.7         | 59.6  | 59.6 | 59.6 | 59.6  | 59.6 |
| HC&S      |         |        |                 |       |      |      |              |       |      |      |       |      |
| M15       | 59.8    | 59.6   | 59.8            | 59.8  | 59.8 | 59.7 | 59.9         | 59.8  | 59.8 | 59.7 | 59.8  | 59.7 |
| AWF       | 60.0    |        | 59.8            | 59.7  |      |      | 59.7         | 59.7  |      |      | 59.7  |      |
| KWP       | 59.2    |        | 58.8            | 58.9  |      |      | 58.6         | 59.1  |      |      | 59.2  |      |
| Kanaha_6  | 59.5    | 59.8   | 59.5            | 59.6  | 59.8 | 59.7 | 59.4         | 59.8  | 59.8 | 59.8 | 59.8  | 59.8 |
| Puunene_  | 59.9    | 59.8   | 59.9            | 59.9  | 59.9 | 59.7 | 59.9         | 59.8  | 59.8 | 59.8 | 59.8  | 59.8 |
| Waiinu_6  | 59.4    | 59.7   | 59.4            | 59.5  | 59.8 | 59.7 | 59.3         | 59.8  | 59.8 | 59.7 | 59.8  | 59.7 |
| Maa-Laha  | 59.7    | 59.7   | 59.7            | 59.7  | 59.8 | 59.6 | 59.3         | 60.0  | 59.7 | 59.5 | 60.0  | 59.5 |
| Maa-KWP   | 59.7    | 59.7   | 59.7            | 59.7  | 59.7 | 59.6 | 59.4         | 60.0  | 59.7 | 59.5 | 60.0  | 59.5 |
| Maa-Kihe  | 59.7    | 59.7   | 59.7            | 59.8  | 59.7 | 59.6 | 59.5         | 60.0  | 59.7 | 59.6 | 60.0  | 59.6 |
| Kanaha-P  | 59.6    | 59.8   | 59.6            | 59.6  | 59.9 | 59.8 | 59.5         | 59.9  | 59.8 | 59.9 | 59.9  | 59.9 |
| Lahaina-L | 59.5    | 59.9   | 59.5            | 59.5  | 59.9 | 59.8 | 59.3         | 59.7  | 59.8 | 59.9 | 59.8  | 59.9 |
|           | Stage1  | Stage2 | Stage3          |       |      |      |              |       |      |      |       |      |

Table D-18. Minimum Frequency Results with KPP 3, KPP 4, DTCC1 and ½ DTCC2 Baseloaded

Table D-18 shows that stage 2 of load shedding can be averted without any additional contingency reserves as long as Maui Electric adheres to the HSIS regulating reserve requirements. Stage 2 was not used even with the boundary case dispatch. The high frequencies encountered in these simulations indicate that if the HSIS regulation requirement is met during all periods of the day, the regulation requirement is larger than the contingency requirement.

Table D-19 shows the minimum frequency results for the 2017 cases without the KPP 3 and KPP4 units baseloaded.

|                  | 0 MW BESS |        |                 |       |      |      | 10 MW BESS |      |                 |       |      |      |
|------------------|-----------|--------|-----------------|-------|------|------|------------|------|-----------------|-------|------|------|
|                  | Minimum   |        | Daytime Minimum |       |      |      | Minimum    |      | Daytime Minimum |       |      |      |
|                  | Windy     | Calm   | Windy           | Windy | Calm | Calm | Windy      | Calm | Windy           | Windy | Calm | Calm |
|                  |           |        | Sun             | Cld   | Sun  | Cld  |            |      | Sun             | Cld   | Sun  | Cld  |
| Outage           | Min       | Min    | Min             | Min   | Min  | Min  | Min        | Min  | Min             | Min   | Min  | Min  |
| M14              | 59.6      | 58.6   | 59.5            | 59.5  | 59.3 | 59.5 | 59.6       | 59.4 | 59.6            | 59.6  | 59.4 | 59.6 |
| MGS10            |           | 59.5   |                 | 59.5  |      | 59.6 |            | 59.6 |                 | 59.6  |      | 59.7 |
| M16              | 59.6      | 58.6   | 59.6            | 59.5  | 59.3 | 59.5 | 59.7       | 59.4 | 59.6            | 59.6  | 59.4 | 59.6 |
| HC&S             |           |        |                 |       |      |      |            |      |                 |       |      |      |
| M15              | 59.8      | 59.6   | 59.8            | 59.8  | 59.7 | 59.7 | 59.8       | 59.7 | 59.8            | 59.8  | 59.7 | 59.7 |
| AWF              | 59.5      |        | 59.5            | 59.6  |      |      | 59.6       |      | 59.6            | 59.7  |      |      |
| KWP              | 58.4      |        | 58.1            | 58.5  |      |      | 58.9       |      | 58.6            | 59.1  |      |      |
| Kanaha_6923      | 59.4      | 59.8   | 59.4            | 59.6  | 59.8 | 59.8 | 59.4       | 59.8 | 59.4            | 59.5  | 59.9 | 59.8 |
| Puunene_6923     | 59.9      | 59.8   | 59.9            | 59.9  | 59.8 | 59.8 | 59.9       | 59.8 | 59.9            | 59.9  | 59.9 | 59.8 |
| Waiinu_6923      | 59.4      | 59.7   | 59.4            | 59.5  | 59.8 | 59.7 | 59.4       | 59.7 | 59.4            | 59.4  | 59.9 | 59.7 |
| Maa-Lahaluna     | 60.0      | 59.7   | 60.0            | 60.0  | 59.6 | 59.6 | 60.0       | 59.8 | 59.9            | 60.0  | 59.5 | 59.8 |
| Maa-KWP          | 60.0      | 59.7   | 60.0            | 60.0  | 59.6 | 59.6 | 60.0       | 59.8 | 59.9            | 60.0  | 59.5 | 59.8 |
| Maa-Kihei        | 60.0      | 59.8   | 60.0            | 60.0  | 59.6 | 59.7 | 60.0       | 59.8 | 60.0            | 60.0  | 59.5 | 59.8 |
| Kanaha-Puunene   | 59.5      | 59.9   | 59.5            | 59.6  | 59.9 | 59.9 | 59.5       | 59.9 | 59.4            | 59.5  | 59.9 | 59.9 |
| Lahaina-Lahaluna | 59.5      | 59.9   | 59.5            | 59.5  | 59.8 | 59.8 | 59.5       | 59.9 | 59.4            | 59.5  | 59.9 | 59.9 |
|                  | Stage1    | Stage2 | Stage3          |       |      |      |            |      |                 |       |      |      |

Table D-19. Minimum Frequency Results with DTCCI and 1/2 DTCC2 Baseloaded

Table D-19 shows the minimum frequency results for the sensitivity cases without KPP 3 and KPP 4. The loss of the KWP generation causes the frequency to decay below the stage 2 trip settings. In order to prevent the second stage of load shedding, 10 MW of BESS was added to the simulation. The minimum frequency results with a 10 MW BESS are shown on the right side of Table D-19.

Similar analysis was performed assuming that the DTCC2 would not be baseloaded. The results are shown in Table D-20.

|                  | 0 MW BESS |        |                 |       |      |      | 10 MW BESS |      |                 |       |      |      |
|------------------|-----------|--------|-----------------|-------|------|------|------------|------|-----------------|-------|------|------|
|                  | Minimum   |        | Daytime Minimum |       |      |      | Minimum    |      | Daytime Minimum |       |      |      |
|                  | Windy     | Calm   | Windy           | Windy | Calm | Calm | Windy      | Calm | Windy           | Windy | Calm | Calm |
|                  |           |        | Sun             | Cld   | Sun  | Cld  |            |      | Sun             | Cld   | Sun  | Cld  |
| Outage           | Min       | Min    | Min             | Min   | Min  | Min  | Min        | Min  | Min             | Min   | Min  | Min  |
| M14              | 59.7      | 59.3   | 59.6            | 59.6  | 59.6 | 59.5 | 59.7       | 59.6 | 59.7            | 59.7  | 59.7 | 59.6 |
| MGS10            |           |        |                 | 59.6  |      | 59.7 |            |      |                 | 59.7  |      | 59.7 |
| M16              | 59.7      | 59.3   | 59.7            | 59.6  | 59.6 | 59.5 | 59.8       | 59.5 | 59.7            | 59.7  | 59.7 | 59.6 |
| HC&S             |           |        |                 |       | 59.6 |      |            |      |                 |       | 59.6 |      |
| M15              | 59.9      | 59.6   | 59.8            | 59.8  | 59.8 | 59.7 | 59.9       | 59.7 | 59.9            | 59.8  | 59.8 | 59.7 |
| AWF              | 59.6      |        | 59.6            | 59.7  |      |      | 59.7       |      | 59.7            | 59.7  |      |      |
| KWP              | 58.5      |        | 58.2            | 58.9  |      |      | 59.0       |      | 58.7            | 59.3  |      |      |
| Kanaha_6923      | 59.4      | 59.8   | 59.3            | 59.6  | 59.8 | 59.7 | 59.3       | 59.8 | 59.3            | 59.6  | 59.9 | 59.8 |
| Puunene_6923     | 59.8      | 59.8   | 59.8            | 59.9  | 59.9 | 59.7 | 59.8       | 59.8 | 59.8            | 59.9  | 59.9 | 59.8 |
| Waiinu_6923      | 59.3      | 59.7   | 59.3            | 59.5  | 59.9 | 59.7 | 59.3       | 59.7 | 59.3            | 59.5  | 59.9 | 59.7 |
| Maa-Lahaluna     | 59.4      | 59.7   | 59.6            | 59.7  | 59.8 | 59.6 | 59.1       | 59.7 | 59.1            | 59.8  | 59.8 | 59.5 |
| Maa-KWP          | 59.4      | 59.7   | 59.6            | 59.7  | 59.8 | 59.6 | 59.1       | 59.7 | 59.3            | 59.8  | 59.8 | 59.5 |
| Maa-Kihei        | 59.5      | 59.7   | 59.6            | 59.8  | 59.8 | 59.6 | 59.3       | 59.7 | 59.3            | 59.8  | 59.8 | 59.6 |
| Kanaha-Puunene   | 59.4      | 59.8   | 59.3            | 59.6  | 59.9 | 59.8 | 59.4       | 59.9 | 59.3            | 59.6  | 59.9 | 59.9 |
| Lahaina-Lahaluna | 59.3      | 59.9   | 59.3            | 59.5  | 59.9 | 59.8 | 59.3       | 59.9 | 59.3            | 59.5  | 59.9 | 59.9 |
|                  | Stage1    | Stage2 | Stage3          |       |      |      |            |      |                 |       |      |      |

Table D-20. Minimum Frequency Results with KPP3, KPP4, and DTCCI Baseloaded

## D. System Security Standards

Year 2017 Analysis

Table D-20 shows the minimum frequency results for the sensitivity cases without DTCC2. The loss of the KWP generation causes the frequency to decay below the stage 2 trip settings. In order to prevent the second stage of load shedding, 10 MW of BESS was added to the simulation. The minimum frequency results with a 10 MW BESS are shown on the right side of Table D-20.

Similar analysis was performed assuming that only DTCC1 would be baseloaded. The results are shown in Table D-21.

|                  | 0 MW BESS |        |                 |       |      |      | 20 MW BESS |      |                 |       |      |      |
|------------------|-----------|--------|-----------------|-------|------|------|------------|------|-----------------|-------|------|------|
|                  | Minimum   |        | Daytime Minimum |       |      |      | Minimum    |      | Daytime Minimum |       |      |      |
|                  | Windy     | Calm   | Windy           | Windy | Calm | Calm | Windy      | Calm | Windy           | Windy | Calm | Calm |
|                  |           |        | Sun             | Cld   | Sun  | Cld  |            |      | Sun             | Cld   | Sun  | Cld  |
| Outage           | Min       | Min    | Min             | Min   | Min  | Min  | Min        | Min  | Min             | Min   | Min  | Min  |
| M14              | 59.4      | 58.6   | 59.4            | 59.5  | 59.3 | 59.5 | 59.6       | 59.5 | 59.6            | 59.6  | 59.6 | 59.7 |
| MGS10            |           | 59.5   |                 | 59.5  |      | 59.6 |            | 59.6 |                 | 59.6  |      | 59.7 |
| M16              | 59.6      | 58.6   | 59.5            | 59.5  | 59.3 | 59.5 | 59.7       | 59.5 | 59.7            | 59.7  | 59.5 | 59.6 |
| HC&S             |           |        |                 |       |      |      |            |      |                 |       |      |      |
| M15              | 59.8      | 59.6   | 59.8            | 59.8  | 59.7 | 59.7 | 59.9       | 59.7 | 59.9            | 59.8  | 59.8 | 59.8 |
| AWF              | 59.4      |        | 59.4            | 59.6  |      |      | 59.6       |      | 59.6            | 59.7  |      |      |
| KWP              | 57.9      |        | 57.3            | 58.5  |      |      | 58.8       |      | 58.8            | 59.3  |      |      |
| Kanaha_6923      | 58.9      | 59.8   | 59.1            | 59.6  | 59.8 | 59.8 | 58.9       | 59.8 | 59.1            | 59.5  | 59.9 | 59.8 |
| Puunene_6923     | 59.7      | 59.8   | 59.7            | 59.9  | 59.8 | 59.8 | 59.7       | 59.8 | 59.7            | 59.9  | 59.9 | 59.8 |
| Waiinu_6923      | 58.9      | 59.7   | 59.1            | 59.5  | 59.8 | 59.7 | 58.9       | 59.8 | 59.1            | 59.4  | 59.8 | 59.8 |
| Maa-Lahaluna     | 59.8      | 59.7   | 59.8            | 60.0  | 59.6 | 59.6 | 59.9       | 59.5 | 59.4            | 59.9  | 59.4 | 59.7 |
| Maa-KWP          | 59.8      | 59.7   | 59.8            | 60.0  | 59.6 | 59.6 | 59.9       | 59.5 | 59.4            | 59.9  | 59.4 | 59.7 |
| Maa-Kihei        | 59.9      | 59.8   | 59.8            | 60.0  | 59.6 | 59.7 | 59.9       | 59.5 | 59.5            | 59.9  | 59.4 | 59.7 |
| Kanaha-Puunene   | 58.9      | 59.9   | 59.1            | 59.6  | 59.9 | 59.9 | 58.9       | 59.9 | 59.1            | 59.5  | 59.9 | 59.9 |
| Lahaina-Lahaluna | 58.9      | 59.9   | 59.1            | 59.5  | 59.8 | 59.8 | 59.0       | 59.8 | 59.1            | 59.5  | 59.8 | 59.9 |
|                  | Stage1    | Stage2 | Stage3          |       |      |      |            |      |                 |       |      |      |

Table D-21. Minimum Frequency Results with Only DTCC1 Baseloaded

Table D-21 shows the minimum frequency results for the sensitivity cases with only DTCC1 baseloaded. The loss of the KWP generation causes the frequency to decay below the stage 3 trip settings. In order to prevent the second stage of load shedding, 20 MW of BESS was added to the simulation. The minimum frequency results with a 20 MW BESS are shown on the right side of Table D-21.

The worst case contingency for the boundary cases was also the loss of the KWP plant at full output. With minimum reserve on the generation units, the minimum frequency was much lower for these dispatch cases. The minimum frequency for the loss of the KWP plant at full output with several levels of additional BESS support is shown in Table D-22.

|                 | Baseloaded Units | DTCC1     | DTCC1     | DTCC1     | DTCC1 |
|-----------------|------------------|-----------|-----------|-----------|-------|
|                 |                  | KPP3,KPP4 | KPP3,KPP4 |           |       |
|                 |                  | 1/2 DTCC2 |           | 1/2 DTCC2 |       |
| Additional BESS | 0 MW             | 58.6      | 57.7      | 57.7      | 38.6  |
|                 | 5 MW             | 58.7      | 58        | 58.1      | 45.6  |
|                 | 10 MW            | 59.3      | 58.4      | 58.4      | 53.2  |
|                 | 15 MW            | 59.4      | 58.7      | 58.7      | 57.8  |
|                 | 20 MW            | 59.4      | 59.3      | 59.1      | 58.3  |
|                 | 25 MW            | 59.5      | 59.3      | 59.2      | 58.7  |

Table D-22. Minimum Frequency Results for Boundary Cases



The results from Table D-22 define the contingency reserve requirement for the 2017 year as 20 MW of additional BESS being required to prevent Stage 2 UFLS.

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## YEAR 2023 ANALYSIS

Power flow cases were created for the peak load times. The 2023 year was selected to identify the operating restrictions required to prevent line overloads and low voltage conditions for the peak load in the study time frame. The year has the addition of several new generation units added between 2019 and 2023 and can be used to judge the security of the 2019-2023 period. The peak load is 218.5 MW in 2023 and will drop to 206.3 MW in 2030.

The assumptions used for the 2023 cases are in the list below:

- These cases assume that the Kamalii line upgrade does not take place
  - Sensitivity cases were run with the line upgrade to confirm that the upgrade resolves the low voltage issues
- The Wai'inu-Kanaha line upgrade is included in all cases
- The MPP-Pu'unene and MPP: Wai'inu lines are reconductored in all cases
- Only the peak loading case was studied
- Only steady state analysis was performed

## D. System Security Standards

Year 2023 Analysis

### 2023 Generation Dispatches

Only the peak cases were run for 2023 since it has the highest peak load in the study time frame. Details of the generation dispatches for the 2023 study year are shown in Table D-23.

| 2023         |                 |       |       |
|--------------|-----------------|-------|-------|
|              | Peak Load Level |       |       |
| Wind Level   | Windy           | Calm  | Windy |
| MPP 14       | 17.7            | 19.2  | 18.0  |
| MPP 15       | 8.0             | 11.5  | 11.5  |
| MPP 16       | 17.7            | 19.0  | 19.0  |
| MPP 17       | 17.5            | 20.0  | 20.0  |
| MPP 18       | 9.0             | 12.0  | 12.0  |
| MPP 19       | 18.0            | 20.0  | 20.0  |
| HC&S         |                 |       | 8.0   |
| MPP 10       | 10.0            | 12.0  | 12.0  |
| MPP 11       | 10.0            | 12.0  | 12.0  |
| MPP 12       | 10.0            | 12.0  | 12.0  |
| MPP 13       | 10.0            | 12.0  | 12.0  |
| MPP 4        |                 | 5.4   | 5.4   |
| MPP 6        |                 | 5.4   |       |
| MPP 8        |                 | 5.4   |       |
| MPP 9        |                 | 5.4   |       |
| MPP 1        | 2.5             | 2.5   | 2.5   |
| MPP 2        | 2.5             | 2.5   | 2.5   |
| MPP 3        |                 | 2.5   |       |
| WPP ICE 1    | 7.5             | 8.0   | 8.0   |
| WPP ICE 2    |                 | 8.0   | 8.0   |
| WPP ICE 3    |                 | 8.0   | 8.0   |
| S.Maui ICE 1 |                 |       |       |
| S.Maui ICE 2 |                 |       |       |
| S.Maui ICE 3 |                 |       |       |
| Wind Total   | 72.0            | 0.0   | 36.0  |
| Load         | 220.4           | 218.8 | 226.9 |
| Reg Up       | 31.6            | 10.8  | 15.0  |
| Reg Down     | 47.5            | 100.8 | 77.9  |

Table D-23. 2023 Peak Generation Dispatch

Each of the 2023 peak cases listed in Table D-23 do not have generation online in South Maui in order to stress the transmission around the South Maui area. The third dispatch was setup as a boundary case that mirrors previous studies performed for Maui Electric and has a system load that is 3% higher than predicted for 2023.

### 2023 Results

The MPP-Kihei outage is the critical contingency without the new Ma'alaea-Kamalii line. The loss of this line will cause low voltages, line overloads, and potential voltage collapse in the South Maui area.

Figure D-1 shows the impact that this outage has on the South Maui transmission system with the MPP-Kihei outage.

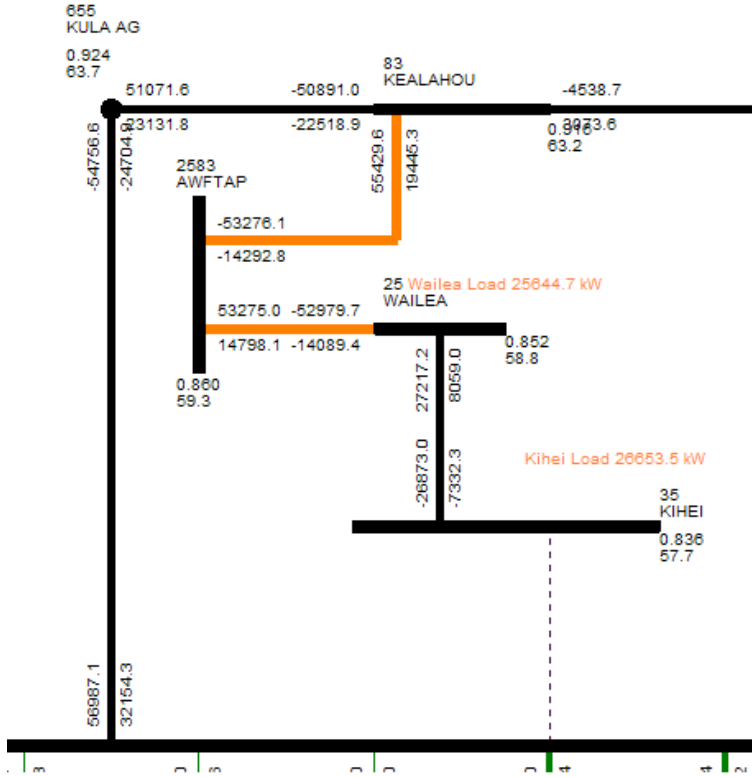


Figure D-I. MPP - Kihei Outage - Boundary Case

With the MPP–Kihei line out of service, the voltage at the Kihei bus is 0.836 pu, and is nearing voltage collapse. The Kealahou–AWFTAP and AWFTAP–Wailea lines are also overloaded. We studied this contingency with several load levels to determine the generation requirements needed in the South Maui area to prevent these low voltage and overload issues. The Kihei voltage remains above 0.90 for load levels below 173 MW with the loss of the MPP–Kihei line. Load levels above 173 MW require generation in South Maui. One 8 MW Wartsilla engine would be sufficient until the load level reaches 193 MW at which time a second unit would be required. When the load level reaches 223 MW, a third unit is required. Table D-24 shows the generation requirements in South Maui to prevent low voltages for various system load levels.

| Description   | # Units in South Maui to keep Kihei 69kV Voltage > 0.90 | System Net Generation |
|---|---|-----------------------|
| With 7.2 MVAR of cap banks online, Peak Load 223      | 3   | If System load >223   |
| With 7.2 MVAR of cap banks online, High Load of 193   | 2   | If System load >193   |
| With 7.2 MVAR of cap banks online, Medium Load of 173 | 1   | If System load >173   |
| With 7.2 MVAR of cap banks online, Medium Load of 173 | 0   | If System load <173   |

Table D-24. Generation Required in South Maui to Prevent Low Voltage

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## YEAR 2030 ANALYSIS

Power flow cases were created for the minimum, day minimum, day peak, and peak load times. Renewable generation resources consist of 130 MW of distributed PV (10 MW legacy PV) and 72 MW of wind. These focus on the generation associated with the Non-Transmission Alternatives which rely on firm generation in the South Maui area to relieve transmission constraints.

The assumptions used for the 2030 cases are in the list below:

- Cases with the Ma'alaea-Kamalii line addition were run
  - Non-Transmission Alternative cases were also run (NTA)
- NTA generation was run with Pumped Storage Hydro (PSH)
  - The use of 8 MW Wartsilla internal combustion engines was also analyzed
- DTCC1 and ½ DTCC2 are baseloaded
  - Sensitivity cases were run with only DTCC1 baseloaded
- Distributed generation was curtailed before the KWP1 plant since the KWP plant is the largest single generation contingency.

## 2030 Generation Dispatches

Table D-25 shows the dispatch cases created for the 2030 analysis.

| 2030            |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
|-----------------|--------------------|------|----------------------------|-------|-------|-------|-------------------------|-------|-------|-------|-----------------|-------|
|                 | Minimum Load Level |      | Daytime Minimum Load Level |       |       |       | Daytime Peak Load Level |       |       |       | Peak Load Level |       |
| Wind Level      | Windy              | Calm | Windy                      | Windy | Calm  | Calm  | Windy                   | Windy | Calm  | Calm  | Windy           | Calm  |
| Solar Gen (Cap) | 0.0                | 0.0  | 110.5                      | 13.0  | 110.5 | 13.0  | 110.5                   | 13.0  | 110.5 | 13.0  | 0.0             | 0.0   |
| Curtailed Solar |                    |      | 62.9                       |       | 6.0   |       | 31.5                    |       |       |       |                 |       |
| Solar Gen (MW)  |                    |      | 47.6                       | 13.0  | 104.5 | 13.0  | 79.0                    | 13.0  | 110.5 | 13.0  |                 |       |
| KPP 1           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| KPP 2           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| KPP 3           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| KPP 4           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 14          | 9.9                | 18.0 | 9.5                        | 12.5  | 9.3   | 18.5  | 9.2                     | 16.2  | 14.8  | 18.2  | 17.0            | 18.8  |
| MPP 15          | 4.0                | 12.0 | 4.0                        | 6.5   | 4.0   | 12.0  | 4.0                     | 8.5   | 7.0   | 11.0  | 8.0             | 11.5  |
| MPP 16          | 9.0                | 19.0 | 9.0                        | 13.0  | 9.0   | 18.0  | 10.0                    | 16.5  | 14.8  | 18.0  | 17.0            | 19.0  |
| MPP 17          | 14.4               | 18.0 | 14.5                       | 14.5  | 14.5  | 18.0  | 14.5                    | 17.0  | 15.5  | 19.0  | 18.0            | 20.0  |
| MPP 18          | 4.5                | 7.0  | 4.1                        | 4.5   | 4.1   | 10.0  | 4.5                     | 8.0   | 5.0   | 10.5  | 9.0             | 12.0  |
| MPP 19          |                    |      |                            |       |       | 18.0  |                         | 17.0  |       | 19.0  | 18.0            | 20.0  |
| HC&S            |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 10          |                    | 10.0 |                            | 12.0  |       | 10.0  |                         | 9.0   |       | 12.0  | 10.0            | 12.0  |
| MPP 11          |                    |      |                            |       |       | 11.0  |                         | 9.0   | 9.0   | 11.0  | 10.0            | 12.0  |
| MPP 12          |                    |      |                            |       |       | 11.0  |                         | 9.0   | 9.0   | 11.0  | 10.0            | 12.0  |
| MPP 13          |                    |      |                            |       |       |       |                         |       |       | 11.0  |                 | 12.0  |
| MPP 4           |                    |      |                            |       |       |       |                         |       |       |       |                 | 5.4   |
| MPP 6           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 8           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 9           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 1           |                    |      |                            |       |       |       |                         |       |       |       | 2.5             | 2.5   |
| MPP 2           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| MPP 3           |                    |      |                            |       |       |       |                         |       |       |       |                 |       |
| WPP ICE 1       |                    |      |                            |       |       |       |                         |       | 6.0   | 8.0   | 7.5             | 8.0   |
| WPP ICE 2       |                    |      |                            |       |       |       |                         |       |       | 8.0   |                 | 8.0   |
| WPP ICE 3       |                    |      |                            |       |       |       |                         |       |       | 8.0   |                 | 8.0   |
| S.Maui ICE 1    |                    | 6.5  |                            |       |       | 7.5   |                         |       |       | 8.0   | 8.0             | 8.0   |
| S.Maui ICE 2    |                    |      |                            |       |       |       |                         |       |       | 8.0   |                 | 8.0   |
| S.Maui ICE 3    |                    |      |                            |       |       |       |                         |       |       |       |                 | 8.0   |
| Wind Total      | 50.0               | 0.0  | 58.5                       | 72.0  | 0.0   | 0.0   | 72.0                    | 72.0  | 0.0   | 0.0   | 72.0            | 0.0   |
| Load            | 91.8               | 90.5 | 147.2                      | 148.0 | 145.4 | 147.0 | 193.2                   | 195.2 | 191.6 | 193.7 | 207.0           | 205.2 |
| Reg Up          | 40.5               | 10.6 | 39.2                       | 29.6  | 39.4  | 16.3  | 38.1                    | 32.6  | 32.2  | 16.5  | 30.1            | 11.4  |
| Reg Down        | 7.3                | 41.6 | 6.6                        | 20.6  | 6.4   | 45.1  | 6.7                     | 28.8  | 25.5  | 79.9  | 44.5            | 95.8  |

Table D-25. Dispatch Cases with DTCC1 and 1/2 DTCC2 Baseloaded

Each of these dispatch cases adheres to the HSIS reserve requirements. We created some sensitivity cases to determine the defining boundary cases. These boundary definition dispatch cases are shown below in Table D-26.

## D. System Security Standards

Year 2030 Analysis

| 2030            |                    |                            |       |       |                         |       |                          |       |
|-----------------|--------------------|----------------------------|-------|-------|-------------------------|-------|--------------------------|-------|
|                 | Minimum Load Level | Daytime Minimum Load Level |       |       | Daytime Peak Load Level |       | Boundary Case Dispatches |       |
| Wind Level      | Windy              | Windy                      | Calm  | Windy | Windy                   | Calm  | Windy                    | Windy |
| Solar Gen (Cap) | 0.0                | 130.0                      | 130.0 | 13.0  | 130.0                   | 130.0 | 130.0                    | 130.0 |
| Curtailed Solar |                    | 57.9                       |       |       | 12.5                    |       | 28.2                     | 41.9  |
| Solar Gen (MW)  | 0.0                | 52.6                       | 110.5 | 13.0  | 98.0                    | 110.5 | 82.3                     | 68.6  |
| MPP 14          | 10.6               | 9.6                        | 9.4   | 19.5  | 9.0                     | 20.0  | 19.9                     | 20.0  |
| MPP 15          | 4.0                | 4.0                        | 4.0   | 13.0  | 4.0                     | 12.0  | 13.0                     | 13.0  |
| MPP 16          | 9.0                | 9.0                        | 9.0   | 19.6  | 10.0                    | 19.5  | 20.0                     | 20.0  |
| MPP 17          |                    |                            | 12.4  |       |                         | 20.0  | 20.0                     |       |
| MPP 18          |                    |                            |       |       |                         | 7.2   | 7.2                      |       |
| MPP 19          |                    |                            |       |       |                         |       |                          |       |
| HC&S            |                    |                            |       |       |                         |       |                          |       |
| MPP 10          |                    |                            |       |       |                         |       |                          |       |
| MPP 11          |                    |                            |       | 11.0  |                         |       |                          |       |
| MPP 12          |                    |                            |       |       |                         |       |                          |       |
| MPP 13          |                    |                            |       |       |                         |       |                          |       |
| MPP 1           |                    |                            |       |       |                         | 2.5   |                          |       |
| MPP 2           |                    |                            |       |       |                         |       |                          |       |
| MPP 3           |                    |                            |       |       |                         |       |                          |       |
| Wind Total      | 68.0               | 72.0                       | 0.0   | 72.0  | 72.0                    | 0.0   | 30.0                     | 72.0  |
| Load            | 91.6               | 147.2                      | 145.3 | 148.1 | 193.0                   | 191.7 | 192.4                    | 193.6 |
| Reg Up          | 31.4               | 30.4                       | 35.8  | 2.2   | 30.0                    | 1.6   | 0.2                      | 0.0   |
| Reg Down        | 7.6                | 6.6                        | 10.9  | 39.2  | 6.0                     | 41.2  | 44.6                     | 36.0  |

Table D-26. Dispatch Cases with DTCC1 Baseloaded and 2 Boundary Case Dispatch Cases

The dispatch cases listed in Table D-26 were created to show the impact that removing ½ DTCC2 from the baseload commitment would have on the system stability constraints. The ‘Boundary Case Dispatches’ were created to show the system response to a contingency assuming all regulating reserve is being carried by battery systems. One of the boundary case dispatches assumed that DTCC1 and ½ DTCC2 were baseloaded, while the other assumed that only DTCC1 was baseloaded.

Simulations were run to determine the size of the regulating reserves needed in addition to the currently installed BESS systems, to prevent the second stage of load shedding. If the system frequency dropped low enough to trigger stage 2 of load shedding, then additional regulating reserves were added in 5 MW increments until the frequency stayed above the stage 2 load shedding setpoint.

## 2030 Results

The worst case event for each of the dispatch cases simulated was the loss of the KWP unit at maximum output. Since two alternatives for the non-transmission alternative were studied, the pumped storage hydro results are shown because this alternative has a slightly worse frequency response, but does not change the conclusions related to the size of BESS necessary to prevent stage 2 load shedding. Table D-27 and Table D-28 below show the minimum frequency results for the loss of the KWP plant.

| Loss of KWP |                 |           |           |            |          |
|-------------|-----------------|-----------|-----------|------------|----------|
| Case        | Thermal Reserve | 0 MW BESS | 5 MW BESS | 10 MW BESS | *Stage 1 |
| m_wnd       | 40.5            | 58.4      | 58.6      | 59.7       | *Stage 2 |
| m_clm       | 10.6            | -         | -         | -          |          |
| dm_wnd_sun  | 39.2            | 58.1      | 58.4      | 58.5       |          |
| dm_wnd_cld  | 29.6            | 58.6      | 58.7      | 58.9       |          |
| dm_clm_sun  | 39.4            | -         | -         | -          |          |
| dm_clm_cld  | 16.3            | -         | -         | -          |          |
| dp_wnd_sun  | 38.1            | 58.2      | 58.4      | 58.5       |          |
| dp_wnd_cld  | 32.6            | 59.1      | 59.2      | 59.2       |          |
| dp_clm_sun  | 32.2            | -         | -         | -          |          |
| dp_clm_cld  | 16.5            | -         | -         | -          |          |
| p_wnd       | 30.1            | 59.2      | 59.3      | 59.3       |          |
| p_clm       | 11.4            | -         | -         | -          |          |

Table D-27. Minimum Frequency for Loss of KWP: DTCC1 + ½ DTCC2 (Thermal Reserves)

| Loss of KWP |                 |            |            |            |          |
|-------------|-----------------|------------|------------|------------|----------|
|             | Thermal Reserve | 10 MW BESS | 15 MW BESS | 20 MW BESS | *Stage 1 |
| m_wnd       | 31.4            | 58.4       | 58.7       | 58.9       | *Stage 2 |
| dm_wnd_sun  | 30.4            | 58.2       | 58.5       | 58.8       |          |
| dm_wnd_cld  | 35.8            | 58.5       | 58.9       | 59.1       |          |
| dm_clm_sun  | -               | -          | -          | -          |          |
| dp_wnd_sun  | 30              | 58.1       | 58.5       | 58.8       |          |
| dp_wnd_cld  | 1.6             | 58.7       | 59.2       | 59.3       |          |

Table D-28. Minimum Frequency for Loss of KWP: DTCC1 Only (Thermal Reserves)

With reserves carried on the thermal units, a BESS system is still required to prevent the second stage of load shedding. From Table D-27, 49.2 MW contingency reserves (39.2 MW thermal reserves + 10 MW BESS) are required to prevent stage 2 for the dm\_wnd\_sun dispatch case. When DTCC1 is the only thermal unit online, the total contingency reserves required is approximately 50.4 MW (30.4 MW thermal reserves + 20 MW BESS). If ½ of DTCC2 is online, the additional BESS support can be reduced to 10 MW but would have additional thermal reserves online, and additional renewable curtailment.

When the system has all the reserve carried on the BESS systems, the total BESS required to prevent stage 2 load shedding is higher. The results for these cases are shown in Table D-29.

| Loss of KWP     |                 |          |       |       |       |       |          |
|-----------------|-----------------|----------|-------|-------|-------|-------|----------|
|                 | Thermal Reserve | 0 MW     | 10 MW | 15 MW | 20 MW | 25 MW | *Stage 1 |
| DTCC1 Only      | 0               | -        | -     | -     | 58.5  | 58.9  | *Stage 2 |
| DTCC1+1/2 DTCC2 | 0               | Collapse | 57.9  | 58.4  | 58.6  | -     | *Stage 3 |

Table D-29. Minimum Frequency for Loss of KWP with Boundary Cases (BESS Reserves)

If all the reserves are carried on the thermal units, 20 MW of additional BESS support is required with DTCC1 + ½ DTCC2 online. 25 MW of additional BESS support is required with only DTCC1 online.

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## CONCLUSIONS

EPS has completed analysis for the Maui Electric system defining the boundary conditions as to the operations of the system for the 2015, 2016, 2017, 2023, and 2030 case years. The boundary conditions represent the likely operating requirements due to the large additions of renewable energy and changes in load and generation expected in the future.

To aid in clarifying the different results, security tables were created showing the operating requirements for each year and each configuration within that year. The security tables include data values as to the minimum number for thermal units required, the ramp rate requirements, the regulation requirements, contingency reserves, and 30-minute reserves.

The ramp rate requirement was assumed to be 10% per minute for both PV and wind energy resources. This value was derived from analysis EPS has completed that is not part of this report.

The regulation requirements include values for day time and night time periods. The daytime regulation reserve is calculated as the summation of 20% of the installed DG PV, and 1:1 MW up to 50% of the installed wind. The night time regulation reserve is calculated as only 1:1 MW up to 50% of the installed wind.

For years 2017 and beyond the contingency reserve is calculated as the amount of reserves (energy storage) required in order to meet criteria for the largest unit or wind farm outage. For years before 2017 the contingency reserve is calculated as the amount of spinning reserves required in order to meet criteria for the largest unit or wind farm outage. The 30-minute reserves are equal to the largest unit or wind farm outage and is the required amount of energy to be brought online to displace the short term contingency reserves.

### Security Tables

The security tables for the 2015 and 2016 years assume that the utilities are unable to acquire a storage system, and therefore must meet the criteria with their operating practices with their current fleet of units and up to 10 MW of BESS for either contingency or regulation.



| MECO 2015- Min Thermal Units, No ESS |   |               |   |                        |                     |                                  |                      |                    |                     |
|--------------------------------------|---|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|---------------------|
|                                      |   | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30 Minute Reserves | DTT Scheme Required |
|                                      | Wind  | 72            | DTCC1 + KPP 3, KPP 4                              | 12.5 MW                | 47.25 MW            | 36 MW                            | 24 MW                | 40.2 MW            | Yes                 |
| PV Level                             | DG  | 75            |   |                        |                     |                                  |                      |                    |                     |
| Largest Unit                         |   | 30            |   |                        |                     |                                  |                      |                    |                     |
|                                      | Wind  | 72            | DTCC1 + 1/2 DTCC2 KPP 3, KPP 4                    | 12.5 MW                | 47.25 MW            | 36 MW                            | 45 MW                | 40.2 MW            | No                  |
| PV Level                             | DG  | 75            |   |                        |                     |                                  |                      |                    |                     |
| Largest Unit                         |   | 30            |   |                        |                     |                                  |                      |                    |                     |
| Notes:                               | 1: DTT Scheme refers to a direct transfer trip of Stage 1 of load shedding for select unit outages. In order to prevent the tripping of the second stage of load shedding, the first stage of load shedding should be transfer tripped for the loss of the KWP plant or any of the combustion turbines. |               |   |                        |                     |                                  |                      |                    |                     |

Table D-30. 2015 Security Table

| MECO 2016- Min Thermal Units, No ESS |   |               |   |                        |                     |                                  |                      |                    |                     |
|--------------------------------------|---|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|---------------------|
|                                      |   | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30 Minute Reserves | DTT Scheme Required |
|                                      | Wind  | 72            | DTCC1 + KPP 3, KPP 4                              | 14 MW                  | 49.5 MW             | 36 MW                            | 45 MW                | 40.2 MW            | No                  |
| PV Level                             | DG  | 90            |   |                        |                     |                                  |                      |                    |                     |
| Largest Unit                         |   | 30            |   |                        |                     |                                  |                      |                    |                     |
| Notes:                               | 1: DTT Scheme refers to a direct transfer trip of Stage 1 of load shedding for select unit outages. |               |   |                        |                     |                                  |                      |                    |                     |

Table D-31. 2016 Security Table

## D. System Security Standards

### Conclusions

The security tables for years after 2016 assume that the utility will have the capability to install an energy storage system to meet the criteria.

| MECO 2017- Min Thermal Units, Maximum ESS |  |               |   |                        |                     |                                  |                      |                    |
|---|--|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|
|   |  | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30 Minute Reserves |
|   | Wind   | 72            | DTCC1   | 14.6 MW                | 50.4 MW             | 36 MW                            | 25 MW                | 38.5 MW            |
| PV Level                                  | DG   | 96            |   |                        |                     |                                  |                      |                    |
| Largest Unit                              |  | 30            |   |                        |                     |                                  |                      |                    |
|   | Wind   | 72            | DTCC1 + 1/2 DTCC2                                 | 14.6 MW                | 50.4 MW             | 36 MW                            | 10 MW                | 38.5 MW            |
| PV Level                                  | DG   | 96            |   |                        |                     |                                  |                      |                    |
| Largest Unit                              |  | 30            |   |                        |                     |                                  |                      |                    |
|   | Wind   | 72            | DTCC1 + KPP 3, KPP 4                              | 14.6 MW                | 50.4 MW             | 36 MW                            | 10 MW                | 38.5 MW            |
| PV Level                                  | DG   | 96            |   |                        |                     |                                  |                      |                    |
| Largest Unit                              |  | 30            |   |                        |                     |                                  |                      |                    |
|   | Wind   | 72            | DTCC1 + 1/2 DTCC2 KPP 3, KPP 4                    | 14.6 MW                | 50.4 MW             | 36 MW                            | 0 MW                 | 38.5 MW            |
| PV Level                                  | DG   | 96            |   |                        |                     |                                  |                      |                    |
| Largest Unit                              |  | 30            |   |                        |                     |                                  |                      |                    |
| Notes:                                    | 1: The DTCC1 + 1/2 DTCC2 minimum unit combination closely matches the 2019 daytime cases since the load increase during the day is offset by the increase in the solar capacity. For this reason, 2019 cases were not run. |               |   |                        |                     |                                  |                      |                    |

Table D-32. 2017 Security Table

| MECO 2030 Baseline- Min Thermal Units, Maximum ESS |  |               |   |                        |                     |                                  |                      |                    |                         |
|--|--|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|-------------------------|
|  |  | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30-Minute Reserves | Transmission Constraint |
|  | Wind   | 72            | DTCC1   | 18 MW                  | 55.5 MW             | 36 MW                            | 25 MW                | 38.5 MW            | No                      |
| PV Level   | DG   | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |  | 30            |   |                        |                     |                                  |                      |                    |                         |
|  | Wind   | 72            | DTCC1 + 1/2 DTCC2                                 | 18 MW                  | 55.5 MW             | 36 MW                            | 20 MW                | 38.5 MW            | No                      |
| PV Level   | DG   | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |  | 30            |   |                        |                     |                                  |                      |                    |                         |
| Notes:   | 1. With the proposed transmission upgrades, the generation dispatch is not constrained by transmission |               |   |                        |                     |                                  |                      |                    |                         |

Table D-33. 2030 Security Table Baseline

| MECO 2030 NTA - PSH Min Thermal Units, Maximum ESS |   |               |   |                        |                     |                                  |                      |                    |                         |
|--|---|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|-------------------------|
|  |   | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30 Minute Reserves | Transmission Constraint |
|  | Wind  | 72            | DTCC1   | 18 MW                  | 55.5 MW             | 36 MW                            | 25 MW                | 38.5 MW            | Yes                     |
| PV Level   | DG  | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |   | 30            |   |                        |                     |                                  |                      |                    |                         |
|  | Wind  | 72            | DTCC1 + 1/2 DTCC2                                 | 18 MW                  | 55.5 MW             | 36 MW                            | 10 MW                | 38.5 MW            | Yes                     |
| PV Level   | DG  | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |   | 30            |   |                        |                     |                                  |                      |                    |                         |
| Notes:   | 1. With a 30 MW PSH located in South Maui, all transmission constraints can be relieved. Minimum frequency for unit trip events are slightly lower compared to the same contingencies with the proposed ICE units located in South Maui |               |   |                        |                     |                                  |                      |                    |                         |

Table D-34. 2030 Security Table NTA PSH Case

| MECO 2030 NTA - ICE Min Thermal Units, Maximum ESS |  |               |   |                        |                     |                                  |                      |                    |                         |
|--|--|---------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|-------------------------|
|  |  | Capacity (MW) | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30-Minute Reserves | Transmission Constraint |
|  | Wind   | 72            | DTCC1   | 18 MW                  | 55.5 MW             | 36 MW                            | 25 MW                | 38.5 MW            | Yes                     |
| PV Level   | DG   | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |  | 30            |   |                        |                     |                                  |                      |                    |                         |
|  | Wind   | 72            | DTCC1 + 1/2 DTCC2                                 | 18 MW                  | 55.5 MW             | 36 MW                            | 10 MW                | 38.5 MW            | Yes                     |
| PV Level   | DG   | 130           |   |                        |                     |                                  |                      |                    |                         |
| Largest Unit                                       |  | 30            |   |                        |                     |                                  |                      |                    |                         |
| Notes:   | 1. With a 24 MW of ICE units located in South Maui, all transmission constraints can be relieved. Minimum frequency for unit trip events are slightly better compared to the same contingencies with the proposed PSH unit located in South Maui. The difference in response between the PSH and ICE units does not warrant a change in the contingency reserve requirements |               |   |                        |                     |                                  |                      |                    |                         |

Table D-35. 2030 Security Table NTA ICE Case

## LANA'I PSIP 2030 SYSTEM SECURITY CASES

This study identifies the security requirements for various generation and load scenarios under study for the Lana'i system. As such the cases were intended to establish the boundary conditions for the security analysis.

### Assumptions

Several dispatch cases were created to determine the contingency reserve requirements of the Lana'i grid for the 2030 year. The assumed load level and PV generation for the island are shown below in Table D-36. Maui Electric provided a zip file containing the Lana'i power flow and dynamics database. The Lana'i generation characteristics used in this study are listed in Table D-37.

|            | Minimum | Daytime Minimum | Daytime Peak | Peak  |
|------------|---------|-----------------|--------------|-------|
| Load Level | 1,734   | 4,020           | 5,300        | 5,600 |
| Max PV     | -       | 2,242           | 2,242        | -     |
| Net Load   | 2,550   | 1,180           | 3,058        | 5,600 |

Table D-36: Lana'i 2030 Load and PV Generation Levels

|                                 | FUEL TYPE    | UNIT TYPE | NTL (GROSS MW) | MIN. LOAD (GROSS MW) | Reactive Power Limit | Typically On AGC When Running | Regulating / Load Following Capability | Regulation Mode | MODE OF OPERATION | RAMP RATES (GROSS MW/ MIN) |
|---------------------------------|--------------|-----------|----------------|----------------------|----------------------|-------------------------------|--|-----------------|-------------------|----------------------------|
| <b>LANAI GENERATING STATION</b> |              |           |                |                      |                      |                               |  |                 |                   |                            |
| LANAI1                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| LANAI2                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| LANAI3                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| LANAI4                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| LANAI5                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| LANAI6                          | No. 2 Diesel | ICE       | 1.19           | 0.25                 | 0.95                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 0.50                       |
| L7,D-7                          | No. 2 Diesel | ICE       | 2.20           | 0.55                 | 1.76                 | No AGC                        | Yes                                    | Isoch           | Baseload          | 1.10                       |
| L8,D-8                          | No. 2 Diesel | ICE       | 2.20           | 0.55                 | 1.76                 | No AGC                        | Yes                                    | 5% droop        | Baseload          | 1.10                       |
| L9,D-9                          | No. 2 Diesel | ICE       | 2.20           | 0.55                 | 1.76                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 1.10                       |
| L10,D-10                        | No. 2 Diesel | ICE       | 2.20           | 0.55                 | 1.76                 | No AGC                        | Yes                                    | 5% droop        | Peaking           | 1.10                       |

Table D-37. Lana'i Generating Characteristics

Table D-38 lists the PV trip settings used in this study, and is based on the IEEE 1547 PV trip settings, existing rule 14H settings, and the proposed 14H extended ride-through settings. The legacy PV has the IEEE 1547 trip settings which are a must-trip standard which means that the distributed generation must cease to energize the circuit by the specified delay times. Rule 14H is a standard that originally mimicked IEEE 1547 but has been modified to incorporate the unique characteristics of island power systems and

variable generation. The latest proposed modification to Rule 14H with extended ride-through settings increases the ride-through capability of the PV during severe system events. In addition, it is assumed that all PV that has the 14H (original modification and proposed ride-through settings) can also be curtailed.

| Frequency Settings | Under Frequency |       | Over Frequency |       |  |  |  |  |  |
|--------------------|-----------------|-------|----------------|-------|--|--|--|--|--|
|                    | Hz              | Delay | Hz             | Delay |  |  |  |  |  |
| IEEE 1547          | 59.3            | 0.167 | 60.5           | 0.167 |  |  |  |  |  |
| Rule 14H           | 57.0            | 0.167 | 60.5           | 0.167 |  |  |  |  |  |
| Rule 14H Extended  | 57.0            | 20.0  | 63.0           | 20.0  |  |  |  |  |  |

| Voltage Settings  | Under Voltage 1 |       | Under Voltage 2 |       | Over Voltage 1 |       | Over Voltage 2 |       |
|-------------------|-----------------|-------|-----------------|-------|----------------|-------|----------------|-------|
|                   | PU              | Delay | PU              | Delay | PU             | Delay | PU             | Delay |
| IEEE 1547         | 0.5             | 0.167 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |
| Rule 14H          | 0.5             | 0.167 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |
| Rule 14H Extended | 0.5             | 0.500 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |

Table D-38. PV Trip Setting Comparison IEEE 1547 vs. Rule 14H

The database provided by Maui Electric had no PV modeled in the power flow cases nor any associated under-frequency relays that would trip the PV generation at a frequency of 59.3 Hz. Therefore some assumptions were made as to modeling the different amounts or types of PV on the Lana'i system. The PV was modeled in two different scenarios. Scenario 1 assumed 673 kW of legacy PV, 736 kW of Rule 14H PV, and 833 kW of proposed Rule 14H Extended PV based on the estimated installation dates. Scenario 2 assumed that 80 % of the Legacy PV plus Modified Rule 14H PV was retrofitted to proposed Rule 14H Extended PV, resulting in 280 kW of legacy PV and 1960 kW of Rule 14H Extended PV. The two different scenarios were created in order to determine the impact on the ESS recommendations due to an inability to upgrade or retrofit existing PV installations. The two scenarios are shown below in Table D-39.

| PV Scenario | 1    | 2    |
|-------------|------|------|
| Legacy PV   | 673  | 282  |
| Rule 14 PV  | 736  |      |
| Extended PV | 833  | 1960 |
| Total PV    | 2242 | 2242 |

Table D-39. PV Configuration Scenarios

Simulations were used to determine the size of the regulating reserves needed to prevent the second stage of load shedding. If the system frequency dropped low enough to trigger stage 2 of load shedding, then additional contingency reserves were added in 100 kW increments until the frequency stayed above the stage 2 load shedding setpoint. The energy storage system was configured to utilize auto-scheduling that would allow the battery to go to full output 6 cycles after a loss of a unit. It should be noted that it appears that the Lana'i system consists of Stage 1 UFLS settings with slightly different frequency set points and relay timers between stage 1 and stage 2. Due to the characteristics of the Lana'i system, it is possible to trip Stage 2 and not trip Stage 1 with the existing settings.

## D. System Security Standards

Lana'i PSIP 2030 System Security Cases

It is recommended that the UFLS relays for 58.65 Hz and 0.4 second relay timer be changed to 0.2 second delay to allow for better coordination.

The load shedding settings listed in the provided database are shown in Table D-40.

| Stage    | Frequency (Hz) | Delay (seconds) |
|----------|----------------|-----------------|
| Kicker 1 | 58             | 3.0             |
| Kicker 2 | 58             | 4.5             |
| Stage 1  | 58.65-58.5     | 0.2-0.4         |
| Stage 2  | 57.5           | 0.25            |
| Stage 3  | 57             | 0.1-0.12        |

Table D-40. Under-Frequency Trip Settings

## Dispatch Cases

Table D-41 shows the dispatch cases that were created for the Lana'i 2030 cases.

| Unit             | Capacity |      | Day Minimum |      | Day Peak |      |
|------------------|----------|------|-------------|------|----------|------|
|                  | Pmax     | Pmin | A           | B    | A        | B    |
| LANAI1           | 1188     | 250  | 0           | 0    | 0        | 0    |
| LANAI2           | 1188     | 250  | 0           | 0    | 0        | 0    |
| LANAI3           | 1188     | 250  | 0           | 0    | 0        | 0    |
| LANAI4           | 1188     | 250  | 0           | 250  | 0        | 250  |
| LANAI5           | 1188     | 250  | 0           | 250  | 0        | 250  |
| LANAI6           | 1188     | 250  | 0           | 0    | 0        | 0    |
| L7,D-7           | 2200     | 550  | 2200        | 2200 | 2200     | 2200 |
| L8,D-8           | 2200     | 550  | 550         | 550  | 920      | 550  |
| L9,D-9           | 2200     | 550  | 0           | 0    | 0        | 0    |
| L10,D-10         | 2200     | 550  | 0           | 0    | 0        | 0    |
| Thermal Gen      |          |      | 2750        | 3250 | 3120     | 3250 |
| Solar Available  |          |      | 2242        | 2242 | 2242     | 2242 |
| Curtailed Solar  |          |      | 922         | 1422 | 0        | 130  |
| Solar Generation |          |      | 1320        | 820  | 2242     | 2112 |
| System Load      |          |      | 4020        | 4020 | 5300     | 5300 |
| Regulation Up    |          |      | 1650        | 3525 | 1280     | 3525 |
| Regulation Dn    |          |      | 1650        | 1650 | 2020     | 1650 |

Table D-41. 2030 Dispatch Cases

The cases were configured for the day minimum and day peak with a minimum generation scenario (A) and a larger generation dispatch scenario (B). Note that the day minimum cases required curtailment of the PV close to 50%. The day peak cases require minimal curtailment, if any.

## Results

The ESS size necessary to prevent the second stage of load shedding was tabulated for each of the dispatch cases and each of the PV configuration scenarios. These results are shown in Table D-42.

| Dispatch | PV Scenario | Daytime Minimum | Daytime Peak |
|----------|-------------|-----------------|--------------|
| "A"      | 1           | 1600 kW         | 1500 kW      |
| "A"      | 2           | 1400 kW         | 1300 kW      |
| "B"      | 1           | 1400 kW         | 1300 kW      |
| "B"      | 2           | 1100 kW         | 1100 kW      |

Table D-42. ESS Size Requirement

The results show that utilizing additional extended ride through PV settings can result in a decrease of ESS size by 200–300 kW. Also, adding additional units online can further decrease ESS size by 200–300 kW, especially for the daytime minimum case.

## Security Tables

To aid in clarifying the different results, security tables were created showing the operating requirements. The security tables include data values as to the minimum number for thermal units required, the ramp rate requirements, the regulation requirements, contingency and 30-minute reserves, and required voltage support, and are shown in Table D-43.

The ramp rate requirement was assumed to be 10% per minute for PV energy resources. This value was derived from analysis for other islands EPS has completed that is not part of this report.

The regulation requirements include values for day time and night time periods. The daytime regulation reserve is calculated as the summation of 20% of the installed PV. The night time regulation reserve is calculated as only 50% of the installed wind, and therefore is valued at 0 kW for the Lana'i system due to a lack in wind energy resources.

The contingency reserve is calculated as the amount of reserves (energy storage or PV regulation) required in order to meet criteria for the largest unit outage. The 30-minute reserves are equal to the largest unit outage and is the required amount of energy to be brought online to displace the short term contingency reserves.

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Moloka'i PSIP 2030 Cases

| Value    |              | Capacity (kW) | # of Thermal units required | Ramp Rate Requirements | Regulation Reserves - Day time | Regulation Reserves - Night time | Contingency Reserves | 30 Minute Reserves | Voltage Support (SVC) |
|----------|--------------|---------------|-----------------------------|------------------------|--------------------------------|----------------------------------|----------------------|--------------------|-----------------------|
| PV Level | Station      | 0             | 2                           | 224.2kW / Min          | 785 kW (20% of DG PV)          | 0 MW (50% of Wind)               | 1600 kW              | 2200 kW            | 0                     |
|          | DG           | 2242          |                             |                        |                                |                                  |                      |                    |                       |
|          | Wind         | 0             |                             |                        |                                |                                  |                      |                    |                       |
|          | Largest Unit | 2200          |                             |                        |                                |                                  |                      |                    |                       |
| PV Level | Station      | 0             | 4                           | 224.2kW / Min          | 785 kW (20% of DG PV)          | 0 MW (50% of Wind)               | 1500 kW              | 2200 kW            | 0                     |
|          | DG           | 2242          |                             |                        |                                |                                  |                      |                    |                       |
|          | Wind         | 0             |                             |                        |                                |                                  |                      |                    |                       |
|          | Largest Unit | 2200          |                             |                        |                                |                                  |                      |                    |                       |

Table D-43. Lana'i Security Tables

## MOLOKA'I PSIP 2030 CASES

This study identifies the security requirements for various generation and load scenarios under study for the Moloka'i system. As such the cases were intended to establish the boundary conditions for the security analysis.

### Assumptions

Several dispatch cases were created to determine the contingency reserve requirements of the Moloka'i grid for the 2030 year. The assumed load level and PV generation for the island are shown below in Table D-44. Maui Electric provided a zip file containing the Moloka'i power flow and dynamics database. The Moloka'i generation characteristics used in this study are listed in Table D-45.

Table D-45. Moloka'i Generation Characteristics

|            | Minimum | Daytime Minimum | Daytime Peak | Peak  |
|------------|---------|-----------------|--------------|-------|
| Load Level | 2,550   | 3,950           | 5,200        | 5,600 |
| Max PV     | -       | 2,770           | 2,770        | -     |
| Net Load   | 2,550   | 1,180           | 2,430        | 5,600 |

Table D-44. Moloka'i 2030 Load and PV Generation Levels



|                                  | FUEL TYPE    | UNIT TYPE | NTL (GROSS MW) | MIN. LOAD (GROSS MW) | Reactive Power Limit | Typically On AGC When Running | Regulating / Load Following Capability | Regulation Mode | MODE OF OPERATION | RAMP RATES (GROSS MW/MIN) |
|----------------------------------|--------------|-----------|----------------|----------------------|----------------------|-------------------------------|--|-----------------|-------------------|---------------------------|
| <b>PALAAU GENERATING STATION</b> |              |           |                |                      |                      |                               |  |                 |                   |                           |
| G01                              | No. 2 Diesel | ICE       | 1.25           | 0.4                  | 1.00                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G02                              | No. 2 Diesel | ICE       | 1.25           | 0.4                  | 1.00                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G03                              | No. 2 Diesel | ICE       | 0.97           | 0.4                  | 0.78                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G04                              | No. 2 Diesel | ICE       | 0.97           | 0.4                  | 0.78                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G05                              | No. 2 Diesel | ICE       | 0.97           | 0.4                  | 0.78                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G06                              | No. 2 Diesel | ICE       | 0.97           | 0.4                  | 0.78                 | No AGC                        | Yes                                    | 4% droop        | Cycling           | 0.5                       |
| G07                              | No. 2 Diesel | ICE       | 2.20           | 1.1                  | 1.76                 | No AGC                        | Yes                                    | Isoch           | Baseload          | 1.1                       |
| G08                              | No. 2 Diesel | ICE       | 2.20           | 1.1                  | 1.76                 | No AGC                        | Yes                                    | Isoch           | Baseload          | 1.1                       |
| G09                              | No. 2 Diesel | ICE       | 2.20           | 1.1                  | 1.76                 | No AGC                        | Yes                                    | Isoch           | Baseload          | 1.1                       |
| GT1                              | No. 2 Diesel | CT        | 2.22           | 1.1                  | 1.78                 | No AGC                        | Yes                                    | 4% droop        | Peaking           | 1.1                       |

Table D-45. Moloka'i Generation Characteristics

Table D-46 lists the PV trip settings used in this study, and is based on the IEEE 1547 PV trip settings and the proposed 14H extended ride-through settings. The legacy PV has the IEEE 1547 trip settings which are a must-trip standard which means that the distributed generation must cease to energize the circuit by the specified delay times. The proposed Rule 14H is a ride-through standard that specifies that the distributed generation must stay connected to the system until the abnormal system conditions have existed for at least as long as the delay. In addition, it is assumed that all PV that has the 14H extended ride through settings can also be curtailed.

| Frequency Settings    | Under Frequency |       | Over Frequency |       |  |  |  |  |
|-----------------------|-----------------|-------|----------------|-------|--|--|--|--|
|                       | Hz              | Delay | Hz             | Delay |  |  |  |  |
| IEEE 1547             | 59.3            | 0.167 | 60.5           | 0.167 |  |  |  |  |
| Modified Rule 14H     | 57.0            | 0.167 | 60.5           | 0.167 |  |  |  |  |
| Proposed 14H Extended | 57.0            | 20.0  | 63.0           | 20.0  |  |  |  |  |

| Voltage Settings      | Under Voltage 1 |       | Under Voltage 2 |       | Over Voltage 1 |       | Over Voltage 2 |       |
|-----------------------|-----------------|-------|-----------------|-------|----------------|-------|----------------|-------|
|                       | PU              | Delay | PU              | Delay | PU             | Delay | PU             | Delay |
| IEEE 1547             | 0.5             | 0.167 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |
| Modified Rule 14H     | 0.5             | 0.167 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |
| Proposed 14H Extended | 0.5             | 0.500 | 0.9             | 2.000 | 1.1            | 1.000 | 1.2            | 0.167 |

Table D-46. PV Trip Setting Comparison IEEE 1547 vs. Rule 14H

The database provided by Maui Electric 30% of the PV being tripped at 59.3 Hz to account for the legacy PV installations. The database had 1,620 kW of distributed PV, resulting in approximately 490 kW of PV capacity that would trip offline using the IEEE 1547 trip settings. We performed a sensitivity analysis that focused on the impact that retrofitting the currently installed PV has on the contingency reserve requirement for the Moloka'i system.

We assumed that the amount of PV that trips at 59.3 Hz would be decreased from 30% to 20% (similar to the amount of PV for the Maui Electric system). This assumption provides for a similar PV to peak system load ratio as seen on the Hawai'i Electric Light, Maui Electric, and Hawaiian Electric systems. The remaining PV utilize the proposed

## D. System Security Standards

Moloka'i PSIP 2030 Cases

extended ride-through settings. The result would be 324 kW of PV capacity that would use the IEEE 1547 trip settings, and the remainder would use the proposed Rule 14H extended ride-through settings.

To illustrate the importance of retrofitting the existing PV, a case was completed assuming none of the existing PV would be retrofitted. This results in approximately 490 kW that would trip offline at a frequency of 59.3 Hz and 60.5 Hz, and the remaining 1,134 kW PV would use the modified Rule 14H settings and trip offline at 57 Hz with a 10 cycle delay with all other trip settings identical to the IEEE 1547 trip settings. All future PV would use the extended ride-through settings highlighted in Table D-46. The two PV configuration scenarios are shown in Table D-47.

| PV Scenario           | No Retrofit | With Retrofit |
|-----------------------|-------------|---------------|
| Legacy PV             | 490 kW      | 324 kW        |
| Modified Rule 14 H PV | 1,134 kW    | -             |
| Proposed 14H Extended | 1,643 kW    | 2,939 kW      |
| Total PV              | 3,263 kW    | 3,263 kW      |

Table D-47. PV Configuration Scenarios (Capacity)

Simulations were run to determine the size of the regulating reserves needed to prevent the second stage of load shedding. If the system frequency dropped low enough to trigger stage 2 of load shedding, then additional regulating reserves were added in 100 kW increments until the frequency stayed above the stage 2 load shedding setpoint. The battery system was configured to have a 1% droop response with a deadband of  $\pm 0.05$  Hz.

The load shedding settings listed in the provided database are shown below in Table D-48.

| Stage    | Frequency (Hz) | Delay (seconds) |
|----------|----------------|-----------------|
| Kicker 1 | 58.7           | 5.0             |
| Kicker 2 | 57.75          | 2.5             |
| Stage 1  | 57.5           | 0.16            |
| Stage 2  | 57.25          | 0.75            |
| Stage 3  | 56             | 0.5             |

Table D-48. Under-Frequency Trip Settings

## Dispatch Cases

Table D-49 shows the dispatch cases that were created for the Moloka'i 2030 cases with all values listed in kW.

| Unit             | Capacity |       | Minimum Solar   |          |          |                   |          |          | Maximum Solar   |          |          |                   |          |          |
|------------------|----------|-------|-----------------|----------|----------|-------------------|----------|----------|-----------------|----------|----------|-------------------|----------|----------|
|                  |          |       | Daytime Minimum |          |          | Daytime Peak Load |          |          | Daytime Minimum |          |          | Daytime Peak Load |          |          |
|                  | Max      | Min   | Base            | Case 'A' | Case 'B' | Base              | Case 'A' | Case 'B' | Case 'C'        | Case 'D' | Case 'E' | Case 'C'          | Case 'D' | Case 'E' |
| G07              | 2,200    | 1,100 | 2,178           | 2,066    | 1,107    | 2,199             | 2,196    | 2,200    | 1,176           | 1,113    | 1,138    | 1,592             | 1,192    | 1,119    |
| G08              | 2,200    | 1,100 | 1,100           | 1,100    | 1,100    | 1,100             | 1,100    | 1,100    | 1,100           | 1,100    | 1,100    | 1,100             | 1,100    | 1,100    |
| G09              | 2,200    | 1,100 |                 |          | 1,100    |                   |          | 1,100    |                 |          | 1,100    |                   |          | 1,100    |
| G01              | 1,250    | 400   |                 | 400      |          |                   | 400      |          |                 | 400      |          |                   | 400      |          |
| G02              | 1,250    | 400   |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| G03              | 970      | 400   |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| G04              | 970      | 400   |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| G05              | 970      | 400   |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| G06              | 970      | 400   |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| GT1              | 2,220    | 1,100 |                 |          |          |                   |          |          |                 |          |          |                   |          |          |
| Solar Available  |          |       | 2,770           | 2,770    | 2,770    | 2,770             | 2,770    | 2,770    | 2,770           | 2,770    | 2,770    | 2,770             | 2,770    | 2,770    |
| Curtailed Solar  |          |       | 2,220           | 2,490    | 2,240    | 590               | 990      | 1,680    | 1,220           | 1,570    | 2,270    | 0                 | 0        | 620      |
| Solar Generation |          |       | 550             | 280      | 530      | 2,180             | 1,780    | 1,090    | 1,550           | 1,200    | 500      | 2,770             | 2,770    | 2,150    |
| System Load      |          |       | 3,828           | 3,846    | 3,837    | 5,479             | 5,476    | 5,490    | 3,826           | 3,813    | 3,838    | 5,462             | 5,462    | 5,469    |
| Regulation Up    |          |       | 1,122           | 2,084    | 3,293    | 1,101             | 1,954    | 2,200    | 2,124           | 3,037    | 3,262    | 1,708             | 2,958    | 3,281    |
| Regulation Dn    |          |       | 1,078           | 966      | 7        | 1,099             | 1,096    | 1,100    | 76              | 13       | 38       | 492               | 92       | 19       |

Table D-49. 2030 Dispatch Cases

The base and case 'C' dispatches only have 2 of the 2,200 kW units online. Case 'A' and case 'D' dispatches have two 2,200 kW units plus a 1,250 kW unit online. Case 'B' and case 'E' dispatches have three of the 2,200 kW units online. The base case, case 'A', and case 'B' are all dispatched with as much solar generation curtailed as possible. Case 'C', case 'D', and case 'E' are all accepting the maximum allowable solar generation. Even during the day peak load, case 'E' requires some solar curtailment.

The loss of either the G07 or the G08 unit was simulated for each of the dispatch cases listed above. A line fault and trip was also studied with 27 cycle clearing. This line goes from Pala'au-Kamehameha (Bus 1012-1091)

## D. System Security Standards

Moloka'i PSIP 2030 Cases

### Results

The BESS size necessary to prevent the second stage of load shedding was tabulated for each of the unit trips and dispatch cases. These results are shown in Table D-50.

| Dispatch | Retrofit     |                 | No Retrofit  |                 |
|----------|--------------|-----------------|--------------|-----------------|
|          | Daytime Peak | Daytime Minimum | Daytime Peak | Daytime Minimum |
| Base     | 700 kW       | 700 kW          | 1,300 kW     | 900 kW          |
| Case 'A' | 200 kW       | 200 kW          | 700 kW       | 300 kW          |
| Case 'B' | 0 kW         | 0 kW            | 0 kW         | 0 kW            |
| Case 'C' | 100 kW       | 0 kW            | 900 kW       | 300 kW          |
| Case 'D' | 0 kW         | 0 kW            | 0 kW         | 0 kW            |
| Case 'E' | 0 kW         | 0 kW            | 0 kW         | 0 kW            |

Table D-50. BESS Required to Prevent Stage 2 of Load Shedding

### Security Tables

Contingency reserves increased by 100 kW for '2x 2200 kW units' and '2x 2200 kW Units + 1x 1200 kW Unit'.

| Molokai 2030 Baseline- Min Thermal Units, Maximum ESS - WITH RETROFIT |   |                   |   |                        |                     |                                  |                      |                    |
|---|---|-------------------|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|
|   |   | Capacity (kW)     | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30-Minute Reserves |
|   | Wind  | 0                 | 2x 2200 kW Units                                  | 320 kW                 | 640 kW              | 0 kW                             | 700 kW               | 2470 kW            |
| PV Level  | DG  | 3263              |   |                        |                     |                                  |                      |                    |
|   |   | Largest Unit 2200 |   |                        |                     |                                  |                      |                    |
|   | Wind  | 0                 | 2x 2200 kW Units + 1x 1200 kW Unit                | 320 kW                 | 640 kW              | 0 kW                             | 200 kW               | 2470 kW            |
| PV Level  | DG  | 3263              |   |                        |                     |                                  |                      |                    |
|   |   | Largest Unit 2200 |   |                        |                     |                                  |                      |                    |
|   | Wind  | 0                 | 3x 2200 kW Units                                  | 320 kW                 | 640 kW              | 0 kW                             | 0 kW                 | 2470 kW            |
| PV Level  | DG  | 3263              |   |                        |                     |                                  |                      |                    |
|   |   | Largest Unit 2200 |   |                        |                     |                                  |                      |                    |
| Notes:  | <p>1: This case represents the case with max PV/Wind with minimum thermal units required for system stability. It is the extreme case for the minimum number of operating thermal units on the system.</p> <p>2: The regulation capacity and the ramp rate limit are the total required for the system as a whole. Any curtailed PV can provide both regulation and/or contingency reserves however the quantity should be adjusted to the expected capacity available as opposed to the expected energy levels.</p> <p>3: This analysis assumes the largest single contingency of future PV/Wind resources is limited to the same level of contingency as the largest thermal unit.</p> <p>4: The regulating reserves and the contingency reserves are individual requirements and should be summed together to arrive at the total required reserves.</p> |                   |   |                        |                     |                                  |                      |                    |

Table D-51. Moloka'i 2030 Baseline Minimum Thermal Units with Retrofit

| Molokai 2030 Baseline- Min Thermal Units, Maximum ESS - NO RETROFIT |              |   |   |                        |                     |                                  |                      |                    |
|---|--------------|---|---|------------------------|---------------------|----------------------------------|----------------------|--------------------|
|   |              | Capacity (kW)   | # of Thermal units required (security constraint) | Ramp Rate Requirements | Regulation Reserves | Regulation Reserves - Night time | Contingency Reserves | 30-Minute Reserves |
|   | Wind         | 0   | 2x 2200 kW Units                                  | 320 kW                 | 640 kW              | 0 kW                             | 1300 kW              | 2617 kW            |
| PV Level  | DG           | 3263  |   |                        |                     |                                  |                      |                    |
|   | Largest Unit | 2200  |   |                        |                     |                                  |                      |                    |
|   | Wind         | 0   | 2x 2200 kW Units + 1x 1200 kW Unit                | 320 kW                 | 640 kW              | 0 kW                             | 700 kW               | 2617 kW            |
| PV Level  | DG           | 3263  |   |                        |                     |                                  |                      |                    |
|   | Largest Unit | 2200  |   |                        |                     |                                  |                      |                    |
|   | Wind         | 0   | 3x 2200 kW Units                                  | 320 kW                 | 640 kW              | 0 kW                             | 0 kW                 | 2617 kW            |
| PV Level  | DG           | 3263  |   |                        |                     |                                  |                      |                    |
|   | Largest Unit | 2200  |   |                        |                     |                                  |                      |                    |
| Notes:  |              | <p>1: This case represents the case with max PV/Wind with minimum thermal units required for system stability. It is the extreme case for the minimum number of operating thermal units on the system.</p> <p>2: The regulation capacity and the ramp rate limit are the total required for the system as a whole. Any curtailed PV can provide both regulation and/or contingency reserves however the quantity should be adjusted to the expected capacity available as opposed to the expected energy levels.</p> <p>3: This analysis assumes the largest single contingency of future PV/Wind resources is limited to the same level of contingency as the largest thermal unit.</p> <p>4: The regulating reserves and the contingency reserves are individual requirements and should be summed together to arrive at the total required reserves.</p> |   |                        |                     |                                  |                      |                    |

Table D-52. Moloka'i 2030 Baseline Minimum Thermal Units with No Retrofit

**D. System Security Standards**

Moloka'i PSIP 2030 Cases

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## E. Essential Grid Services

Grid services include generating capacity plus ancillary services, which are both essential to reliable system operation. Generating capacity is used to meet load demands; ancillary services supplement the generating capacity to help meet demand or correct frequency deviations that occur as a result of normal changes in load and generation, as well as the result of abnormal transient events. Ancillary services can occur in layers, with some taking longer to act than others. The system operator needs to designate which ancillary services are necessary for the system characteristics at the time.

Synchronous generation has traditionally provided generating capacity and ancillary services. Increasing amounts of variable generation, however, diminish the amount of dispatchable generation on the system and the ability of dispatchable generation to provide the needed ancillary services. In many cases, the variable generation resources do not provide the level of ancillary services required for the system's security. In addition, the potential loss of variable distributed generation (whether due to large ramping events or trips due to transient events) has become the largest contingency for which many of the ancillary services must be designed.

For these reasons, new generation resources must have the ability to also provide required ancillary services, or new systems that can provide the ancillary services must be added. Variable generation costs should include the cost of periodic testing and maintenance of their accompanying ancillary systems to ensure the reliability of the electric system. The variable generation protection and control devices should be tested and verified at installation, and tested and maintained periodically after that. Every device should be calibrated and tested at least every three years.

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## GRID SERVICES

### Capacity

Capacity is the maximum reliable amount of electrical output available from a resource. Systems must be operated to ensure there is sufficient capacity online to meet demand in the near term. Systems must be planned and designed to ensure that there is adequate supply of capacity to meet future demands. For dispatchable generation, the capacity is the maximum power output of the generating unit<sup>1</sup>. For variable generation (such as wind or solar power), capacity in the near term is the minimum available amount of output expected in the next one to three hours. The capacity of controlled load in the near term is the minimum level of load under control during each of the four six-hour planning periods of a 24-hour day.

For planning capacity margins, the capacity contribution for variable generation is developed by examining the historical availability during the peak demand periods, to determine the amount of capacity which is very probable to be available in the peak period. Similarly, demand response could contribute to capacity if it is available during the peak period. To count as capacity, the generation does not have to be under automatic generation control (AGC) to reach its maximum rating. Unit control can be by AGC, by human intervention, or a combination, so long as the output is controllable and predictable.

Capacity does not have a response time requirement. However, as stated above, it must be reliably available for a period of time.

Generation capacity should be modeled and tested consistent with HI-Mod-0010 and HI-Mod-0025.<sup>2</sup> Controlled load capacity should be modeled and tested in accordance with capacity testing and modeling requirements for conventional generation capacity. Controlled load will need periodic review and exercising to confirm its stated capacity, as the load characteristics change over time.

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<sup>1</sup> Generators are designed higher than its prime mover's capability, therefore the generator's nameplate rating can sometimes be higher than what it actually produces.

<sup>2</sup> HI-Mod-0010 is the proposed Hawaiian standard for modeling unit capacity used for system studies. HI-Mod-0025 is the proposed Hawaiian standard for testing unit capacity to confirm its model for use in electrical studies.



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## ANCILLARY SERVICES

### Regulating Reserve

Regulating reserve is the amount of unloaded capacity of regulation resources that can be used to match system demand with generation resources and maintain normal frequency. Use of regulating reserve is governed by a command from Automatic Generation Control (AGC) to a change in system demand. A change in system demand results in a change in system frequency, and the AGC program will adjust the generating units under its control to return system frequency to the normal state. A regulation resource is a resource that immediately responds, without delay, to commands from AGC to predictably increase or decrease its generation output. Regulation resources must accurately and predictably respond to AGC commands throughout their range of operation.

Regulation resources can also include non-traditional resources such as controlled loads or storage, providing the necessary control capabilities and response for the AGC interface. Non-generation resources participating in regulation must be capable of sustaining the maximum increase or decrease for at least 30 minutes.

Regulating reserve is used to counter normal changes in load or variable generation. Changes in generation output or controlled loads must be completed within 2 seconds of the AGC command, and must be controllable by AGC to a resolution of 0.1 MW.

In our islanded power system, regulation resources are constantly used to balance load and generation to maintain a 60 Hz frequency reference. The number of controls to regulating resources is greater than larger systems, due to a combination of the impacts of the small system size, its isolation, and the amount of variable wind and solar generation on the systems whose variable output requires additional adjustments from regulating resources. As a result, it has been typical on the island systems that all online resources capable of participating in regulation are used for regulation.

If demand response or storage are used for regulation, the cost of modifying the AGC system to be able to utilize these non-traditional resources as a regulation resource should be included in valuation of these alternate resources. The implementation must include special considerations specific to non-generation resources, such as the need to adopt the regulation algorithms to consider that the limits of the storage or demand response (that is, the response cannot be sustained indefinitely, unlike a dispatchable generator), and to include the rotation of DR within the group to limit impact on DR resources of the same type.

### Contingency Reserve

Each of the Companies' systems must be operated such that the system remains operable and the grid frequency can be quickly restored following a contingency situation wherein a generating or transmission resource on the island suddenly trips offline. This can be the largest single unit, the largest combination of dependent units (such as combined cycle units), or the loss of a single transmission line connecting a large generation unit to the system. The contingency reserve is the reserve designated by a system operator to meet these requirements.

Conventional generation, stored energy resources, curtailed variable generation, load shed or DR resources can provide contingency reserves.

Contingency reserves carried on generator resources, including storage, must respond automatically to changes in the system frequency, with a droop response determined by the system operator.

The island systems are unique in that all imbalances between supply and demand result in a change in system frequency. There are no interconnections to draw additional power from in the event of loss of generation. As a result, the island systems rely heavily upon instantaneous underfrequency load-shed to provide protection reserves and contingency reserves. If participating in the instantaneous protection, which may be used for contingency reserves or system protection, DR or load shed must be accurate to  $\pm 0.02$  Hz and  $\pm 0.0167$  cycles. The response time from frequency trigger to load removal can be no more than 7 cycles.

DR that cannot meet the 7-cycle requirement may be used for a time-delay, or the "kicker block" of under frequency load-shed. This block of load-shed is used for smaller increments of generation loss than the contingency reserves (set at a higher frequency set-point than the faster, instantaneous load-shed). Resources deployed for time-delay load-shed must be controllable within an accuracy of  $\pm 0.02$  Hz and  $\pm 0.02$  seconds, and have a response time from frequency trigger to load removal adjustable in increments of 0.5 seconds up to 30 seconds, to be considered for use as time delay load-shed.

To ensure consistent performance, DR controls and loads used for contingency reserve should be tested and certified annually. (See HI-Mod-012, HI-Mod-010, and HI-Mod-025, 26, 27.<sup>3</sup>) Annual costs for testing and certification should be included in the total cost for these provisions.

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<sup>3</sup> HI-Mod-0012 is the proposed Hawaiian standard for modeling and reporting the dynamic response of system models and results of simulations using these models. HI-Mod-0260 is the proposed Hawaiian standard for verifying plant or excitation equipment used in system models. HI-MOD-0027 is the proposed Hawaiian standard for verifying the models for turbine/governor and frequency control functions.

Controllable load used in any other DR program cannot be included in the loads designated as contingency reserves. The impacts of any DR use on the instantaneous underfrequency load-shed schemes must be evaluated and incorporated into the design to ensure adequate system protection remains.

### 10-Minute Reserve

Off-line, quick-start resources can be used as 10-minute reserves provided they can be started and synchronized to the grid in 10 minutes or less. These resources may be used for restoring regulation or contingency reserves.

When conditions warrant, a system operator starts the 10-minute reserve resource remotely, and automatically synchronizes it to the power system. The system operator then either loads the resource to a predetermined level, or places it under AGC control, either of which must be completed within 10 minutes. The 10-minute reserve must be able to provide the declared output capability for a minimum of two hours.

The resource can be any resource with a known output capability. Resources can include generators, storage, and controllable loads. A system operator must be able to control these resources to restore regulation or contingency reserves.

### 30-Minute Reserve

Off-line, 30-minute reserve resources shall be resources that can be operated during normal load and generation conditions, and can be started and synchronized to the grid in 30 minutes or less. They can be counted as capacity resources to meet expected load and demand, or to restore contingency reserves.

When conditions warrant, a system operator starts the resource remotely, synchronizes it, and (if participating in regulating reserves) places it under AGC control within 30 minutes; when it must then be able to serve the capacity for at least three hours.

The 30-minute reserve resource can be any resource with a known capacity. A system operator must be able to control these load resources to restore contingency or regulation reserves.

### Long Lead-Time Reserve

Resources that take longer than 30 minutes to be started, synchronized, and placed under AGC control (if participating in regulating reserves) are considered long lead-time reserves. They can be operated during normal load and generation conditions. These resources may be used as capacity resources to meet expected load and demand, and for restoring contingency reserves.

## E. Essential Grid Services

### Ancillary Services

Long lead-time reserves can include any resource with a known capacity. System operators must be able to control these load resources to restore contingency reserves.

Long-lead time resources can be used to meet forecast peak demand, in addition to restoring contingency reserves or the replacement of fast-start reserves. Long-lead time reserves must be able to serve the capacity for at least three hours.

### Black Start Resource

A black start resource is a generating unit and its associated equipment that can be started without support from the power system, or is designed to remain energized without connection to the remainder of the power system. A black start resource needs to be able to energize a bus, meeting a system operator's restoration plan needs for real and reactive power capability, frequency, and voltage control. It must also be included in the transmission operator's restoration plan.

A black start resource must be capable of starting within 10 minutes. The starting sequence can be manual or automatic.

### Primary Frequency Response

Primary frequency response is a generation resource's automatic response to an increase or decrease in frequency. The primary frequency response is the result of governor control, not control by AGC or frequency triggers, and must be sustainable. Unless controlled by a governor or droop response device, controlled load cannot provide primary frequency control.

The resource must immediately alter its output in direct proportion to the change in frequency, to counter the change in frequency. The response is determined by the design setting, which is specified by the system operator as a droop response from 1 to 5 percent. The response must be measurable within 10 seconds of the change in frequency. Under certain conditions, a certain generator resource may be placed on zero droop (also called isochronous control), such as under disturbance and restoration. Under these conditions, the isochronous generator will control system frequency instead of AGC.

Primary frequency response of a device is subject to the limitations of equipment. Equipment that is at its maximum operating output is not able to increase output in response to low frequency, but will still decrease its output in response to increasing frequency. Any generator at its maximum output, or a variable wind generator producing the maximum output for the available wind energy, may, if designed to have a frequency response, provide downward response to high frequency, but will not be able to increase output in response to low frequency. Curtailed variable generation or conventional generation operating below its maximum limit and above its minimum

limit can contribute both upward and downward primary frequency response. Based on the design of its system, energy storage systems can also provide primary frequency response.

Primary frequency response cannot be withdrawn if frequency is within the bandwidth of a reportable disturbance as defined in BAL-HI-002. The primary frequency response should replace the inertia or fast frequency response of the system without a drop in system frequency.

### Inertial or Fast Frequency Response

Inertial or fast frequency response is a local response to a change in frequency, reducing its rate of change. The response is immediate (measured in milliseconds), continuous, and proportional to the change in frequency, and does not rely on governor controls. The response is available even if the resource is also being used for other services (such as regulation or ramping). This response is short-lived, lasting not more than two to three seconds.

Inertial response relies on the rotating mass of a conventional generator. It can also be supplied by flywheels. Fast frequency response can be supplied by battery storage. If the inertia or fast response reserves are supplied from a resource that cannot sustain the load, primary or secondary resources must be available to take over without a drop in system frequency.

### Secondary Frequency Control

Secondary (or supplemental) frequency control is provided by resources in response to AGC to correct a change in frequency, using both the regulating and contingency reserves. Secondary frequency response can be provided by conventional generation, load control, or variable generation, all of which must be under AGC control. If AGC is disabled, such as during system restoration, secondary frequency control will be provided by manual operation of resources to maintain the isochronous generator within its lower and upper limits. The response requirements for secondary control are the same as for participation in regulating reserves.

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## F. Modeling Assumptions Data

The Hawaiian Electric Companies created this PSIP based, in parts, on a realization of the current state of the electric systems in Hawai'i, forecast conditions, and reasonable assumptions regarding technology readiness, availability, performance, applicability, and costs. As a result, this plan presents a reasonable and viable path into the future for the evolution of our power systems. We have attempted to document and be fully transparent about the assumptions and methodologies utilized to develop this plan. We recognize, however, that over time these forecasts and assumptions may or may not prove to be accurate or representative, and that the plan would need to be updated to reflect changes. As we move forward, we will continually evaluate the impacts of any changes to our material assumptions, seek to improve the planning methodologies, and evaluate and revise the plan to best meet the needs of our customers.

This appendix summarizes the assumptions utilized to perform the PSIP analyses.

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## UTILITY COST OF CAPITAL AND FINANCIAL ASSUMPTIONS

The Hawaiian Electric Companies finance their investments through two main sources of capital: debt (borrowed money) or equity (invested money). In both cases, we pay a certain rate of return for the use of this money. This rate of return is our *Cost of Capital*.

Table F-1 lists the various sources of capital, their weight (percent of the entire capital portfolio), and their individual rates of return. Composite percentages for costs of capital are presented under the table.

| Capital Source                | Weight | Rate  |
|-------------------------------|--------|-------|
| Short Term Debt               | 3.0%   | 4.0%  |
| Long Term Debt (Taxable Debt) | 39.0%  | 7.0%  |
| Hybrids                       | 0.0%   | 6.5%  |
| Preferred Stock               | 1.0%   | 6.5%  |
| Common Stock                  | 57.0%  | 11.0% |

Composite Weighted Average 9.185%  
 After-Tax Composite Weighted Average 8.076%

Table F-1. Utility Cost of Capital

## FUEL SUPPLY AND PRICES FORECASTS

The potential cost of producing electricity will depend, in part, on the cost of fuels utilized in the generation of power. The cost of different fuels over the next 20-plus years are forecast and used in the PSIP analyses. Maui Electric may burn the following different types of fuels during the study period on Lanai, Molokai, and/or Maui:

- *High Sulfur Diesel (HSD)* is a No. 2 oil that is up to 0.4% sulfur content.
- *Medium Sulfur Fuel Oil (MSFO)*, and also referred to as Industrial Fuel Oil (IFO) or Bunker Fuel Oil; is less 2% sulfur content.
- *S500* is a low sulfur diesel fuel that is 500 to 10,000 parts per million of sulfur content.
- *Ultra Low Sulfur Diesel (ULSD)* that is as low as 0.0015% sulfur content.
- *Biodiesel*
- *Liquefied Natural Gas (LNG)* is a natural gas (a fossil fuel) that has been converted to a liquid, which sharply decreases volume and eases transportation and storage.

## F. Modeling Assumptions Data

### Fuel Supply and Prices Forecasts

## How the Fuel Price Forecasts Were Derived

### Petroleum-Based Diesel Fuels

In general, we derived petroleum-based diesel fuels forecasts by applying the relationship between historical crude oil commodity prices and historical fuel purchase prices to forecasts for the crude oil commodity price. The petroleum-based fuel forecasts reflect U.S. Energy Information Administration (EIA) forecast data for *Imported Crude Oil* and *GDP Chain-Type Price Index* from the 2014 Annual Energy Outlook (AEO2014) year-by-year tables. Historical prices for crude oil are EIA publication table data for the *Monthly Energy Review* and macroeconomic data. Historical actual fuel costs incorporate taxes and certain fuel-related and fuel-handling costs including but not limited to trucking and ocean transport, petroleum inspection, and terminalling fees.

### Biodiesel

Biodiesel forecasts are generally derived by comparing commodity forecasts with recent biofuel contracts and RFP bids to determine adjustments needed to derive each company's respective biodiesel price forecast from forecasted commodities. EIA provides low, reference, and high petroleum forecasts, which are used to project low, reference, and high petroleum-based fuel price forecasts. A similar commodity forecast has not been found for biodiesel, although EIA might provide one in the future. In lieu of such a source, we used the Food and Agricultural Policy Research Institute at Iowa State University (FAPRI) to create a reference forecast, which we then scaled on the EIA Petroleum forecasts to create a low and high biodiesel forecast.

### Liquefied Natural Gas (LNG)

We do not have historical purchase data for LNG in Hawai'i. For purposes of this PSIP analyses, LNG pricing (delivered to the power generation facilities) were developed as described in Appendix I: LNG to Hawai'i.

### Maui Electric Fuel Price Forecasts

| \$/MMBtu | Fuel Price Forecasts |                |                |                |                  |                    |                     |                                      |
|----------|----------------------|----------------|----------------|----------------|------------------|--------------------|---------------------|--------------------------------------|
|          | HSD<br>(Maui)        | MSFO<br>(Maui) | S500<br>(Maui) | ULSD<br>(Maui) | ULSD<br>(Lana'i) | ULSD<br>(Moloka'i) | Biodiesel<br>(Maui) | LNG<br>(Maui, Lana'i,<br>& Moloka'i) |
| 2014     | \$22.81              | \$15.67        | \$23.40        | \$33.67        | \$23.67          | \$27.30            | \$33.67             | n/a                                  |
| 2015     | \$22.78              | \$15.63        | \$23.37        | \$30.23        | \$23.65          | \$27.35            | \$30.23             | n/a                                  |
| 2016     | \$22.31              | \$15.25        | \$22.89        | \$30.41        | \$23.17          | \$26.95            | \$30.41             | n/a                                  |
| 2017     | \$22.28              | \$15.20        | \$22.86        | \$31.15        | \$23.14          | \$26.98            | \$31.15             | \$16.71                              |
| 2018     | \$22.77              | \$15.55        | \$23.36        | \$31.83        | \$23.65          | \$27.55            | \$31.83             | \$16.81                              |
| 2019     | \$23.56              | \$16.12        | \$24.17        | \$31.87        | \$24.46          | \$28.41            | \$31.87             | \$17.00                              |
| 2020     | \$24.45              | \$16.76        | \$25.09        | \$31.93        | \$25.38          | \$29.38            | \$31.93             | \$17.30                              |
| 2021     | \$25.45              | \$17.48        | \$26.11        | \$32.17        | \$26.40          | \$30.45            | \$32.17             | \$17.69                              |
| 2022     | \$26.49              | \$18.24        | \$27.17        | \$32.56        | \$27.47          | \$31.58            | \$32.56             | \$13.73                              |
| 2023     | \$27.59              | \$19.04        | \$28.31        | \$32.69        | \$28.61          | \$32.77            | \$32.69             | \$13.95                              |
| 2024     | \$28.69              | \$19.84        | \$29.43        | \$33.19        | \$29.74          | \$33.96            | \$33.19             | \$14.12                              |
| 2025     | \$29.77              | \$20.62        | \$30.54        | \$33.49        | \$30.85          | \$35.13            | \$33.49             | \$14.33                              |
| 2026     | \$30.79              | \$21.35        | \$31.59        | \$33.80        | \$31.90          | \$36.24            | \$33.80             | \$14.61                              |
| 2027     | \$31.97              | \$22.21        | \$32.80        | \$34.11        | \$33.12          | \$37.52            | \$34.11             | \$15.02                              |
| 2028     | \$33.07              | \$23.00        | \$33.92        | \$34.42        | \$34.25          | \$38.71            | \$34.42             | \$15.39                              |
| 2029     | \$34.23              | \$23.84        | \$35.12        | \$34.72        | \$35.44          | \$39.98            | \$34.72             | \$15.78                              |
| 2030     | \$35.33              | \$24.64        | \$36.25        | \$35.03        | \$36.58          | \$41.19            | \$35.03             | \$16.21                              |

Table F-2. Fuel Price Forecasts

## F. Modeling Assumptions Data

### Sales and Peak Forecasts

## SALES AND PEAK FORECASTS

Sales and net peak forecasts were developed with and without the effects of Dynamic Pricing. As described in the *Integrated Demand Response Portfolio Plan (IDRPP)*<sup>1</sup> Dynamic Pricing is a demand response program that incent customers (on a voluntary basis) to change their energy use behavior, resulting in increased load demand during certain periods of the day and decreased net peak demand.

### Sales Forecasts (without Dynamic Pricing Adjustments)

| Year | Load without DG-PV         |                            | Total DG-PV (Uncurtailed) |                     | Sales with DG-PV        |
|------|----------------------------|----------------------------|---------------------------|---------------------|-------------------------|
|      | Net Generation:<br>GWh (a) | Sales: Customer<br>GWh (b) | Net GWh<br>(c)            | Customer GWh<br>(d) | Customer GWh<br>(b – d) |
| 2015 | 1,221.2                    | 1,152.7                    | 124.4                     | 117.4               | 1,035.3                 |
| 2016 | 1,243.3                    | 1,173.6                    | 146.3                     | 138.1               | 1,035.5                 |
| 2017 | 1,274.7                    | 1,203.3                    | 152.3                     | 143.8               | 1,059.5                 |
| 2018 | 1,313.8                    | 1,240.2                    | 160.3                     | 151.3               | 1,088.9                 |
| 2019 | 1,338.4                    | 1,263.4                    | 167.5                     | 158.2               | 1,105.2                 |
| 2020 | 1,356.2                    | 1,280.2                    | 174.5                     | 164.7               | 1,115.5                 |
| 2021 | 1,361.9                    | 1,285.6                    | 179.4                     | 169.4               | 1,116.3                 |
| 2022 | 1,367.3                    | 1,290.7                    | 183.9                     | 173.6               | 1,117.1                 |
| 2023 | 1,372.1                    | 1,295.2                    | 188.1                     | 177.6               | 1,117.6                 |
| 2024 | 1,379.5                    | 1,302.2                    | 192.1                     | 181.3               | 1,120.9                 |
| 2025 | 1,376.2                    | 1,299.1                    | 195.9                     | 184.9               | 1,114.2                 |
| 2026 | 1,370.8                    | 1,294.0                    | 199.5                     | 188.3               | 1,105.7                 |
| 2027 | 1,361.8                    | 1,285.5                    | 203.0                     | 191.6               | 1,093.9                 |
| 2028 | 1,351.0                    | 1,275.3                    | 206.4                     | 194.8               | 1,080.5                 |
| 2029 | 1,332.3                    | 1,257.7                    | 209.5                     | 197.8               | 1,059.9                 |
| 2030 | 1,311.0                    | 1,237.6                    | 212.5                     | 200.6               | 1,036.9                 |

Loss Factor: 5.60%

Table F-3. Sales Forecasts (without Dynamic Pricing Adjustments)

<sup>1</sup> The IDRPP was filed on July 28, 2014.

Sales Forecasts (with Dynamic Pricing Adjustments)

| Year | Load without DG-PV         |                            | Total DG-PV (Uncurtailed) |                     | Sales with DG-PV        |
|------|----------------------------|----------------------------|---------------------------|---------------------|-------------------------|
|      | Net Generation:<br>GWh (a) | Sales: Customer<br>GWh (b) | Net GWh<br>(c)            | Customer GWh<br>(d) | Customer GWh<br>(b – d) |
| 2015 | 1,221.2                    | 1,152.7                    | 124.4                     | 117.4               | 1,035.3                 |
| 2016 | 1,243.3                    | 1,173.6                    | 146.3                     | 138.1               | 1,035.5                 |
| 2017 | 1,278.7                    | 1,207.0                    | 152.3                     | 143.8               | 1,063.2                 |
| 2018 | 1,317.9                    | 1,244.0                    | 160.3                     | 151.3               | 1,092.7                 |
| 2019 | 1,342.3                    | 1,267.1                    | 167.5                     | 158.2               | 1,108.9                 |
| 2020 | 1,360.1                    | 1,283.9                    | 174.5                     | 164.7               | 1,119.2                 |
| 2021 | 1,365.8                    | 1,289.3                    | 179.4                     | 169.4               | 1,120.0                 |
| 2022 | 1,371.3                    | 1,294.4                    | 183.9                     | 173.6               | 1,120.9                 |
| 2023 | 1,376.2                    | 1,299.0                    | 188.1                     | 177.6               | 1,121.5                 |
| 2024 | 1,383.6                    | 1,306.0                    | 192.1                     | 181.3               | 1,124.7                 |
| 2025 | 1,380.3                    | 1,303.0                    | 195.9                     | 184.9               | 1,118.0                 |
| 2026 | 1,374.9                    | 1,297.8                    | 199.5                     | 188.3               | 1,109.5                 |
| 2027 | 1,365.8                    | 1,289.3                    | 203.0                     | 191.6               | 1,097.7                 |
| 2028 | 1,355.0                    | 1,279.1                    | 206.4                     | 194.8               | 1,084.3                 |
| 2029 | 1,336.2                    | 1,261.4                    | 209.5                     | 197.8               | 1,063.6                 |
| 2030 | 1,314.9                    | 1,241.2                    | 212.5                     | 200.6               | 1,040.6                 |

Table F-4. Sales Forecasts (with Dynamic Pricing Adjustments)

## F. Modeling Assumptions Data

Sales and Peak Forecasts

### Lana'i Sales Forecasts (without Dynamic Pricing Adjustments)

| Year | Load without DG-PV         |                            | Total DG-PV (Uncurtailed) |                     | Sales with DG-PV        |
|------|----------------------------|----------------------------|---------------------------|---------------------|-------------------------|
|      | Net Generation:<br>MWh (a) | Sales: Customer<br>MWh (b) | Net MWh<br>(c)            | Customer MWh<br>(d) | Customer MWh<br>(b – d) |
| 2015 | 28,715                     | 27,360                     | 3,106                     | 2,959               | 24,400                  |
| 2016 | 29,220                     | 27,840                     | 3,411                     | 3,250               | 24,590                  |
| 2017 | 29,611                     | 28,212                     | 3,596                     | 3,426               | 24,786                  |
| 2018 | 30,043                     | 28,624                     | 3,735                     | 3,559               | 25,066                  |
| 2019 | 30,384                     | 28,949                     | 3,839                     | 3,658               | 25,291                  |
| 2020 | 30,687                     | 29,238                     | 3,943                     | 3,757               | 25,481                  |
| 2021 | 30,963                     | 29,501                     | 4,047                     | 3,856               | 25,645                  |
| 2022 | 31,212                     | 29,739                     | 4,151                     | 3,955               | 25,783                  |
| 2023 | 31,453                     | 29,968                     | 4,185                     | 3,987               | 25,981                  |
| 2024 | 31,693                     | 30,197                     | 4,189                     | 3,991               | 26,206                  |
| 2025 | 31,926                     | 30,418                     | 4,189                     | 3,991               | 26,427                  |
| 2026 | 32,115                     | 30,599                     | 4,204                     | 4,006               | 26,593                  |
| 2027 | 32,283                     | 30,758                     | 4,223                     | 4,024               | 26,735                  |
| 2028 | 32,426                     | 30,895                     | 4,285                     | 4,082               | 26,812                  |
| 2029 | 32,568                     | 31,030                     | 4,356                     | 4,150               | 26,880                  |
| 2030 | 32,713                     | 31,169                     | 4,356                     | 4,150               | 27,019                  |

1. Adjusted July 2014 Maui Electric forecast

2. Loss factor 4.72%

Table F-5. Lana'i Sales Forecasts (without Dynamic Pricing Adjustments)

Moloka'i Sales Forecasts (without Dynamic Pricing Adjustments)

| Year | Load without DG-PV         |                            | Total DG-PV (Uncurtailed) |                     | Sales with DG-PV        |
|------|----------------------------|----------------------------|---------------------------|---------------------|-------------------------|
|      | Net Generation:<br>MWh (a) | Sales: Customer<br>MWh (b) | Net MWh<br>(c)            | Customer MWh<br>(d) | Customer MWh<br>(b – d) |
| 2015 | 34,115                     | 31,137                     | 3,584                     | 3,271               | 27,866                  |
| 2016 | 34,202                     | 31,216                     | 3,972                     | 3,625               | 27,590                  |
| 2017 | 34,342                     | 31,344                     | 4,224                     | 3,855               | 27,489                  |
| 2018 | 34,376                     | 31,375                     | 4,326                     | 3,948               | 27,427                  |
| 2019 | 34,397                     | 31,394                     | 4,776                     | 4,359               | 27,035                  |
| 2020 | 34,400                     | 31,397                     | 5,084                     | 4,640               | 26,757                  |
| 2021 | 34,350                     | 31,352                     | 5,224                     | 4,768               | 26,583                  |
| 2022 | 34,299                     | 31,304                     | 5,260                     | 4,801               | 26,503                  |
| 2023 | 34,247                     | 31,258                     | 5,293                     | 4,831               | 26,426                  |
| 2024 | 34,172                     | 31,189                     | 5,320                     | 4,855               | 26,333                  |
| 2025 | 34,115                     | 31,137                     | 5,346                     | 4,879               | 26,258                  |
| 2026 | 34,079                     | 31,104                     | 5,372                     | 4,903               | 26,200                  |
| 2027 | 34,009                     | 31,040                     | 5,399                     | 4,927               | 26,113                  |
| 2028 | 33,954                     | 30,990                     | 5,425                     | 4,951               | 26,039                  |
| 2029 | 33,911                     | 30,951                     | 5,451                     | 4,975               | 25,976                  |
| 2030 | 33,847                     | 30,892                     | 5,470                     | 4,992               | 25,900                  |

1. Adjusted July 2014 Maui Electric forecast
2. Loss factor 8.73%

Table F-6. Moloka'i Sales Forecasts (without Dynamic Pricing Adjustments)

## F. Modeling Assumptions Data

Sales and Peak Forecasts

### Net Peak Forecasts

| Year | Net Peak<br>(w/o DG-PV +<br>w/ Dynamic Pricing) | Net Peak<br>(w/o DG-PV +<br>w/o Dynamic Pricing) | Total DG-PV) |
|------|---|--|--------------|
|      | MW  | MW   | MW           |
| 2015 | 195.4   | 195.4  | 79.4         |
| 2016 | 197.4   | 197.7  | 95.3         |
| 2017 | 197.6   | 203.7  | 101.2        |
| 2018 | 203.4   | 209.8  | 106.0        |
| 2019 | 207.0   | 213.6  | 110.3        |
| 2020 | 208.5   | 215.2  | 114.5        |
| 2021 | 210.3   | 217.1  | 117.4        |
| 2022 | 211.0   | 217.8  | 120.1        |
| 2023 | 211.7   | 218.5  | 122.6        |
| 2024 | 211.5   | 218.3  | 125.0        |
| 2025 | 211.7   | 218.5  | 127.2        |
| 2026 | 210.5   | 217.3  | 129.4        |
| 2027 | 208.9   | 215.6  | 131.5        |
| 2028 | 205.8   | 212.4  | 133.5        |
| 2029 | 203.7   | 210.2  | 135.4        |
| 2030 | 199.9   | 206.3  | 137.2        |

I. May 2014 Maui Electric peak forecast

Table F-7. Net Peak Forecasts



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## DEMAND RESPONSE

### Demand Response Programs

The *Integrated Demand Response Portfolio Plan*<sup>2</sup> introduced seven categories of programs.

**Residential and Small Business Direct Load Control Program (RBDLC).** This new RBDLC program continues and expands upon the existing RDLC and Small Business Direct Load Control (SBDLC) programs. RBDLC enables new and existing single-family, multi-family, and master metered residential customers, in addition to small businesses, to participate in an interruptible load program for electric water heaters, air conditioning, and other specific end uses.

**Residential and Small Business Flexible Program.** This new program enables residential and small business customers with targeted devices (such as controllable grid-interactive water heaters) to meet ancillary service requirements by providing adjustable load control and thermal energy storage features over various timeframes.

**Commercial & Industrial Direct Load Control Program (CIDLC).** The updated CIDLC program allows commercial and industrial customers to help shift load, usually during peak periods, by allowing their central air conditioning, electric water heaters, and other applicable appliances to be remotely cycled or disconnected.

**Commercial & Industrial Flexible Program.** This new program enables commercial and industrial customers with targeted devices (such as air conditioning, ventilation, refrigeration, water heating, and lighting) to meet ancillary service requirements by providing adjustable load control and/or thermal energy storage features over differing timeframes.

**Commercial & Industrial Pumping Program.** The Commercial & Industrial Pumping program enables county and privately owned water facilities with pumping loads and water storage capabilities to be dynamically controlled. This will be accomplished by using variable frequency drives and emergency standby generation to adjust power demand and supply at the water facilities, and better balance supply and demand of power system loads.

**Customer Firm Generation Program.** Commercial and industrial customers who participate in this program allow system operators to dispatch their on-site standby generators to help meet power system load demand. Monitoring equipment on the

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<sup>2</sup> *ibid.*

## F. Modeling Assumptions Data

### Demand Response

standby generators tracks the usage of program participation, testing, and assures environmental permit compliance.

**Dynamic & Critical Peak Pricing program.** This program enables load shifting to “smooth” the daily system load profiles based on demand and price.

### Cost of DR Programs

Several grid services foretell the cost of the demand response programs. The avoided cost for a grid service is the cost of an alternative resource (energy storage or a generator) providing the equivalent service. Avoided cost could be based on several factors, including installed capacity costs, fuel costs, and cost of alternatives, each of which depends on the current state of the system. Potential avoided cost calculations include:

**Capacity:** The cost of new capacity deferral.

**Regulating Reserve:** The cost of a frequency support energy storage device, or the savings from reduced regulating reserve requirements, as calculated using a production cost model.

**Contingency Reserve:** For O’ahu, the fuel cost savings resulting from a reduction in the contingency reserve requirement from thermal generation commensurate with the DR resources assumed to meet the contingency reserve requirements, as calculated using a production cost model. For Maui and Hawai’i, this would offset under-frequency load shedding, which potentially provides a customer benefit but not a readily evaluated economic benefit.

**Non-AGC Ramping:** The fuel cost and maintenance savings resulting from deferring the start of units to compensate for variable energy down ramps.

**Non-Spinning Reserve:** The cost of maintaining existing resources that currently meet non-spinning reserves (small diesel units).

**Advanced Energy Delivery:** The production cost savings incurred by shifting demand, as compared to production costs if demand were not shifted.

All of the above avoided costs are offset by the program costs and reduced sales. Where a resource or program can meet two or more grid service requirements, although not simultaneously, the avoided cost is determined by the most economic use. The maximum price paid for a DR program would be the difference between the avoided cost and the program’s operational cost. At the maximum price, the overall rate impact to customers would be economically neutral.

## DR Grid Service Requirements and MW Benefits

| Grid Service | Capacity <sup>1</sup> | Non-AGC Ramping <sup>2</sup> | Non-Spinning Reserve <sup>3</sup> | Regulating Reserve <sup>4</sup> | Accelerated Energy Delivery |
|--------------|-----------------------|------------------------------|-----------------------------------|---------------------------------|-----------------------------|
| Frequency    | Unlimited             | Unlimited                    | Unlimited                         | Continuous                      | Continuous                  |
| Event Length | 1 hour                | 1 hour                       | 1 hour                            | Minutes                         | Minutes                     |
| Event Cost   | None                  | None                         | None                              | None                            | None                        |
| <b>Year</b>  | <b>MW</b>             | <b>MW</b>                    | <b>MW</b>                         | <b>MW</b>                       | <b>MW</b>                   |
| 2015         | 0.8                   | 0.5                          | 0.1                               | 0                               | 0.1                         |
| 2016         | 4.7                   | 1.8                          | 0.4                               | 0                               | 0.3                         |
| 2017         | 5.6                   | 3.1                          | 0.8                               | 0                               | 0.4                         |
| 2018         | 6.5                   | 4.5                          | 1.1                               | 0                               | 0.6                         |
| 2019         | 7.4                   | 5.8                          | 1.4                               | 0                               | 0.7                         |
| 2020         | 8.4                   | 7.1                          | 1.8                               | 0                               | 0.9                         |
| 2021         | 8.4                   | 7.4                          | 1.8                               | 0                               | 1                           |
| 2022         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2023         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2024         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2025         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2026         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2027         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2028         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2029         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |
| 2030         | 8.4                   | 7.7                          | 1.8                               | 0                               | 1.1                         |

Table F-8. Demand Response Program Grid Service Requirements and MW Benefits

- 1 Residential and Small Business Direct Load Control (RBDLC) assumed to have a 1 hour duration limit. RBDLC capacity value equals program potential divided by three to cover 3 hour priority peak period.
- 2 RBDLC Non-AGC Ramping value equals 75% of program potential (balance assigned to Non-Spinning Reserve).
- 3 RBDLC Non-Spinning Reserve value equals 25% of program potential (balance assigned to Non-AGC Ramping).
- 4 Aggregated Regulating Reserves program potential does not provide value in terms of system regulation needs and operational unit dispatch.

Amounts shown in Table F-8 reflect quantities by grid service requirement as modeled in PSIP production cost runs. In practice, system operators may be able to use a single end use resource to provide different grid services at different times as system needs change, provided the resources are not expected to provide multiple grid services simultaneously. For planning purposes though, the end use potentials included in the Integrated Demand Response Portfolio Plan have been allocated to the single grid service deemed to offer the highest value service to customers (to account for the fact that a single end use resource typically cannot provide multiple grid services simultaneously).

## RESOURCE CAPITAL COSTS<sup>3</sup>

The calculations for the capital cost for different resources used in the PSIP modeling analyses are shown in Table F-10 through Table F-23.

The overall cost escalation rate used throughout our analyses is 1.83%.

Table Legend

| Column Heading                           | Explanation   |
|--|---|
| NREL Capital Cost, 2009 \$, \$/kW        | The starting basis for capital costs used in the analyses unless noted otherwise                |
| B&V Hawai'i Capital Cost, 2009 \$, \$/kW | The starting basis for capital cost of the ICE (<100 MW)  |
| BCG Capital Cost, 2009 \$, \$/kW         | The starting basis for capital cost of the ICE (>100 MW)  |
| EIA Capital Cost, 2009 \$, \$/kW         | The starting basis for capital cost of the Waste-to-Energy resource                             |
| Capital Cost, Nominal \$, \$/kW          | An escalated capital cost of the resource from 2009 dollars up to the year of installation      |
| EIA Adjustment Factor                    | A location specific cost adjustment factor for Hawai'i  |
| Utility Adjustment Factor                | A technology specific cost adjustment factor  |
| Adjusted Capital Cost, Nominal \$, \$/kW | An escalated capital cost of the resource that reflects any cost adjustment factors             |
| NREL Fixed O&M, 2009 \$, \$/kW-year      | The starting basis for fixed O&M used in the analyses   |
| Fixed O&M, Nominal \$, \$/kW             | An escalated fixed O&M cost of the resource from 2009 dollars up to the year of installation    |
| NREL Variable O&M, 2009 \$, \$/MWh       | The starting basis for variable O&M used in the analyses  |
| Variable O&M, Nominal \$, \$/MWh         | An escalated variable O&M cost of the resource from 2009 dollars up to the year of installation |

Table F-9. Resource Capital Cost Table Legend

<sup>3</sup> Calculations were based on *Cost and Performance Data for Power Generation Technologies*, prepared for the National Renewable Energy Laboratory (NREL), Black & Veatch, February 2012.

Simple Cycle Combustion Turbine

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$651.00                       | \$726.04                    | 51.5%                 | 1.46                      | \$1,608.29                           | \$5.26                           | \$5.87                   | \$29.90                         | \$33.35                      |
| 2020           | \$651.00                       | \$795.14                    | 51.5%                 | 1.46                      | \$1,761.36                           | \$5.26                           | \$6.42                   | \$29.90                         | \$36.52                      |
| 2025           | \$651.00                       | \$870.81                    | 51.5%                 | 1.46                      | \$1,928.99                           | \$5.26                           | \$7.04                   | \$29.90                         | \$40.00                      |
| 2030           | \$651.00                       | \$953.69                    | 51.5%                 | 1.46                      | \$2,112.58                           | \$5.26                           | \$7.71                   | \$29.90                         | \$43.80                      |

Table F-10. Simple Cycle Combustion Turbine

Combined Cycle Turbine

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$1,230.00                     | \$1,371.78                  | 53.1%                 | 1.21                      | \$2,533.86                           | \$6.31                           | \$7.04                   | \$3.67                          | \$4.09                       |
| 2020           | \$1,230.00                     | \$1,502.34                  | 53.1%                 | 1.21                      | \$2,775.02                           | \$6.31                           | \$7.71                   | \$3.67                          | \$4.48                       |
| 2025           | \$1,230.00                     | \$1,645.32                  | 53.1%                 | 1.21                      | \$3,039.13                           | \$6.31                           | \$8.44                   | \$3.67                          | \$4.91                       |
| 2030           | \$1,230.00                     | \$1,801.91                  | 53.1%                 | 1.21                      | \$3,328.37                           | \$6.31                           | \$9.24                   | \$3.67                          | \$5.38                       |

Table F-11. Combined Cycle Turbine

**F. Modeling Assumptions Data**

Resource Capital Costs

**Internal Combustion (<100 MW) Engine**

| Year Installed | B&V Hawai'i Capital Cost, 2012 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|---------------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$2,810.00                            | \$2,967.54                  | 0.0%                  | 1.00                      | \$2,967.54                           | \$10.14                          | \$11.31                  | \$11.74                         | \$13.09                      |
| 2020           | \$2,810.00                            | \$3,249.96                  | 0.0%                  | 1.00                      | \$3,249.96                           | \$10.14                          | \$12.39                  | \$11.74                         | \$14.34                      |
| 2025           | \$2,810.00                            | \$3,559.27                  | 0.0%                  | 1.00                      | \$3,559.27                           | \$10.14                          | \$13.56                  | \$11.74                         | \$15.70                      |
| 2030           | \$2,810.00                            | \$3,898.02                  | 0.0%                  | 1.00                      | \$3,898.02                           | \$10.14                          | \$14.85                  | \$11.74                         | \$17.20                      |

Table F-12. Internal Combustion (<100 MW) Engine

**Internal Combustion (>100 MW) Engine**

| Year Installed | BCG Capital Cost, 2012 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|-------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$1,352.00                    | \$1,427.80                  | 0.0%                  | 1.20                      | \$1,713.36                           | \$10.14                          | \$11.31                  | \$11.74                         | \$13.09                      |
| 2020           | \$1,352.00                    | \$1,563.68                  | 0.0%                  | 1.20                      | \$1,876.42                           | \$10.14                          | \$12.39                  | \$11.74                         | \$14.34                      |
| 2025           | \$1,352.00                    | \$1,712.50                  | 0.0%                  | 1.20                      | \$2,055.01                           | \$10.14                          | \$13.56                  | \$11.74                         | \$15.70                      |
| 2030           | \$1,352.00                    | \$1,875.49                  | 0.0%                  | 1.20                      | \$2,250.59                           | \$10.14                          | \$14.85                  | \$11.74                         | \$17.20                      |

Table F-13. Internal Combustion (>100 MW) Engine

Residential Photovoltaics

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$4,340.00                     | \$4,840.26                  | 0.0%                  | 1.00                      | \$4,840.26                           | \$48.00                          | \$53.53                  | \$0.00                          | \$0.00                       |
| 2020           | \$3,750.00                     | \$4,580.29                  | 0.0%                  | 1.00                      | \$4,580.29                           | \$45.00                          | \$54.96                  | \$0.00                          | \$0.00                       |
| 2025           | \$3,460.00                     | \$4,628.29                  | 0.0%                  | 1.00                      | \$4,628.29                           | \$43.00                          | \$57.52                  | \$0.00                          | \$0.00                       |
| 2030           | \$3,290.00                     | \$4,819.74                  | 0.0%                  | 1.00                      | \$4,819.74                           | \$41.00                          | \$60.06                  | \$0.00                          | \$0.00                       |

Table F-14. Residential Photovoltaics

Utility Scale Photovoltaics (Fixed Tilt)

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$2,550.00                     | \$2,843.93                  | 0.0%                  | 0.75                      | \$2,132.95                           | \$48.00                          | \$53.53                  | \$0.00                          | \$0.00                       |
| 2020           | \$2,410.00                     | \$2,943.60                  | 0.0%                  | 0.75                      | \$2,207.70                           | \$45.00                          | \$54.96                  | \$0.00                          | \$0.00                       |
| 2025           | \$2,280.00                     | \$3,049.86                  | 0.0%                  | 0.75                      | \$2,287.39                           | \$43.00                          | \$57.52                  | \$0.00                          | \$0.00                       |
| 2030           | \$2,180.00                     | \$3,193.62                  | 0.0%                  | 0.75                      | \$2,395.22                           | \$41.00                          | \$60.06                  | \$0.00                          | \$0.00                       |

Table F-15. Utility Scale Photovoltaics (Fixed Tilt)

**F. Modeling Assumptions Data**

Resource Capital Costs

**Geothermal, Non-Dispatchable**

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$5,940.00                     | \$6,624.69                  | 27.2%                 | 1.00                      | \$8,426.61                           | \$36.00                          | \$40.15                  | \$31.00                         | \$34.57                      |
| 2020           | \$5,940.00                     | \$7,255.18                  | 27.2%                 | 1.00                      | \$9,228.59                           | \$36.00                          | \$43.97                  | \$31.00                         | \$37.86                      |
| 2025           | \$5,940.00                     | \$7,945.68                  | 27.2%                 | 1.00                      | \$10,106.91                          | \$36.00                          | \$48.16                  | \$31.00                         | \$41.47                      |
| 2030           | \$5,940.00                     | \$8,701.89                  | 27.2%                 | 1.00                      | \$11,068.81                          | \$36.00                          | \$52.74                  | \$31.00                         | \$45.41                      |

Table F-16. Geothermal, Non-Dispatchable

**Geothermal, Fully Dispatchable**

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$6,065.00                     | \$6,764.10                  | 27.2%                 | 1.00                      | \$8,603.94                           | \$36.00                          | \$40.15                  | \$31.00                         | \$34.57                      |
| 2020           | \$6,065.00                     | \$7,407.86                  | 27.2%                 | 1.00                      | \$9,422.80                           | \$36.00                          | \$43.97                  | \$31.00                         | \$37.86                      |
| 2025           | \$6,065.00                     | \$8,112.89                  | 27.2%                 | 1.00                      | \$10,319.59                          | \$36.00                          | \$48.16                  | \$31.00                         | \$41.47                      |
| 2030           | \$6,065.00                     | \$8,885.02                  | 27.2%                 | 1.00                      | \$11,301.74                          | \$36.00                          | \$52.74                  | \$31.00                         | \$45.41                      |

Table F-17. Geothermal, Fully Dispatchable



Run-of-River Hydroelectric

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$3,500.00                     | \$3,903.44                  | 19.1%                 | 1.35                      | \$6,276.14                           | \$15.00                          | \$16.73                  | \$24.00                         | \$26.77                      |
| 2020           | \$3,500.00                     | \$4,274.94                  | 19.1%                 | 1.35                      | \$6,873.46                           | \$15.00                          | \$18.32                  | \$24.00                         | \$29.31                      |
| 2025           | \$3,500.00                     | \$4,681.80                  | 19.1%                 | 1.35                      | \$7,527.63                           | \$15.00                          | \$20.06                  | \$24.00                         | \$32.10                      |
| 2030           | \$3,500.00                     | \$5,127.38                  | 19.1%                 | 1.35                      | \$8,244.06                           | \$15.00                          | \$21.97                  | \$24.00                         | \$35.16                      |

Table F-18. Run-of-River Hydroelectric

Waste-to-Energy

| Year Installed | EIA Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|-------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$8,312.00                    | \$8,777.99                  | 19.6%                 | 1.00                      | \$10,498.48                          | \$392.82                         | \$414.84                 | \$8.75                          | \$9.24                       |
| 2020           | \$8,312.00                    | \$9,613.42                  | 19.6%                 | 1.00                      | \$11,497.65                          | \$392.82                         | \$454.32                 | \$8.75                          | \$10.12                      |
| 2025           | \$8,312.00                    | \$10,528.36                 | 19.6%                 | 1.00                      | \$12,591.91                          | \$392.82                         | \$497.56                 | \$8.75                          | \$11.08                      |
| 2030           | \$8,312.00                    | \$11,530.37                 | 19.6%                 | 1.00                      | \$13,790.32                          | \$392.82                         | \$544.92                 | \$8.75                          | \$12.14                      |

Table F-19. Waste-to-Energy

**F. Modeling Assumptions Data**

Resource Capital Costs

Wind, Onshore

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$1,980.00                     | \$2,208.23                  | 30.1%                 | 1.00                      | \$2,872.91                           | \$60.00                          | \$66.92                  | \$0.00                          | \$0.00                       |
| 2020           | \$1,980.00                     | \$2,418.39                  | 30.1%                 | 1.00                      | \$3,146.33                           | \$60.00                          | \$73.28                  | \$0.00                          | \$0.00                       |
| 2025           | \$1,980.00                     | \$2,648.56                  | 30.1%                 | 1.00                      | \$3,445.78                           | \$60.00                          | \$80.26                  | \$0.00                          | \$0.00                       |
| 2030           | \$1,980.00                     | \$2,900.63                  | 30.1%                 | 1.00                      | \$3,773.72                           | \$60.00                          | \$87.90                  | \$0.00                          | \$0.00                       |

Table F-20. Wind, Onshore

Wind, Offshore (Floating Platform)

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | Not Commercial                 | Not Commercial              | 0.0%                  | Not Commercial            | \$0.00                               | \$0.00                           | \$0.00                   | \$0.00                          | Not Commercial               |
| 2020           | \$4,200.00                     | \$5,129.93                  | 30.1%                 | 1.00                      | \$6,674.04                           | \$130.00                         | \$158.78                 | \$0.00                          | \$0.00                       |
| 2025           | \$4,090.00                     | \$5,471.02                  | 30.1%                 | 1.00                      | \$7,117.79                           | \$130.00                         | \$173.90                 | \$0.00                          | \$0.00                       |
| 2030           | \$3,990.00                     | \$5,845.21                  | 30.1%                 | 1.00                      | \$7,604.62                           | \$130.00                         | \$190.45                 | \$0.00                          | \$0.00                       |

Table F-21. Wind, Offshore (Floating Platform)

Biomass Steam

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$3,830.00                     | \$4,271.48                  | 53.6%                 | 1.00                      | \$6,560.99                           | \$95.00                          | \$105.95                 | \$15.00                         | \$16.73                      |
| 2020           | \$3,830.00                     | \$4,678.01                  | 53.6%                 | 1.00                      | \$7,185.42                           | \$95.00                          | \$116.03                 | \$15.00                         | \$18.32                      |
| 2025           | \$3,830.00                     | \$5,123.23                  | 53.6%                 | 1.00                      | \$7,869.27                           | \$95.00                          | \$127.08                 | \$15.00                         | \$20.06                      |
| 2030           | \$3,830.00                     | \$5,610.82                  | 53.6%                 | 1.00                      | \$8,618.22                           | \$95.00                          | \$139.17                 | \$15.00                         | \$21.97                      |

Table F-22. Biomass Steam

Ocean Wave

| Year Installed | NREL Capital Cost, 2009 \$ /kW | Capital Cost Nominal \$ /kW | EIA Adjustment Factor | Utility Adjustment Factor | Adjusted Capital Cost Nominal \$ /kW | NREL Fixed O&M, 2009 \$ /kW-year | Fixed O&M Nominal \$ /kW | NREL Variable O&M, 2009 \$ /MWh | Variable O&M Nominal \$ /MWh |
|----------------|--------------------------------|-----------------------------|-----------------------|---------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------------------|------------------------------|
| 2015           | \$9,240.00                     | \$10,305.08                 | 13.8%                 | 1.00                      | \$11,727.18                          | \$474.00                         | \$528.64                 | \$0.00                          | \$0.00                       |
| 2020           | \$6,960.00                     | \$8,501.02                  | 13.8%                 | 1.00                      | \$9,674.16                           | \$357.00                         | \$436.04                 | \$0.00                          | \$0.00                       |
| 2025           | \$5,700.00                     | \$7,624.64                  | 13.8%                 | 1.00                      | \$8,676.84                           | \$292.00                         | \$390.60                 | \$0.00                          | \$0.00                       |
| 2030           | \$4,730.00                     | \$6,929.29                  | 13.8%                 | 1.00                      | \$7,885.53                           | \$243.00                         | \$355.99                 | \$0.00                          | \$0.00                       |

Table F-23. Ocean Wave

**F. Modeling Assumptions Data**

Resource Capital Costs

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## G. Generation Resources

Electricity is typically produced through a turbine-generator process. The turbine rotates and drives a shaft in the generator to create electrical current.

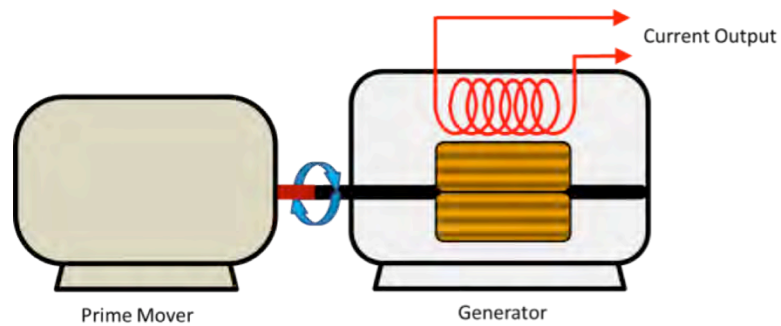


Figure G-1. Turbine-Generator Process

Turbines can be powered by different variable and firm sources. Variable energy is unpredictable because its energy source cannot be scheduled nor can it be controlled. Firm energy can be predicted, scheduled, dispatched, and controlled.

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## VARIABLE RENEWABLE ENERGY RESOURCES

Several variable renewable energy resources were considered in our PSIP analysis, all of which are currently in our generation mix. This type of energy is variable because its primary energy sources (such as wind, sun, and water) cannot be predicted.

The capacity value (essentially the percent of its “nameplate” generating amount that is available to the grid) of variable renewable energy varies by each resource, and is typically a small percentage of the nameplate value or zero. In addition, because the generation from variable renewable energy cannot be scheduled, it cannot be dispatched; in other words, it cannot be used to help regulate the balance between supply and demand.

### Wind

Wind energy generation is the conversion of the wind’s kinetic energy into electricity. Wind generating facilities are best located where wind is persistently steady. On Hawai’i with its terrain of hills, valleys, and ridges, variations in siting can have profound effects on the strength and quantity of wind currents.

As the wind turns a wind turbine’s blades, the main shaft in the turbine rotates which in turn drives a generator (situated in the nacelle) to produce electricity. The annual capacity factor<sup>1</sup> of wind is generally about 25% at locations throughout Hawai’i, although it can attain a capacity factor of more than 50%.

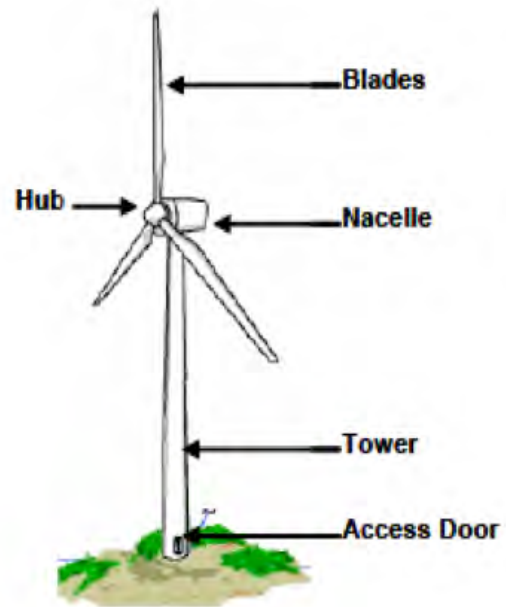


Figure G-2. Wind Turbine and Tower

A wind turbine shuts down when the wind is either too slow or too fast. The size of the wind turbine is generally in direct proportion to how much electricity can be generated. Larger wind turbines generate more power, while smaller turbines generate less. Thus, wind is a variable, non-dispatchable energy source.

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<sup>1</sup> The Annual Capacity Factor, expressed in percent, is the amount of energy produced in a year compared to the amount of energy potentially produced by the facility if it was operated at 100% of its rated capacity for 100% of the time in the year.

## Solar Photovoltaics

Solar photovoltaic energy is generated from its cells, and not by turning a turbine. Photovoltaic (PV) cells are made of semiconductors (such as silicon). When light strikes the cell, a certain portion of it is absorbed within the semiconductor material. The energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the cell, this electric current can be drawn off for external use. The most common solar cell material is crystalline silicon, but newer materials for making solar cells include thin-film materials.

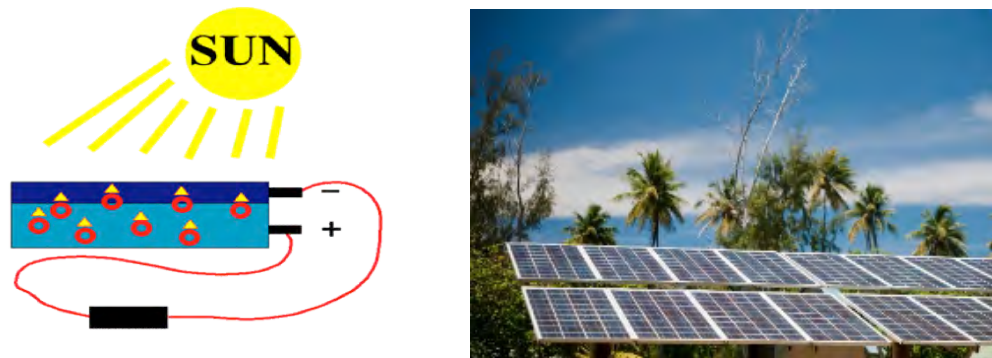


Figure G-3. Schematic of a Photovoltaic (PV) Cell and an Array of PV Panels

Solar PV is a variable renewable energy resource that cannot be scheduled and dispatched. Its annual capacity factor hovers between 18% to 22%. Solar PV only generates power when the sun is out and not blocked by clouds. On cloudless days, solar power gradually increases as the sun rises in the morning, peaks around 2 PM, and then gradually decreases until the sun sets. If at any point during the day a cloud blocks the sun, power output drops suddenly only to jump back up when the cloud passes. Thus, solar PV power generation can be erratic.

While solar PV systems can be made a few different ways, the most predominant is framed panels (as shown in Figure G-3). These panels consist of PV cells packaged as modules and framed into panels using aluminum framing, wiring, and glass enclosures. Multiple panels can be assembled into larger systems as arrays.

## G. Generation Resource

### Variable Renewable Energy Resources

**Distributed Solar Generation (DG-PV).** These arrays can be installed on building rooftops, typically in a fixed direction as illustrated in Figure G-4. This rooftop solar is referred to as distributed generation because of the numerous small PV systems installed in many different locations distributed throughout the grid. These rooftop PV panels produce direct current (DC) electricity fed to an inverter which converts the electricity to alternating current (AC) for use by the building or home. Surplus PV electricity – more than the building can use – flows into the electric power grid.

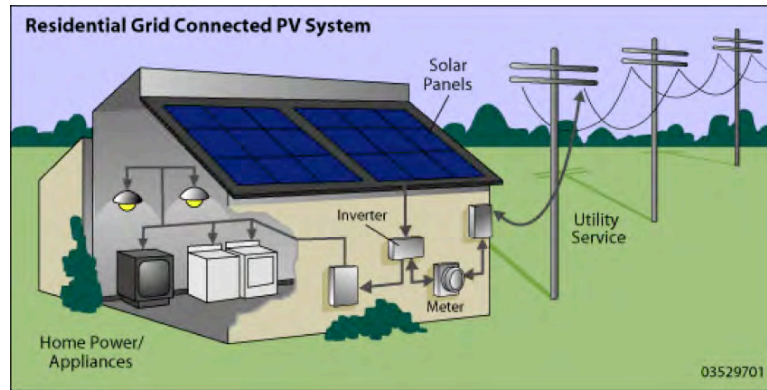


Figure G-4. Residential Distributed Generation PV System

**Utility-Scale Solar PV.** The PV panel arrays can also be mounted in large-scale ground mounted PV generating facilities (also referred to as “solar farms”) that sometimes use tracking systems to actively tilt the PV panels towards the sun as it moves across the sky, thus increasing the annual capacity factor. These panels also produce direct current (DC) electricity. Inverters convert the electricity to alternating current (AC) where it immediately flows into the electric power grid.



## Run-Of-River Hydroelectric

Hydropower is power derived from the energy of falling or moving water, which may be harnessed for useful purposes. Since ancient times, hydropower has been used to irrigate and operate various mechanical devices, such as watermills, sawmills, textile mills, dock cranes, and domestic lifts.

For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. If the river is not flowing, the hydroelectric facility produces no power. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes (such as pumping water) or it can power a turbine-generator to generate electricity.

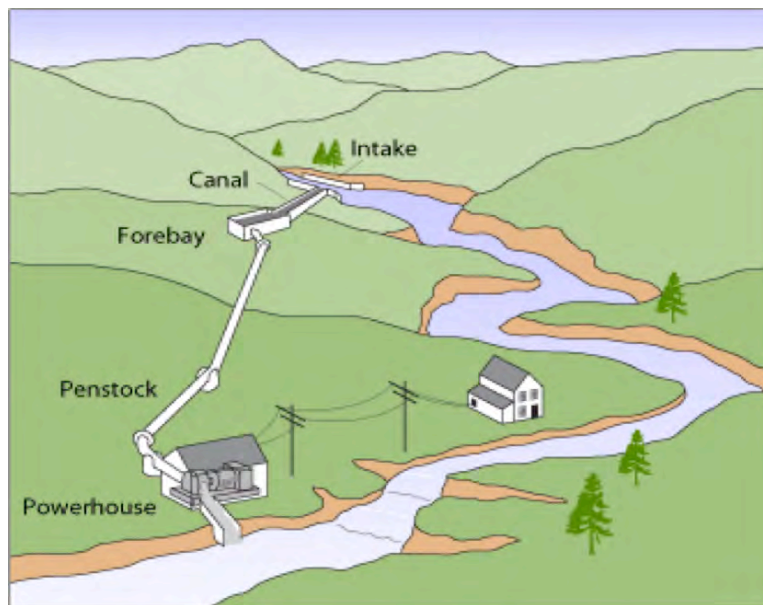


Figure G-5. Run-of-River Hydroelectric Plant

The primary development considerations are finding sites with adequate water flow and pressure, which are located in reasonable proximity to the electric grid for interconnection.

## Energy Storage in Combination with Variable Renewable Energy

Wind, solar, and hydroelectric are all variable renewable energy sources. As such, they cannot be used to maintain the stability of an electric power grid, that delicate balance between supply and demand. Energy storage, however, can alleviate this situation and help provide more reliable energy, or in some cases, firm renewable power.

## G. Generation Resource

### Variable Renewable Energy Resources

Energy storage can capture excess variable energy – generation that is not currently needed to meet demand – and store it in other forms until needed. This stored energy can later be converted back to its electrical form and returned to the grid as needed. Stored in high enough amounts, these sources could then be treated as firm power than may be scheduled and dispatched. (See Appendix J: Energy Storage Plan for more details.)

Pumped-storage hydroelectricity is a type of hydroelectric energy that includes energy storage. Water is pumped from a lower elevation to a higher elevation, where the stored water can be subsequently released through turbines to produce electricity. Electricity for pumping the water would typically occur during off-peak periods when the cost is low, or when during periods when there is excess energy generation from variable renewable resources. The generated electricity is then used during on-peak periods when demand is higher.

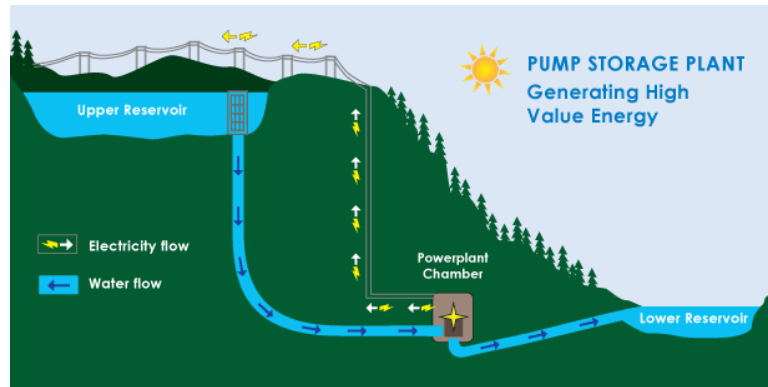


Figure G-6. Pumped Storage Hydroelectricity Plant

## FIRM GENERATION

Several types of firm generation are included in our PSIP analysis, many of which are currently in our generation mix. Firm generation is predictable because its energy source (both fossil fuels and renewable fuels) can be scheduled, dispatched, and controlled.

The annual capacity value of firm generation can also be managed. A firm generation source can be operated as much or as little as necessary to meet demand. As such, firm generation is dispatchable; in other words, it can be used to help regulate the balance between supply and demand.

### Gas Turbine Engine (or Combustion Turbine)

A gas turbine engine rotates as a result of hot gases (the product of the combustion of fuels) traveling through sets of turbine blades. As illustrated in Figure G-7, the flames themselves do not touch the turbine blades – just the gases produced by the flames. The combustor is where the fuel and air are mixed to enable the combustion process to occur. The fuel for this type of prime mover is either gas or liquid (not coal or biomass).

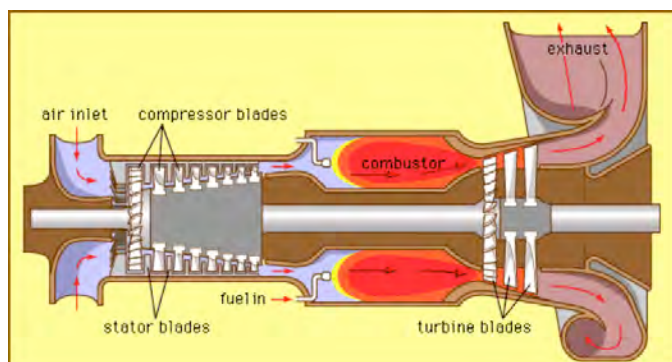


Figure G-7. Gas Turbine Engine

There are two types of gas turbines used for power generation: Aero-derivative and Frame.

**Aero-derivative.** This class of turbine is smaller (up to 100 MW) and can be quickly started and ramped, which makes them more compatible with grids that have large amounts of variable generation.

**Frame.** This type of turbine is generally larger (up to 340 MW), but not as fast reacting for both starting and ramping.

Gas turbines produce firm, dispatchable generation.

## Steam Turbine: Combined Cycle and Boilers

A steam turbine operates by high pressure steam traveling through the turbine blades, causing the turbine shaft to rotate. This high pressure steam can be produced by a variety of technologies including Heat Recovery Steam Generators (HRSG) and fuel-fired boilers. All steam turbines produce firm, dispatchable generation.

### Heat Recovery Steam Generators (HRSG)

HRSG use the high temperature exhaust gas from gas turbines engines to create steam for use in a steam turbine generator. This allows more electricity to be produced without using any additional fuel. The assembly of gas turbine, HRSG, and other auxiliary equipment used is referred to as combined cycle.

Hot combustion gases travel across the gas turbine blades to make the turbine spin where these gases are released at high temperature. A HRSG connects to the end of the gas turbine to take advantage of the energy that remains in the hot exhaust gases. The heat from these hot exhaust gases turns water contained in the HRSG into steam, where it is then sent to a steam turbine causing its connected generator to spin, thus producing electricity. Used steam is then converted back into water and reused again in the HRSG.

As illustrated in Figure G-8, combined cycle turbines can be either “single-train” (that is, one gas turbine and HRSG tied to the steam turbine) or “dual-train” (two gas turbines and HRSG assemblies tied to a single steam turbine).

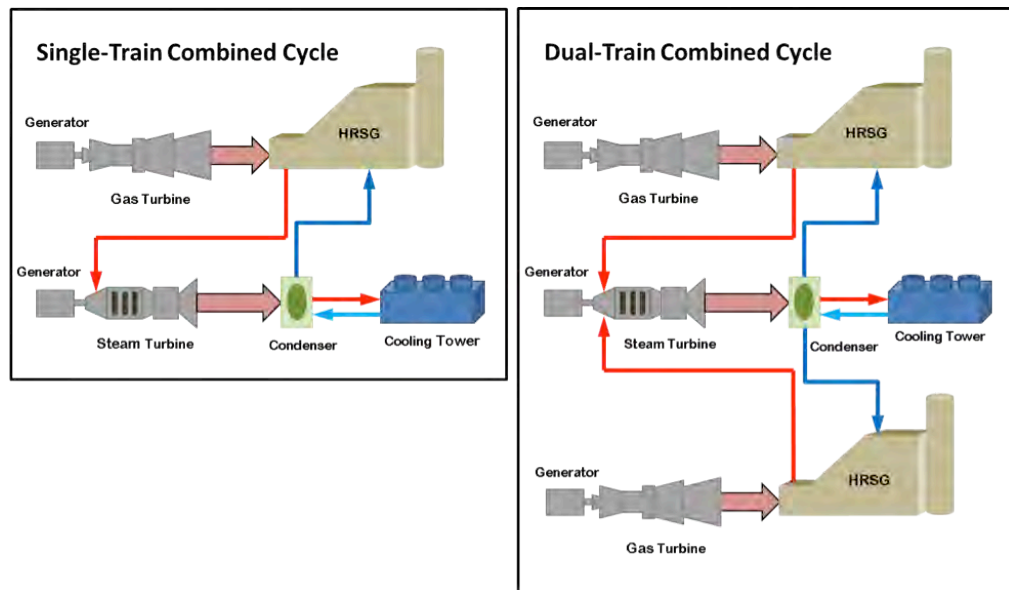


Figure G-8. Combined Cycle Plant: Single-Train and Dual-Train

A dual-train configuration provides twice as much power at a lower cost as a similar sized single-train configuration.

## Reciprocating Internal Combustion Engine (RICE) or “Diesel Engine”

The type of reciprocating internal combustion engine used to produce electricity is a diesel engine. These engines can burn a variety of fuels, including diesel, biodiesel, biocrude, heavy oil, natural gas, and biogas. Diesel engines start and ramp quickly. Diesel engines produce firm, dispatchable generation.

Diesel engines have many combustion chambers called cylinders, each of which drives a piston connected to a common rotating shaft. This shaft is coupled to the generator to make it rotate. The number and size of these cylinders (illustrated as orange in the picture below) determine how much electrical output the engine can produce.

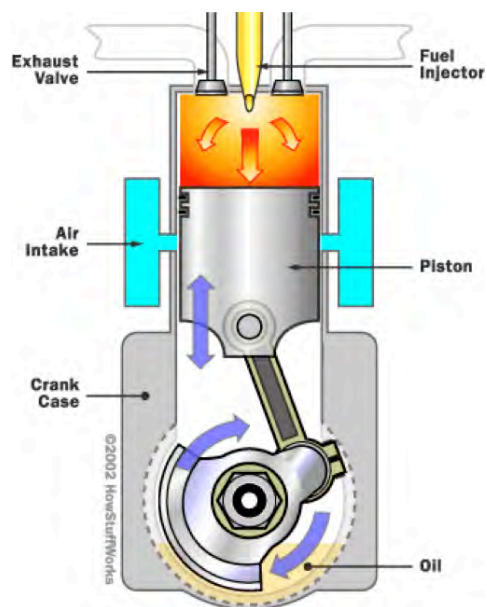


Figure G-9. Diesel Engine

Diesel engine ratings can range from a few kW up to about 18MW. Larger diesel engines, because of their design, preclude them from meeting US Environmental Protection Agency (EPA) air emission limits. In addition, the EPA has different air regulations for diesel engines depending on the size of the cylinders.

### Boilers (or Steam Generators)

A boiler furnace is made up primarily of small diameter (about 2-inch) metal tubes welded side by side to make a rectangular box. The tubes, which contain high purity water, are connected to a steam drum. The large fire inside the furnace transmits heat to the water inside the tubes to create steam in the steam drum. Fuel and air are continually added to the furnace to feed the fire.

Steam leaves the steam drum and travels through an independent set of tubes where it is heated to its final temperature by hot combustion exhaust gases. The steam then moves into the steam turbine, causing them to rotate and thus generate electricity. Boilers use a variety of fuels, including coal, biomass, liquid fuel oil, gas, and garbage.

Boilers come in many types, shapes, and sizes. Figure G-10 shows a simplified boiler steam turbine power plant. The boiler itself is outlined in the dotted red box.

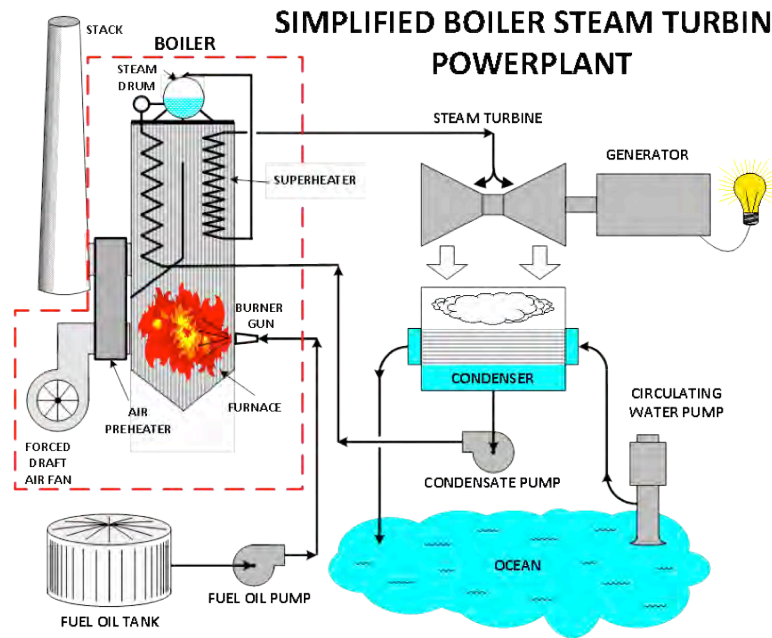


Figure G-10. Simplified Boiler Steam Turbine

Used steam can be converted back into water and reused in the boiler. A condenser forces the steam to travel over metal tubes that contain cold seawater, which causes the steam to turn back into water where it is pumped back into the steam drum, where the generation process begins again.

### Renewable Fuel for Boilers—Waste (or Garbage)

Waste-to-energy is a renewable fuel-fired steam-electric power plant in which waste (or garbage) is burned in whole or in part as an alternative to fossil fuels. Paper, organics, and plastic wastes account for the largest share of solid waste used for the waste-to-energy stream. Incinerating solid waste to generate electricity is one method to reduce this waste volume. The fractions of solid waste—paper, wood waste, food waste, yard waste—are forms of a biomass fuel. Americans generate approximately 4.5 pounds of garbage per day. In Hawai'i, solid waste consists primarily of 30% paper, 25% other organics, and 12% plastics with the remainder comprised of metals, glass, and other materials.

Solid waste is mechanically processed in a “front end” system to produce a more homogenous fuel called refuse-derived fuel (RDF). RDF, in its simplest form, is shredded solid waste with the metals removed. This RDF must be processed further to remove other non-combustible materials such as glass, rocks, non-burnables, and aluminum.

Additional screening and shredding stages can be done to further enhance the RDF. The RDF is then fired in the boiler to produce steam that is directed to a turbine or generator.

In general, a robust waste-to-energy generation reduces the amount of landfill refuse by 90%.

### Renewable Fuel for Boilers—Biomass

Biomass is another renewable fuel that can be used in boilers as alternatives to fossil fuels such as liquefied natural gas (LNG), oil, and coal.

Biomass is commonly defined as material derived from living organic matter (for example, trees, grasses, animal manure). Biomass includes wood and wood waste, herbaceous crops and crop wastes, food processing wastes such as bagasse, animal manures, and miscellaneous related materials. Biomass can be grown for the purpose of power generation from numerous types of plants, including switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, and a variety of trees such as eucalyptus and palm.

Biomass can either be burned directly to produce steam to make electricity, or processed into other energy products such as liquid or gaseous biofuel. In general, generating electricity directly from biomass is more efficient than converting it to biofuel. Siting a power generation facility at the source of the biomass, however, is not always feasible. Biofuel's transportability offers an attractive advantage.

Figure G-11 shows a process for converting wood waste into a biogas, which is then burned to create steam to generate electricity.

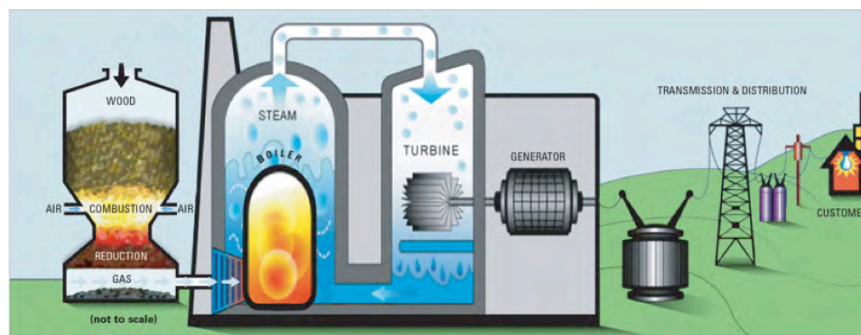


Figure G-11. Biomass Gasification

Aside from their fuel coming from renewable biomass, the power generation components of these facilities are similar to conventional power plants. In many cases, the power plants burn a combination of biofuel and fossil fuel.

## Geothermal

Geothermal energy is heat energy from the earth. A layer of hot and molten rock called magma lies below the earth's crust. Heated ground water exposed to this magma can be extracted to provide geothermal energy at the surface. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the earth's surface where the earth's crust is thinner.

In general, geothermal fluids are tapped through wells, also referred to as "bores" or "bore holes". Except for the higher geothermal temperatures, these wells are similar to oil and gas wells. Geothermal well depths typically range from 600 to 10,000 feet. The fluids surging out of the wells are piped to the power plant. Geothermal steam, or vapor created using geothermal hot water, then spins a turbine-generator to create electricity.

The temperature and quality of the geothermal fluid determines which of the four types of power system that can be used for electrical generation.

**Dry Steam Plants.** Hot 100% steam is piped directly from geothermal reservoirs into generators in the power plant. The steam spins a turbine-generator to produce electricity. The steam is re-injected into the ground. Dry steam geothermal power plants are rare.

**Flash Steam Plants.** Fluids between 300°F and 700°F (148–371°C) are brought up through a well. Some of the water turns to steam, which drives the turbine-generator. When the steam cools, it condenses back into water and is re-injected into the ground.

**Binary Cycle Plants.** Moderately hot geothermal water (less than 300°F) is passed through a heat exchanger. This heat is then transferred to a working fluid (such as isobutene or isopentane) which boils at a lower temperature than water. When that fluid is heated, it turns to vapor which spins the turbine-generator.



**Hybrid Plants.** Combination of the flash steam and binary cycles.

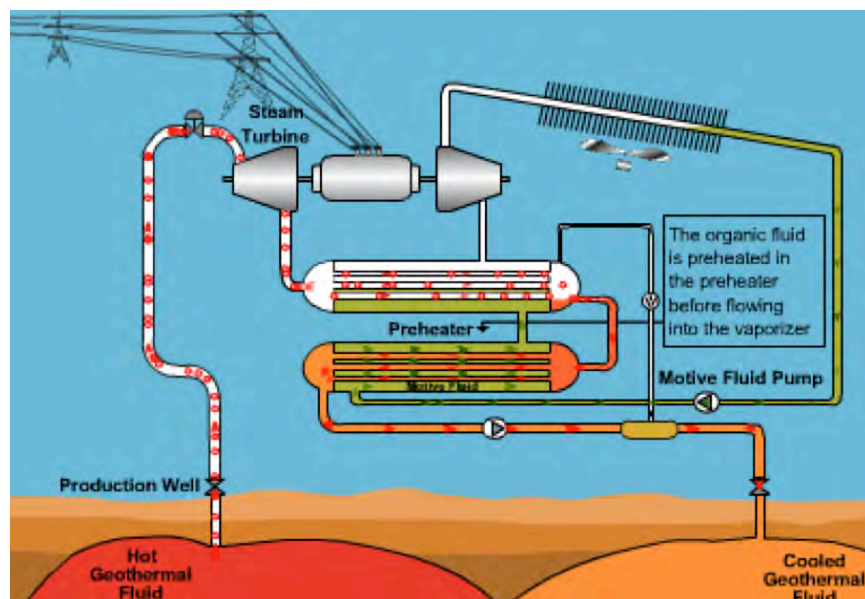


Figure G-12. Geothermal Hybrid Plant

In relation to other renewable energy projects, developing a geothermal power project is relatively complex, and typically involves two major phases: (1) exploratory drilling and (2) project development. The exploratory drilling phase identifies and evaluates potential resources, and drills test well. This phase usually takes a number of years, and in some case, does not identify a viable geothermal resource. After a geothermal resource has been identified, the project development phase begins, which includes drilling production wells and constructing a power plant.

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## H. Commercially Ready Technologies

Our analysis for the PSIPs considered both commercially ready generation technologies as well as emerging technologies that, while not commercially ready, might become available during the planning period (2015–2030).

Which emerging technology will be commercially ready before 2030 is impossible to know with any degree of certainty. As a result, with one exception, we did not attempt to decide which of the most promising of the emerging technologies might become available during the planning period. The exception: our analyses performed limited sensitivity of some emerging technologies (for example, Ocean Thermal Energy Storage) to quantify any potential future value.

Our PSIPs are snapshots of the future based on our best available assumptions. As such, *for the PSIPs, we limited the generating resource options to those technologies that are commercially ready as of 2014.*

This planning assumption is for the PSIP analyses only, and does not affect our intent to thoughtfully consider specific projects that include emerging technologies. In other words, we welcome generating technologies not considered in the PSIPs that are proposed in responses to future request for proposals (RFP) for any of our power systems. We will evaluate any proposal on its commercial viability as well as other attributes that are consistent with RFP requirements. Further, nothing in these planning assumptions is intended to modify or change our position for welcoming test projects, pilot projects, or negotiations that involve any specific technology.

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## COMMERCIAL READINESS INDEX

In order to evaluate whether a technology is commercially ready, the Hawaiian Electric Companies used the Commercial Readiness Index (CRI) methodology developed by the Australian Renewable Energy Agency (ARENA), which was released in February 2014.<sup>1</sup>

NASA first developed a Technology Readiness Level (TRL) in 1974.<sup>2</sup> The TRL ranks technology readiness on a scale of 1 to 9 (1 being the lowest; 9 being the highest level of readiness), with specific attributes identified for each level of readiness.

In 2011, the U.S. Department of Energy published the *Technology Assessment Readiness Guide*,<sup>3</sup> a framework for evaluating energy technologies using the TRL methodology. The TRL methodology characterizes technology readiness from very early stages of a technology life cycle, up to and including commercial readiness.

Building on the work of NASA, ARENA developed a Commercial Readiness Index (CRI), and published the CRI criteria in February 2014 in a document titled *Commercial Readiness Index for Renewable Energy Sectors*.

The CRI scale (1 to 6, with 6 being the highest level of readiness) assesses technology readiness against eight indicators:

- Regulatory environment
- Stakeholder acceptance
- Technical performance
- Financial performance (cost)
- Financial performance (revenue)
- Industry supply chain
- Market opportunity
- Vendor maturity (preference for established companies with strong credit ratings)

ARENA maps its CRI to the TRL, with CRI level 1 corresponding to TRL levels 2 through 8, and CRI level 2 corresponding to TRL level 9. CRI levels 3 through 6, then, include more mature technologies that are closer to commercial deployment, or that are already being used commercially. Except for certain sensitivity analyses, the PSIP did not consider any technologies with a CRI level 4 or less.

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<sup>1</sup> *Commercial Readiness Index for Renewable Energy Sectors*. Australian Renewable Energy Agency. © Commonwealth of Australia, February 2014. <http://arena.gov.au/files/2014/02/Commercial-Readiness-Index.pdf>

<sup>2</sup> "Technology Readiness Levels Demystified." August 20, 2010. [http://www.nasa.gov/topics/aeronautics/features/tri\\_demystified.html#.U7W-g7ZdV9c](http://www.nasa.gov/topics/aeronautics/features/tri_demystified.html#.U7W-g7ZdV9c)

<sup>3</sup> Technology Level Assessment Guide. September 15, 2011. <http://www2.lbl.gov/dir/assets/docs/TRL%20guide.pdf>

To evaluate power generating technologies included in analysis performed for the PSIPs, the CRI methodology provides practical, objective, and actionable guidance. Therefore, we used this methodology to evaluate emerging generation technology options and their suitability for inclusion as resource options in the PSIPs.

For the PSIPs, only those technologies with a CRI Level of 5 or 6 were considered commercially ready, and included as resource options in the PSIPs.

Table H-1 defines the levels of commercial readiness under the CRI methodology.

| CRI Level | Commercial Readiness                             | Definition <sup>4</sup>   |
|-----------|--|---|
| 6         | Bankable grade asset class                       | Financial investors view the technology risk as low enough to provide long-term financing. Known standards and performance expectations are in place, along with appropriate warranties. Vendor capabilities (including both technology vendors and EPC vendors), pricing, and other market forces drive market uptake (“demand pull”).                               |
| 5         | Market competition driving widespread deployment | Competition is emerging across all areas of the supply chain, with commoditization of key components and financial products.  |
| 4         | Multiple commercial applications                 | Full-scale technology demonstrated in an industrial (that is, not R&D) environment for a defined period of time. May still require subsidies. Publicly verifiable data on technical and financial performance. Interest from debt and equity sources, although still requiring government support. Regulatory challenges being addressed in multiple jurisdictions.   |
| 3         | Commercial scale-up                              | Deployment of full-scale technology prototype driven by specific policy. The commercial proposition is driven by technology proponents and by market segment participants (a “supply push”). Publicly discoverable data is driving interest from finance and regulatory sectors, but financing products are not yet widely available. Continues to rely on subsidies. |
| 2         | Commercial trial                                 | Small scale, first-of-a-kind project funded by 100% at-risk capital and/or government support. Commercial proposition backed by evidence of verifiable performance data that is typically not available to the public. Proves that the essential elements of the technology perform as designed.  |
| 1         | Hypothetical commercial proposition              | Technically ready, but commercially untested and unproven. The commercial proposition is driven by technology advocates, with little or no evidence of verifiable technical data to substantiate claims.  |
| 0         | Purely hypothetical <sup>5</sup>                 | Not technically ready. No testing at scale. No technical data.  |

Table H-1. Commercial Readiness Definitions

<sup>4</sup> Based on *Commercial Readiness Index for Renewable Energy Sectors*. Australian Renewable Energy Agency. © Commonwealth of Australia, February 2014. Table 1. p 5.

<sup>5</sup> Not a part of the CRI methodology. Defined here to classify commercial readiness of certain technologies discussed from time to time in Hawai‘i.

## EMERGING GENERATING TECHNOLOGIES

In Hawai'i, certain emerging generating technologies are discussed as potential generating resource options. The most prominent of these are ocean wave/tidal power, ocean thermal energy storage (OTEC), and concentrated solar thermal power (CSP). We evaluated each of these technologies using the CRI ranking methodology. As objective as the CRI methodology attempts to be, the mapping of the indicators for a given technology is necessarily subjective. Reasonable differences of opinion in the state of any one (or even several) of the eight categories of indicators would not change the overall conclusion regarding the commercial readiness of these technologies.

### Summary of CRIs for PSIP Resource Candidates

Table H-2 summarizes the commercial readiness of various generating resource technologies.

| Technology                              | CRI Level |   |   |   |   |   |   | PSIP Resource Option? | Comments   |
|---|-----------|---|---|---|---|---|---|-----------------------|--|
|   | 0         | 1 | 2 | 3 | 4 | 5 | 6 |                       |  |
| Simple cycle combustion turbine (CT)    |           |   |   |   |   |   | x | Yes                   |  |
| Combined cycle CT + heat recovery steam |           |   |   |   |   |   | x | Yes                   |  |
| Internal combustion engines—small       |           |   |   |   |   |   | x | Yes                   |  |
| Internal combustion engines—large       |           |   |   |   |   |   | x | Yes                   |  |
| Geothermal                              |           |   |   |   |   |   | x | Yes                   | Constrained on Maui and Hawai'i. None for O'ahu. |
| Biomass steam                           |           |   |   |   |   |   | x | Yes                   |  |
| Biomass gasification                    |           |   | x |   |   |   |   | No                    |  |
| Run-of-river hydro                      |           |   |   |   |   |   | x | Yes                   | Limited amount of MW available in Hawai'i.       |

**H. Commercially Ready Technologies**  
Emerging Generating Technologies

| Technology                                 | CRI Level |   |   |   |   |   |   | PSIP Resource Option? | Comments  |
|--|-----------|---|---|---|---|---|---|-----------------------|---|
|  | 0         | 1 | 2 | 3 | 4 | 5 | 6 |                       |   |
| Storage hydro                              |           |   |   |   |   |   | x | No                    | No available streams to dam for water storage.  |
| Pumped storage hydro                       |           |   |   |   |   |   | x | Yes                   | Not considered for base cases. Sensitivities only.                                    |
| Ocean wave/ tidal                          |           |   |   | x |   |   |   | No                    |   |
| Ocean thermal (OTEC)                       |           |   | x |   |   |   |   | No                    |   |
| Wind—onshore utility scale                 |           |   |   |   |   |   | x | Yes                   | Limited on O’ahu.   |
| Wind—offshore utility scale                |           |   |   |   | x |   |   | No                    | High capital cost, concerns with ability to site and permit.                          |
| Wind—distributed generation                |           |   |   | x |   |   |   | No                    | Approximately 3–4 times more expensive installed cost compared to solar DG-PV.        |
| Solar PV—utility scale                     |           |   |   |   |   | x |   | Yes                   |   |
| Solar PV—distributed                       |           |   |   |   |   | x |   | Yes                   |   |
| Concentrated solar                         |           |   |   |   | x |   |   | No                    |   |
| Fuel cells—distributed                     |           |   | x |   |   |   |   | No                    | Primary applications are for “high 9s” reliability applications (e.g., data centers). |
| Fuel cells—utility scale                   |           |   | x |   |   |   |   | No                    |   |
| Micro nuclear reactors                     |           | x |   |   |   |   |   | No                    |   |
| Solar power satellites                     | x         |   |   |   |   |   |   | No                    |   |
| Nuclear fusion                             |           | x |   |   |   |   |   | No                    |   |
| Energy harvesting from ambient environment | x         |   |   |   |   |   |   | No                    | Early markets will likely be small scale applications, such as PDA charging.          |

Table H-2. Commercial Readiness of Generating Technologies Considered for PSIPs

## H. Commercially Ready Technologies

Emerging Generating Technologies

### Evaluation of Emerging Technologies

Table H-3 through Table H-5 are CRI assessments of emerging generation technologies that were not included as resource options due to a CRI level of 4 or less.

Table H-3 evaluates wave and tidal power as a potential generating resource as, at best, CRI level 3. Therefore, it was not included for consideration in the PSIPs.

| CRI Level | Regulatory Environment  | Stakeholder Acceptance                  | Technical Performance                                   | Financial Performance (Cost)  | Financial Performance (Revenue)  | Supply Chain  | Market Opportunity  | Company Maturity                                     |
|-----------|---|---|---|---|--|---|---|--|
| 6         |   |   |   |   |  |   |   |  |
| 5         |   |   |   |   |  |   | Market opportunity widely understood. Additional policy support needed to drive uptake. |  |
| 4         |   |   | Performance understood; high confidence in performance. |   |  |   |   |  |
| 3         |   |   |   | Various versions of technologies deployed; Cost drivers beginning to be understood. |  |   |   |  |
| 2         | Ability to permit across various regulatory jurisdictions untested. | Stakeholder support case-by-case basis. |   |   | Revenue projections being tested, however investment community not yet willing to underwrite PPAs on widespread basis. | Supply chain not available. Each project typically unique specification. EPC based on time and materials. |   |  |
| 1         |   |   |   |   |  |   |   | Established industry players not yet part of sector. |

Table H-3. Wave/Tidal Power Commercial Readiness Evaluation



Table H-4 evaluates ocean thermal energy conversion as a potential generating resource as, at best, CRI level 3. Even though the CRI level would suggest that OTEC is not eligible for consideration at this time, due to interest in this technology for Hawai'i and our ongoing negotiations with OTEC International to build an OTEC facility to service O'ahu, a sensitivity was prepared to evaluate OTEC as a resource option for O'ahu.

| CRI Level | Regulatory Environment                                    | Stakeholder Acceptance                    | Technical Performance                              | Financial Performance (Cost)                      | Financial Performance (Revenue)          | Supply Chain                   | Market Opportunity                      | Company Maturity                                     |
|-----------|---|---|--|---|--|--------------------------------|---|--|
| 6         |   |   |  |   |  |                                |   |  |
| 5         |   |   |  |   |  |                                |   |  |
| 4         |   |   |  |   |  |                                |   | Established player (LMCo) considered part of sector. |
| 3         |   |   |  |   |  |                                | Size of potential market is understood. |  |
| 2         | Regulatory issues require specific project consideration. | Stakeholder support a case-by-case basis. | Performance forecasts based on pilot project data. | Key costs based on projections. No data at scale. | Revenue projections at scale not tested. |                                |   |  |
| 1         |   |   |  |   |  | Key elements from specialists. |   |  |

Table H-4. Ocean Thermal Energy Conversion (OTEC) Commercial Readiness Evaluation

## H. Commercially Ready Technologies

### Emerging Generating Technologies

Table H-5 evaluates concentrated solar thermal power as a generating resource at a CRI level 4. While this resource might be considered during our next planning cycle, it was not included in the PSIPs.

| CRI Level | Regulatory Environment   | Stakeholder Acceptance                                    | Technical Performance  | Financial Performance (Cost)        | Financial Performance (Revenue)   | Supply Chain                          | Market Opportunity                         | Company Maturity   |
|-----------|--|---|--|-------------------------------------|---|---------------------------------------|--|--|
| 6         |  |   |  |                                     |   |                                       | Market opportunities clear and understood. |  |
| 5         |  |   |  |                                     | Target is to be cost competitive by 2020. <sup>6</sup>                                      |                                       |  | Leading players with significant balance sheets in sector. |
| 4         | Permitting, regulatory challenges based on actual evidence. Policy settings moving to “market pull”. | Evidence and experience available to inform stakeholders. | Performance understood. High confidence in future project performance. | Cost drivers understood and tested. | Financing still largely underwritten with government guarantees and subsidies. <sup>7</sup> | Limited supply options but improving. |  |  |
| 3         |  |   | Multiple technology designs.   |                                     |   |                                       |  |  |
| 2         |  |   |  |                                     |   |                                       |  |  |
| 1         |  |   |  |                                     |   |                                       |  |  |

Table H-5. Concentrated Solar Thermal Power (CSP) Commercial Readiness Evaluation

<sup>6</sup> See “2014, The Year of Concentrating Solar Power.” U.S. Department of Energy. May 2014.

<sup>7</sup> *Ibid.*

# I. LNG to Hawai'i

Liquefied natural gas (LNG) is critical to reducing customer bills and improving environmental quality in Hawai'i. High oil prices and more stringent air regulations (the Environmental Protection Agency's Mercury Air Toxic Standards (MATS) and National Ambient Air Quality Standards (NAAQS)) increase the need to reduce Hawai'i's dependence on oil. While the majority of Hawaiian Electric's current generation portfolio utilizes oil, LNG has emerged as a viable alternative fuel source that may substantially lower fuel costs while reducing greenhouse gas emissions. In late 2012, the Hawaiian Electric Companies and FACTS Global Energy completed studies that confirmed both the technical and commercial feasibility for importing and utilizing LNG in Hawai'i.

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## DELIVERING LNG TO HAWAI'I

Natural gas is not indigenous to Hawai'i and must first be liquefied into LNG to be cost effectively transported to Hawai'i. LNG can be imported to Hawai'i in two ways: bulk LNG or containerized LNG

**Bulk LNG.** LNG could be transported in bulk via LNG carriers and/or articulated tug barges (ATBs) and received at a bulk LNG import and regasification terminal. The Floating Storage and Regasification Unit (FSRU) is a variant of this option. Pearl Harbor is the best site available for an FSRU when considering factors such as favorable meteorological-ocean conditions, spacious and protected harbor waters, security, cost, and ability to break-bulk (for distribution to the neighbor islands). Natural gas would then be distributed from the FSRU by pipeline to facilities on the individual islands where it would be consumed. Based on our discussions with FERC, we anticipate that a bulk LNG import and regasification terminal project for Hawai'i will take approximately

## I. LNG to Hawai'i

Delivering LNG to Hawai'i

6–8 years to complete (1–2 years planning, 2–3 years FERC permitting, and 2–3 years construction) and could possibly be placed in service between 2020 and 2022.

**Containerized LNG.** LNG could be transported in International Organization for Standardization (ISO) containers using conventional container ships and trucks equipped to handle standard shipping containers. The LNG ISO containers would be delivered directly to the facilities where the LNG would be regasified and consumed. Since FERC permitting is not likely required for LNG delivered by ISO containers, LNG is available today in small quantities, and within a relatively short time for larger quantities.

### Containerized LNG RFP

The Company issued an RFP in March 2014, for LNG to be delivered to Hawai'i in ISO containers (Containerized LNG RFP). We have completed our evaluation of the proposals and have identified two proposals for more in-depth discussion with the bidders. We currently anticipate negotiating and executing a contract, and subsequently submitting an application to the Commission in the fourth quarter of 2014.

The Containerized LNG RFP called for deliveries to start within a window from October 1, 2016 to June 30, 2017. Based on confidential information received via the Containerized LNG RFP process, we believe that an LNG delivery commencement date in the latter part of 2017 remains viable if the following five key milestones are realized by their noted deadlines.

1. Finalization of the LNG Sales and Purchase Agreement (SPA) by fourth quarter 2014.
2. Application submission to the Commission by fourth quarter 2014.
3. Final Order to import LNG issued by the Commission by June 1, 2015.
4. Granting of all other major permits by June 1, 2015.
5. Clearance or waiver of any remaining LNG SPA conditions precedent by July 1, 2015.

Upon achievement of these milestones, we will make the investments necessary to construct, assemble and aggregate the various pieces of the supply chain needed to deliver LNG to Hawai'i in 2017. It nevertheless must be recognized that these milestones are challenging, some of which are beyond our control and they will only be realized if no significant legal, environmental, or social obstacles encumber the process.

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## DELIVERING LNG IN 2017

### Liquefaction Capacity

We believe that ensuring the availability of LNG supply from FortisBC is a critical component for successfully concluding the Containerized LNG RFP process with an executed LNG supply and logistics contract. FortisBC's liquefaction capacity is available under a regulated tariff as early as 2017 and capacity is reserved on a first come, first served basis. The Company believed it was critical to directly secure the required capacity from FortisBC before other parties stepped in. For this reason, on August 8, 2014, we executed an agreement with FortisBC for LNG liquefaction capacity under the FortisBC Rate Schedule 46. FortisBC's liquefaction cost, which is less than \$2.70, is competitive with other liquefaction rates and is, in fact, lower than any other rate we are aware of (including the rates offered by other Gulf of Mexico liquefaction projects). In addition, because FortisBC is in British Columbia, Canada, they are not subject to the Jones Act and, therefore, can provide substantial marine transport savings to Hawaiian Electric through the use of international shipping assets.

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## COST OF SERVICE

The range of proposed conditional delivered LNG pricing to O'ahu power plants and to Hawai'i Island power plants is extremely favorable, and based on the assumed forecasted 2017 natural gas pricing of \$3.58/MBtu.

The pricing mechanisms incorporate pass through provisions of most fixed and variable cost components, with the cost stack to be finalized upon filing of the LNG Sales and Purchase Agreement with the Commission. The build-up of the proposed pricing is based on bidders' current cost estimates, and the ranges for fixed, fixed with escalation, and variable price components.

Included in the fixed cost component are the capital assets (marine assets, ISO containers, etc.) and any services that can be contracted at fixed cost over the term of the SPA. The fixed with escalation cost component include the FortisBC liquefaction costs and other labor costs such as marine terminal handling charges and trucking. Included in the variable cost component is the gas commodity, pipeline toll, and fuel consumed for liquefaction, shipping, and trucking.

The Company and our advisors are undertaking due diligence on the cost elements for each segment in the supply chain. Liquefaction costs are set by FortisBC's Rate Schedule 46 and may be subject to periodic adjustments, if approved by the British Columbia

## I. LNG to Hawai'i

### Cost of Service

Utilities Commission (BCUC). Analysis to date suggests that there is little risk of a cost increase over the bidder's estimates, assuming the above stated milestone are achieved by the milestone dates and the SPA is effective no later than July 1, 2015. Discussions regarding the costs are ongoing with the bidders.

To account for the possibility of stranded assets that could result from a transition to a bulk terminal, a cost adder was included in the LNG forecast between the years of 2017 and 2021 to reflect the potential for a reduced amortization period (5 years versus 15 years).

### Transition to Bulk Terminal: 2022

The development of a bulk receiving terminal will be subject to FERC review and approval and therefore cannot be realistically achieved by 2017. Siting of such a terminal, whether floating or land-based, will require substantial engineering analysis and stakeholder socialization. After consulting with FERC, a realistic schedule to develop a bulk LNG terminal is approximately 6 to 8 years.

The Galway Group estimated LNG pricing for 2022 and beyond by using current gas commodity forecasts, liquefaction costs from FortisBC, and estimated costs for shipping of the LNG and for a bulk terminal utilizing a FSRU. We are also assuming annual price increases in our forecasting. The build-up of the LNG forecast for 2022 is as follows:

| Item                               | Price   |
|------------------------------------|---------|
| Gas Commodity                      | \$4.31  |
| Pipeline Header (Fixed)            | \$0.60  |
| Pipeline Cost of Fuel              | \$0.11  |
| Marketer Fee (Fixed)               | \$0.01  |
| Liquefaction (Fixed)               | \$1.99  |
| Liquefaction Cost of Power         | \$0.91  |
| Process Fuel Gas                   | \$0.04  |
| B.C. LNG Export Tax                | \$0.00  |
| Marine Terminal                    | \$0.33  |
| LNG FOB FortisBC                   | \$8.30  |
| Shipping                           | \$1.89  |
| FSRU + Gas Pipeline                | \$2.54  |
| 2022 LNG Forecast w/ Bulk Terminal | \$12.73 |

Table I-1. LNG Itemized Pricing

The LNG price forecast escalates beyond 2022 due to increases in the gas commodity price forecast, which is derived from NYMEX futures-derived forecasted values for Henry Hub; and 2% inflation adjustment applied to fixed with escalation and variable cost components.

## J. Energy Storage For Grid Applications

Electricity is a commodity that is most efficiently produced when it is needed. The continuously varying demand for electricity requires utilities to have the appropriate mix of generating and demand-side resources to meet these varying demands. Energy storage is an extremely flexible tool for managing the supply-demand balance.

- Energy storage can be a substitute for generation resource alternatives;
- Energy storage can be used in conjunction with generation to help optimize generation capital costs and reduce system operating costs;
- For system security and reliability applications, storage has unique operational characteristics that may provide benefits not available through other resources.

The ability of energy storage to serve in any one of these roles is dependent upon the cost-effectiveness and operational characteristics of the energy storage asset under consideration, and the operational characteristics of all resources on the system.

Until relatively recently, the only way to store electricity in large (or bulk) quantities has been large mechanical storage devices (for example, pumped storage hydro, compressed air energy storage), which are highly dependent on site availability, may face substantial permitting and public acceptance challenges, have high capital costs and require long lead times (more than seven years) to develop. A new generation of chemical energy storage technologies (that is, batteries with new chemistries) and large-scale flywheel devices add to the commercially available options for energy storage in grid applications. In addition, there may be opportunities to aggregate customer-owned energy storage to provide value to all customers.

## J. Energy Storage for Grid Applications

### Commercial Status of Energy Storage

The Commission requested in the April 28, 2014 Decisions and Orders (D&Os) that the Companies consider the role that energy storage can play in managing the reliability of the electric grid. More specifically, the D&Os include the following topics for the Companies to address in the PSIPs:

- Discuss potential energy storage technologies and their capabilities;
- Analyze the fundamental benefit and costs of energy storage technologies;
- Discuss how energy storage is utilized in the preferred resource plan;
- Provide a plan for utilization of energy storage resources to address steady state frequency control and dynamic stability requirements, and to mitigate other renewable energy integration challenges;
- Provide a plan to improve utilization of existing energy storage on Maui and Lanai to improve system reliability and reduce system operation costs in those systems;
- Discuss the use of customer-side energy storage;
- Analyze the use of pumped storage hydro to provide ancillary services and bulk energy storage for renewable energy.

The Companies share the Commission's interest in energy storage for providing essential grid services. Energy storage has been integrated with certain independent power producer (IPP)-owned wind and solar projects to help manage ancillary service requirements. A project to design and procure storage for contingency reserves to mitigate the impacts from distributed solar on system security was initiated for the Hawai'i Electric Light system. Recently, a Request for Proposals (RFP) for commercial-scale and use of energy services to provide ancillary services was issued by Hawaiian Electric. As more fully described herein, the Companies have also implemented several pilot and demonstration projects.

This Appendix J will address the Commissions' questions about the Companies' plans to utilize energy storage in their systems.

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## COMMERCIAL STATUS OF ENERGY STORAGE

Pumped storage hydroelectric and compressed air energy storage technologies are mature and proven, with a great deal of performance data in commercial applications. Batteries (particularly lead-acid) and flywheel type energy storage devices have been around for many years and could also be considered mature technologies, but not for grid level applications such as renewable energy integration on island-based grids. The use of batteries and flywheel devices for use in bulk power systems and applications to integrate, or mitigate the impacts of, intermittent renewable energy in island-based



electric grid systems is relatively new and there is somewhat limited data regarding their performance in commercial power grid applications. It is therefore worth discussing the status of commercialization of battery and flywheel energy storage for grid applications. This section will discuss several aspects<sup>1</sup> of the status of these technologies in terms of their commercialization. The evidence points to these technologies being at the cusp of commercial readiness.

## Regulatory Environment

The regulatory environment for energy storage manufacturers is favorable. Most notably, on October 21, 2013 the California Public Utilities Commission (CPUC) issued the “Decision Adopting Energy Storage Procurement Framework and Design Program<sup>2</sup>.” This CPUC decision set a target of 1,325 MW of energy storage to be installed in the three major investor-owned utility systems in California by the end of 2024. Other state commissions are looking at this CPUC decision<sup>3</sup>. This decision provides commercial opportunities for energy storage technology companies and energy storage project developers, and is therefore favorable for the commercial readiness of energy storage technologies. Of interest, the decision excludes pumped storage hydroelectric projects larger than 50 MW, a mature technology, from the target in order to promote development of smaller grid-scale storage projects.

At the federal level, the Federal Energy Regulatory Commission’s (FERC) Order No. 755<sup>4</sup>, required wholesale markets to develop compensation mechanisms for the provision of frequency regulation, a service that is technically well suited for certain energy storage technologies. The regulatory accounting treatment for energy storage remains an area that will require additional discussions by electric utilities and regulators<sup>5</sup>. For example, energy storage might be implemented for the purpose of relieving grid congestion (functionally classified as transmission), but the same energy storage project might also be able to provide ancillary services (functionally classified as a production service). Grid level energy storage might be implemented to mitigate the effects of variable distributed generation, while at the same time providing other grid support services. However,

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<sup>1</sup> See Appendix G for a discussion of the “Commercial Readiness Index” (CRI) and the factors that are considered in determining a CRI.

<sup>2</sup> Decision 13-10-040, October 17, 2013 (issued October 21, 2014). PUC Rulemaking 10-12-007. Order Instituting Rulemaking Pursuant to Assembly Bill 2514 to Consider the Adoption of Procurement Targets for Viable and Cost-Effective Energy Storage Systems. Full decision available at: <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M079/K533/79533378.PDF>

<sup>3</sup> “California poised to adopt first-in-nation energy storage mandate.” San Jose Mercury-News. October 16, 2013.

<sup>4</sup> *Frequency Regulation Compensation in Organized Wholesale Power Markets*. FERC Order No. 755. FERC Docket Nos. RM11-7-000 and AD10-11-000. Issued October 20, 2011. Order 755 available at: <http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf>

<sup>5</sup> Bhatnagar, Currier, Hernandez, Ma, Kirby. *Market and Policy Barriers to Energy Storage Deployment*. Sandia National Laboratory. Report SAND2013-7606. September 2013. Report available at: <http://www.sandia.gov/ess/publications/SAND2013-7606.pdf>

## J. Energy Storage for Grid Applications

### Commercial Status of Energy Storage

when leveraging storage for multiple purposes, the energy storage must retain the necessary charge level to satisfy the requirements for each use. For example, storage that is deferring transmission investment must retain sufficient charge to handle the transmission constraint; that stored energy cannot be used to provide other services. These situations present issues for regulators in terms of ensuring that the benefits and costs of energy storage are properly allocated.

## Stakeholder Acceptance

There are several dimensions to stakeholder acceptance of energy storage technologies, including:

**Industry Acceptance:** The electric utility industry, including non-utility project developers, has generally accepted grid-scale energy storage technologies as viable solutions for meeting grid needs. This is evidenced by installations of several hundred megawatts of energy storage worldwide in the past few years, including installations in Hawai'i in conjunction with wind and solar projects. Automotive applications for batteries in electric vehicles are expected to drive manufacturing costs down for lithium-ion batteries.<sup>6</sup> As a result, utility industry planners expect distributed energy storage to become more economical and are preparing for distributed storage integration into the future grid.

**Equitable Regulatory Environment:** Monetization of energy storage benefits is generally available in competitive wholesale market environments, where there are markets for capacity, energy and ancillary services. Monetization in vertically integrated utility markets (including Hawai'i) is generally driven by the cost effectiveness of energy storage relative to alternatives that provide similar functions. Cost recovery of energy storage systems is for the most part rationalized in the market. It is worth noting that energy storage project installations do not typically qualify for tax incentives, except in limited circumstances<sup>7</sup>.

**Public Concerns:** Energy storage technologies are generally considered to be safe, however, there are public concerns with these systems related to potential fire hazards, toxic waste disposal, and dam breaches.

**Financial Community Acceptance:** Most of the capital invested in this sector to date has been in the form of venture capital funding, the purpose of which is to commercialize and refine the technologies and develop viable business models. To date, there is no known example of project level debt financing using project debt secured only by the revenues and the project itself (a typical financing model in the IPP industry). Rather,

<sup>6</sup> See for example: <http://www.electric-vehiclenews.com/2010/03/deutsche-bank-battery-costs-appear-to.html>

<sup>7</sup> For an example of such exceptions, see <http://www.chadbourne.com/Large-Batteries-11-30-2011/>

most of the projects have been financed off of the balance sheets of the developers themselves. As the market for energy storage becomes more of a “demand-pull” (as opposed to “supply-push”) the interest of the mainstream investment community is growing. Several large financial institutions are marketing financing solutions for energy storage<sup>8</sup>. Some financial analysts predict that distributed energy storage, when combined with distributed solar PV, is on the cusp of being a technology that is disruptive to the traditional utility business model<sup>9</sup>.

## Technical Performance

Although in general this industry is still in the formative stages, the technical performance of energy storage technologies, particular battery, flywheel systems, and pumped storage hydroelectric is well understood. And, with several hundred megawatts of grid-scale energy storage devices installed worldwide, the body of data is growing rapidly. The technical performance of most of the grid-scale energy storage projects to date (excluding pumped storage hydroelectric) is underwritten with technology performance guarantees (with liquidated damages provisions) from well-capitalized, strong balance sheet, engineering-procurement-construction (EPC) contractors and/or project developers.

Distributed energy storage is being marketed to customers interested in PV as well as enabled by the advent of electric vehicles (EV’s) and the interest on the part of the sellers of EV’s to address consumer “range-anxiety.” Improvement in EV battery technology will increasingly find its way into distributed energy storage applications for consumers, including the ability to use EV’s as a storage device for energy consumed in a customer’s premises.

## Financial Performance

The financial performance of energy storage is dependent upon the particular grid application and energy storage technology being deployed. Grid-scale energy storage costs are still relatively high<sup>10</sup>. In general, the cost of energy storage systems is declining, but challenges remain to deliver grid scale energy storage at low costs. Some sources believe that energy storage costs will decline precipitously over the next decade, at a rate of cost decline similar to that experienced with solar PV technology cost<sup>11</sup>. With respect

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<sup>8</sup> For example see: <http://www.goldmansachs.com/what-we-do/investing-and-lending/middle-market-financing-and-investing/alternative-energy/>

<sup>9</sup> See for example: <http://www.utilitydive.com/news/barclays-downgrades-entire-us-electric-utility-sector/266936/>

<sup>10</sup> See: Bhatnagar, Currier, et. al.

<sup>11</sup> For example, see: <http://rameznaam.com/2013/09/25/energy-storage-gets-exponentially-cheaper-too/>

to value (benefits) of utility scale grid storage, as technology improves, the ability of energy storage to cost effectively provide grid services also increases.

## Industry Supply Chain and Vendor Maturity

While the energy storage industry has its share of venture capital backed startups, large and well-capitalized equipment manufacturers now offer grid level energy storage technologies and solutions. These companies include, but are not limited to: General Electric, Hitachi, LG, Panasonic and NEC. Tesla Motors has recently announced that it is seeking a location for a large battery manufacturing plant in the US, to supply batteries for its EV's. They are actively developing utility uses for these same batteries and may find their way into grid storage applications, including distributed energy storage. Many of the smaller startups and niche players enjoy investments from, and strategic partnerships with, larger companies. These trends indicate that larger manufacturing companies are making the investments in sales, manufacturing, and service ecosystems that support the long-term viability of the energy storage industry. To date however, there is a lack of standardization in the energy storage industry.

## Market Opportunity

The market opportunity for grid-scale energy storage is clearly validated by successful deployments worldwide and by regulatory mandates for energy storage as described above. Distributed energy storage is also viewed as a large market opportunity.

In conclusion, while the grid-scale energy storage industry is clearly in the early stages of commercial viability, it is well beyond the “technology development” stage for many of the available technologies. The Companies can be reasonably confident that energy storage solutions are available that can be designed, financed, constructed, operated and maintained in a manner consistent with the way the Companies deploy other kinds of utility grid infrastructure.

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## ENERGY STORAGE APPLICATIONS

### Defining Characteristics of Energy Storage

Stored energy is generally referred to in physics as “potential energy.” Potential energy is found in various forms; for example, the chemical energy stored in the form of a fuel, mechanical energy stored in a spring, gravitational energy stored in water in a reservoir, etc. In practice, most energy storage systems are used to store energy for use (that is, conversion to “kinetic energy”) at a later time.

Energy storage systems of interest for electricity grid applications can be defined by the following set of characteristics:

**Storage:** Amount of energy that can be stored (measured in megawatt-hours)

**Capacity (or rate of discharge):** the rate (quantity per unit of time) at which the energy storage device can deliver its stored energy to the grid (typically measured in megawatts).

**Storage Duration:** Hours or minutes of energy storage (this is the amount of energy that can be stored divided by the rate of discharge).

**Maximum Depth of Discharge:** This is defined by the energy stored in the device at its minimum level divided by the total energy storage. This is a limiting factor in terms of the actual duration of delivery of stored energy from the device to the grid, since once the device reaches its maximum depth of discharge it cannot release any more of its stored energy. This can be a function of chemistry (for example, in a battery) or physical design (for example, in a pumped storage hydroelectric reservoir).

**Round trip efficiency:** This is the ratio of stored energy available for “release” from the device (AC energy out) to the amount of energy that must be expended to “fill” the device (AC energy in). The perfect storage device would have 100% round trip efficiency (that is, the energy output of the storage device would be equal to the charging energy required.) Actual storage efficiencies range from 70% to 90% depending upon the type of device, size and technology.

**Duty Cycles Available:** The number of charge/discharge cycles available from the device during a given period of time (measured in cycles per unit of time, for example, cycles per year, cycles per minute).

## Grid Applications for Energy Storage

Generalized energy storage applications in electric power grids include the following:

**Load Serving Capacity:** Energy storage devices can be used to provide the equivalent of generating capacity, provided that the available storage duration is long enough (typically hours). Practical applications include substitution for peaking plants such as combustion turbines in markets where additional capacity is required<sup>12</sup>. In such an application, lower cost generating resources would be used to “fill” the energy storage device, and the stored energy would be released at a later time during peak hours. Load serving capacity requires relatively long storage durations (at least 3 hours to qualify as

<sup>12</sup> Denholm, Jorgenson, Hummon, Jenkin, Palcha, Kirby, Ma, O'Malley. The Value of Energy Storage for Grid Applications. National Renewable Energy Laboratory. NREL/TP-6A20-58465. May 2013. Available at: <http://www.nrel.gov/docs/fy13osti/58465.pdf>

## J. Energy Storage for Grid Applications

### Energy Storage Applications

“capacity” for the Companies’ systems) but relatively infrequent use in terms of duty cycles (perhaps 50 – 100 cycles per year).

**Time Shifting of Demand and Energy:** Energy storage can be used to “shift” demand from one time period to another. Time shifting (also referred to as “load shifting”) applications also typically require long duration (hours) of storage in order to be effective. In markets with substantial on-peak/off-peak energy price differentials, storage is valuable in financial arbitrage. In Hawai’i, there is not a large differential between the on peak and off-peak marginal cost of energy production; therefore, price arbitrage is not a primary consideration for energy storage at the grid level. Time shifting using energy storage may be useful in Hawai’i for managing the variability of some renewable energy resources, or to capture the available energy production from variable resources and store it for use at a later time, rather than “spilling” the available energy. Time shifting also requires relatively long storage durations, with the number of duty cycles being dependent on the nature of the market (for price arbitrage) or relative penetration of variable renewable energy and the frequency of curtailment events that could be avoided using energy storage.

**Sub-Second Response:** Fast acting energy storage can be used to supplement inertia and limit under-frequency load shedding that would occur during faults and other abnormalities that occur on the grid, such as loss of generation. See Appendix E, Essential Grid Services.

**Power Quality:** Some energy storage devices can provide power quality and “ride-through” service. Power quality refers to the quality of the AC voltage in the system. Some energy storage devices can respond to changes in AC voltage by absorbing and releasing energy to “smooth” the sinusoidal AC waveform. For example, this type of functionality is used for some wind plants to ensure that equipment remains connected through transient system conditions.

These energy storage applications and the operational requirements associated with them are mapped in Figure J-1.

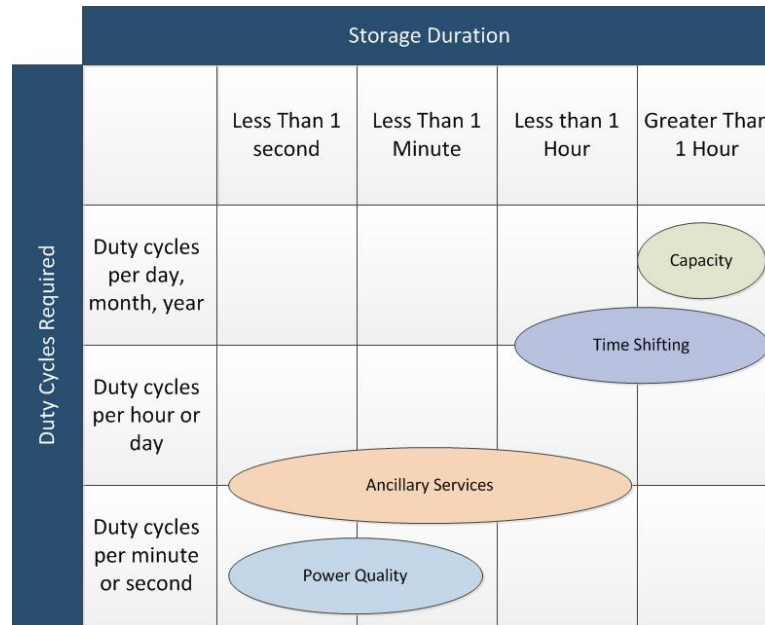


Figure J-1. Energy Storage Applications<sup>13</sup>

## ENERGY STORAGE TECHNOLOGIES

Energy storage technologies can be categorized in terms of the physics utilized to store energy. These categories and the types of specific technologies include:

**Mechanical:** pumped storage hydroelectric (PSH), compressed air energy storage (CAES), flywheels. Underground CAES is not considered viable in Hawai‘i due to lack of suitable geographic features and structural features conducive to CAES. However, aboveground CAES may be technically viable, but has not been considered at this time. PSH and flywheels are considered for Hawai‘i and are discussed below.

**Electrochemical:** secondary batteries (lead-acid, lithium ion, other chemistries)<sup>14</sup>, flow batteries. Lead-acid batteries, lithium ion and flow batteries are considered for Hawai‘i and are discussed below.

**Chemical:** hydrogen (H<sub>2</sub>), synthetic natural gas (SNG). These technologies are not considered for near-term applications in Hawai‘i. A hydrogen infrastructure is, at best, a

<sup>13</sup> Adapted from International Electrotechnical Commission (IEC) Electrical Energy Storage Whitepaper, December 2011. Available at: <http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf>

<sup>14</sup> “Primary” batteries cannot be recharged (for example, a dry cell flashlight battery). In “Secondary” batteries, the charge/discharge cycle can be reversed, meaning that secondary batteries can be recharged.

## J. Energy Storage for Grid Applications

energy storage technologies

decade away. SNG is not economically viable as the round trip efficiency is very low (about 36%)<sup>15</sup>.

**Thermal:** ice storage and grid interactive water heating. Ice storage and other forms of thermal energy storage are not considered here for bulk power applications. Several companies market thermal ice storage systems for managing end-use load (typically air conditioning) against tariff price signals<sup>16</sup>. Thermal energy storage can be useful for implementation by end-users in response to time-based pricing programs that are part of the Companies' demand response initiative (for example, grid interactive water heating).

**Electrical:** ultra-capacitors, superconducting magnet. These technologies are on the cusp of commercial readiness for grid-scale applications. Ultra-capacitors are increasingly being used in power quality applications<sup>17</sup>. Indeed, the Hawi wind plant in the Hawai'i Electric Light system utilizes an ultra-capacitor to ensure it remains connected through grid transients.

The following subsections briefly discuss the specific energy storage technologies that have been assumed to be available for consideration in the PSIP's. The inclusion of these technologies, and the exclusion of others, does not imply that the Companies are closed to considering other technologies. Specific energy storage proposals will be evaluated on their merits, including the commercial readiness of the technology proposed, utilization in specific grid-scale applications, and other relevant factors.

### Flywheels

Flywheels are mechanical devices that store energy in the angular momentum of a rotating mass. The rotating mass is typically mounted on a very low friction bearing. The energy to maintain the angular momentum of the rotating mass is supplied from the grid. During a grid event, such as a sudden loss of load, the inertia of the rotating mass provides energy to drive a generator, which provides replacement power to the grid.

Flywheels are useful to provide inertial response in a power system. They are also increasingly used in commercial applications to provide fast-response, short-term "ride-through" capability that allows seamless transfer of load from the grid to a longer-term backup system such as an emergency generator. Flywheels display excellent load following characteristics over very short duration timeframes. Thus, they are well suited for providing frequency regulation and contingency reserves.

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<sup>15</sup> Pascale, KU Leuven. *Energy Storage and Synthetic Natural Gas*. (undated). Available at: [http://energy.sia-partners.com/files/2014/05/Paulus\\_Pascale\\_ArticleUpdated1.pdf](http://energy.sia-partners.com/files/2014/05/Paulus_Pascale_ArticleUpdated1.pdf)

<sup>16</sup> See for example Ice Energy. <http://www.ice-energy.com/>

<sup>17</sup> Daugherty, Leonard. SolRayo. *Ultracapacitors for Renewable Energy Storage*. (undated). Available at: [http://www.solrayo.com/SolRayo/Presentations\\_files/Ultracapacitors\\_for\\_Renewable\\_Energy\\_Storage\\_Webinar.pdf](http://www.solrayo.com/SolRayo/Presentations_files/Ultracapacitors_for_Renewable_Energy_Storage_Webinar.pdf)



The capital cost of flywheels is fairly high. However, flywheels can provide hundreds of thousands of charge/discharge cycles over their useful life. Flywheel energy storage can be developed in two years or less, not counting regulatory approval lead-times. The round trip efficiency of a flywheel storage system is approximately 85%.

Other than specific site considerations, flywheels have very little environmental impact. Modern metallurgy has produced flywheel technologies that are safe during operation. Several vendors have designs that place flywheels underground for additional safety.

## Advanced Lead Acid Batteries

Lead-acid batteries were invented in the mid 19<sup>th</sup> century. Conventional lead-acid batteries are characterized by low energy density (the amount of energy stored relative to the mass of the battery), relatively high maintenance requirements, and short life cycles. Their principle advantage is the ability to deliver high current over long duration timeframes. Disposal of lead-acid batteries presents environmental considerations, but recycling techniques are well established.

Advanced lead-acid batteries or “UltraBatteries” are now reaching the market. UltraBatteries combine conventional lead-acid batteries with electronic ultra-capacitors to provide high duty cycles. The supercapacitor enhances the power and lifespan of the lead-acid battery, acting as a buffer during high-rate discharge and charge<sup>18</sup>. This makes the UltraBattery a low cost, durable battery technology, with faster discharge/charge rates and a life cycle that is two to three times longer than a regular lead-acid battery<sup>19</sup>.

Like all chemical energy storage systems, capital costs for advanced lead acid batteries are still relatively high for grid-scale applications. Round trip efficiencies are also high at around 90%.

Grid-scale advanced lead acid battery projects can be developed in two years or less, not counting regulatory approval lead-times.

The high market penetration of lead-acid batteries in automotive applications has led to successful lead-acid battery recycling programs. Not only does recycling keep lead out of the waste stream, recycling supplies over 80% of the lead used in new lead-acid batteries.<sup>20</sup>

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<sup>18</sup> *UltraBattery: No Ordinary Battery*. Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). Available at: <http://www.csiro.au/Outcomes/Energy/Storing-renewable-energy/Ultra-Battery/Technology.aspx>

<sup>19</sup> *Ibid*.

<sup>20</sup> Conger, Christine. “Are Batteries Bad for the Environment?” Discovery News. September 16, 2010. Available at: [http://www.nbcnews.com/id/39214032/ns/technology\\_and\\_science-science/t/are-batteries-bad-environment/#.U\\_ATm-VdVS8](http://www.nbcnews.com/id/39214032/ns/technology_and_science-science/t/are-batteries-bad-environment/#.U_ATm-VdVS8)

## Lithium Ion Batteries

“Lithium-ion” refers to a wide range of chemistries all involving the transfer of lithium ions between electrodes during charge and discharge cycles of the battery<sup>21</sup>. Lithium ion batteries are very flexible storage devices with high energy density, a fast charge rate, a fast discharge rate, and a low self-discharge rate, making lithium ion batteries ideal for grid applications<sup>22</sup>.

Capital costs for lithium ion batteries are declining<sup>23</sup>, particularly as the use of lithium ion for electric vehicle batteries rises. Lithium ion batteries themselves have a useful life through 400-500 normal charge/discharge cycles. More frequent use of the full charge/discharge capabilities of lithium ion would shorten the life. Lithium ion battery energy storage can be developed in two years or less, not counting regulatory approval lead-times.

The round trip efficiency for lithium ion technology is around 90%.

Lithium ion batteries do not contain metallic lithium, nor do they contain lead, cadmium, or mercury. Thus, disposal of lithium ion batteries is not a major issue. At the end of their useful life, lithium ion batteries are dismantled and the parts are reused.<sup>24</sup> Overcharging certain lithium ion batteries can lead to explosive battery failure. Thus, the overall safety of lithium ion batteries in grid applications is a function of mechanical design and control systems.

## Flow Redox Batteries

A flow battery is charged and discharged by a reversible reduction-oxidation (“redox”) reaction between two liquid electrolytes of the battery. Unlike conventional batteries, electrolytes are stored in separated storage tanks, not in the power cell of the battery. During operation, these electrolytes are pumped through a stack of power cells, in which a chemical redox reaction takes place and electricity is produced. The design of the power cell can be optimized for the power rating needed, since this is independent of the amount of electrolyte<sup>25</sup>.

Advantages of flow batteries include virtually unlimited cycle life and fast charge/discharge times for the electrolyte, but the power cells do require periodic replacement. Increasing the size of the electrode stack can increase the power output of a

<sup>21</sup> Energy Storage Association. <http://energystorage.org/energy-storage/technologies/lithium-ion-li-ion-batteries>

<sup>22</sup> *Lithium Ion Technical Handbook*. Gold Peak Industries (Taiwan), Ltd.  
[http://web.archive.org/web/20071007175038/http://www.gpbatteries.com/html/pdf/Li-ion\\_handbook.pdf](http://web.archive.org/web/20071007175038/http://www.gpbatteries.com/html/pdf/Li-ion_handbook.pdf)

<sup>23</sup> See for example: <http://rameznaam.com/2013/09/25/energy-storage-gets-exponentially-cheaper-too/>

<sup>24</sup> See for example: <http://auto.howstuffworks.com/fuel-efficiency/vehicles/how-green-are-automotive-lithium-ion-batteries.htm>

<sup>25</sup> This paragraph taken from: <http://www.imergypower.com/products/redox-flow-battery-technology/>

flow battery, and the storage capacity (energy) can be increased by increasing the size of electrolyte storage (or volume of electrolyte tanks). Flow batteries are useful for longer storage duration (hours) applications. Their relatively high capital costs make them less useful for ancillary service applications. Flow batteries are generally considered safe, an important issue for grid-scale batteries where thermal runaway of conventional batteries may cause fire<sup>26</sup>.

Capital costs for flow batteries are still relatively high. The round trip efficiency of a flow battery is relatively low at around 72%.

## Pumped Storage Hydroelectric

Pumped storage hydroelectric (PSH) is a mature technology that has been successfully implemented around the world in grid applications. In a pumped storage hydro system, water is pumped to a higher elevation using energy made available from generating resources that are otherwise unused (for example, low marginal cost off-peak energy or excess renewable energy that would otherwise be curtailed, etc.). During high demand periods, this stored water drives a hydroelectric pump-turbine to generate electricity.

Pumped storage hydroelectric has a relatively high capital cost, but has a useful life typically in excess of 50 years. Pumped storage is very efficient with round trip efficiencies approaching 80%.

Pumped storage hydro installations are very site dependent. Pumped storage investigations in Hawai'i have previously identified several potential sites in the Companies' service territories, with available output capacities typically less than 100 MW in size. Pumped storage hydro installations also face substantial siting and permitting challenges, particular where new reservoirs must be constructed and subsequently flooded. Because of the site specific challenges and the substantial engineering and construction efforts required to build a PSH project, the typical development time for pumped storage is seven years or longer, posing challenges to the utility planner, particularly in an environment where the need to deliver solutions in the near term is paramount.

Due to the inherent economies of scale, the preponderance of pumped storage hydroelectric installations in the United States are typically hundreds or even thousands of megawatts in size. There is very limited data on capital cost and performance for operating pumped storage hydroelectric installations that are less than 100 MW in size.

Pumped storage hydro is a very useful technology for providing peaking capacity and time shifting capabilities. While pumped storage hydro is a quick-start resource, the

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<sup>26</sup> Lamonaca, Martin. "Startup EnerVault Rethinks Flow Battery Chemistry." MIT Technology Review. March 22, 2013.

## J. Energy Storage for Grid Applications

### Economics of Energy Storage

water column constant of a typical pumped storage system is about 7 seconds (that is, this is the time it takes to get the water moving through the turbine to produce electricity). This is a limiting factor with respect to the utilization of an off-line pumped storage system for providing certain ancillary services. The utilization of adjustable speed pump turbine technology in pumped storage hydroelectric projects can provide operating flexibility compared to conventional pump turbines. The main advantage of using adjustable speed technology is the ability to provide more precise power control. This power control can be maintained over a wider operating range of the pumped storage hydroelectric system, allowing the utility to provide ancillary services, such as frequency regulation, spinning reserve, and load following, in both the generation and pumping modes. These benefits and other attributes of an adjustable speed pump turbine can translate into increased operating efficiencies, improved dynamic behavior, and lower operating costs.

Unlike a battery, which already has charge, or a flywheel that has angular momentum, the start of a pumped storage charging cycle requires the delivery of high levels of electric current to start the motors necessary to pump water to the higher elevation. To put this in perspective, a 30 MW pumped storage system in the Hawai'i Electric Light system would require starting 37.5 MW of motor load (assuming an 80% round trip efficiency). The typical daily peak demand of the Hawai'i Electric Light system is about 150 MW. Therefore, the start of the motor would represent an instantaneous load increase of 25% on the system. This may result in currents that exceed the short circuit limits of the transmission system, and without mitigation this would result in a significant frequency disturbance.

The primary environmental impacts from pumped storage hydro occur during construction. If construction of new reservoirs and/or water diversion is required, this can lead to substantial permitting challenges.

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## ECONOMICS OF ENERGY STORAGE

### Energy Storage Capital Cost

The costs assumed in the PSIP's for energy storage systems are generally based on actual proposals for energy storage systems and flywheels, and from a combination of sources for pumped storage hydroelectric. The cost of energy storage for any given storage technology is in part a function of the duration of storage required. Table J-1 summarizes

the capital costs assumed for the PSIP’s mapped against the specific grid services required in the Companies’ systems<sup>27</sup>.

| Grid Service                     | Storage Duration / Discharge    | Technology     |                          |                   |                  |                       |
|----------------------------------|---------------------------------|----------------|--------------------------|-------------------|------------------|-----------------------|
|                                  |                                 | Flywheel \$/KW | Advanced Lead Acid \$/KW | Lithium Ion \$/KW | Flow Redox \$/KW | PSH \$/KW             |
| Inertial, Fast Response Reserves | 0.05 min / 5000 cycles per year | \$997          | NA                       | NA                | NA               | *                     |
| Regulating Reserves              | 30 min / 1000 cycles per year   | \$4,459        | \$1,005                  | \$1,179           | \$1,596          | *                     |
| Contingency Reserves             | 30 min / 20 cycles per year     | \$2,263        | \$802                    | \$942             | \$1,079          | *                     |
| Capacity, Long-term Reserves     | > 3 hours / 50 cycles per year  | NA             | \$4,531                  | \$5,401           | \$2,559          | \$4,500 <sup>28</sup> |

Costs include EPC, land, and overheads. Costs do not include AFUDC. NA = not economic, or unable to provide this service. \* PSH may be able to provide these services when operating, but because the upper reservoir capacity of a given pumped storage project site is defined by geology and other factors, PSH would not typically be economical to build for the sole purpose of providing very short duration services.

Table J-1. Energy Storage Technology Capital Cost Assumptions (2015 Overnight \$/KW)

### Energy Storage Fixed O&M

The PSIP fixed O&M cost assumptions for energy storage were also based on actual proposals, except for pumped storage hydroelectric, which is based on NREL data. Table J-2 summarizes the storage fixed O&M costs.

| Grid Service                     | Storage Duration / Discharge    | Technology |                    |             |            |     |
|----------------------------------|---------------------------------|------------|--------------------|-------------|------------|-----|
|                                  |                                 | Flywheel   | Advanced Lead Acid | Lithium Ion | Flow Redox | PSH |
| Inertial, Fast Response Reserves | 0.05 min / 5000 cycles per year | 58         | NA                 | NA          | NA         | NA  |
| Regulating Reserves*             | 30 min / 1000 cycles per year   | 264        | 31                 | 32          | 43         | NA  |
| Contingency Reserves             | 30 min / 20 cycles per year     | 108        | 25                 | 27          | 29         | NA  |
| Capacity, Long-term Reserves     | > 3 hours / 50 cycles per year  | NA         | 90                 | 105         | 62         | 29  |

Table J-2. Energy Storage Fixed O&M Assumptions (2015 \$/KW-Year)

<sup>27</sup> See Appendix E for a discussion of Essential Grid Services in the Companies’ systems.

<sup>28</sup> There is relatively little actual data available regarding the cost of utility-scale pumped storage projects less than 100 MW in size. This capital cost assumption for pumped storage used in the PSIP analyses was determined through evaluation of a number of different sources, including a review of confidential screening-level cost estimates for site specific projects in Hawai’i, estimates for a 50 MW pumped storage project in the United Kingdom, NREL data, U.S. Energy Information Administration data, and conversations with a potential pumped storage developer in Hawai’i.

## Energy Storage Variable O&M

The PSIP variable O&M cost assumptions for energy storage were also based on actual proposals, except for pumped storage hydroelectric O&M, which is based on NREL data. The variable O&M costs for batteries is solely related to battery and cell replacements and disposal at the end of the duty cycle of the batteries which are assumed to require replacement due to high number of charge/discharge cycles per year associated with provision of regulating reserves. Table J-3 summarizes the storage variable O&M costs

| Grid Service                     | Storage Duration / Discharge    | Technology |                    |             |            |     |
|----------------------------------|---------------------------------|------------|--------------------|-------------|------------|-----|
|                                  |                                 | Flywheel   | Advanced Lead Acid | Lithium Ion | Flow Redox | PSH |
| Inertial, Fast Response Reserves | 0.05 min / 5000 cycles per year | NA         | NA                 | NA          | NA         | NA  |
| Regulating Reserves*             | 30 min / 1000 cycles per year   | -0-        | 88                 | 45          | 30         | NA  |
| Contingency Reserves             | 30 min / 20 cycles per year     | NA         | NA                 | NA          | NA         | NA  |
| Capacity, Long-term Reserves     | > 3 hours / 50 cycles per year  | NA         | NA                 | NA          | NA         | 59  |

Table J-3. Energy Storage Variable O&M Cost Assumptions (2015 \$/MWH)

## Benefits of Energy Storage

In the Companies' systems, energy storage can be used for several purposes.

- Capacity to serve load
- Manage curtailment of variable renewable generation
- Ancillary services
- Integration of renewables

Benefits of energy storage for each of the above uses depend upon specific operating conditions, the capacity adequacy situation in each of the operating systems, and the other resource options available. In general, energy storage can also be used for multiple purposes. For example, energy storage installed to provide capacity to serve load, could also be available to provide ancillary services, provided it is not being used in its load-serving mode. However, if the storage asset is will be used for multiple purposes, it must be designed to ensure the energy allocation and response capability can serve the combined needs. For example, storage used for contingency reserves must be kept at the necessary charge level to provide the required reserve. If also providing regulation, additional energy storage capacity would be required above the minimum required to meet the contingency reserve requirement.

## Capacity

Energy storage can provide capacity to serve load on the Companies' systems, provided that there is a need for capacity<sup>29</sup> and provided that there is the appropriate duration of energy storage available to qualify as capacity<sup>30</sup>. During the PSIP planning period, the Hawaiian Electric and Maui Electric systems are expected to add capacity to replace retiring generation. Thus, energy storage is one of the alternatives that must be considered for providing that capacity.

Figure J-2 conceptually depicts the economic comparison of energy storage to generation for providing capacity.

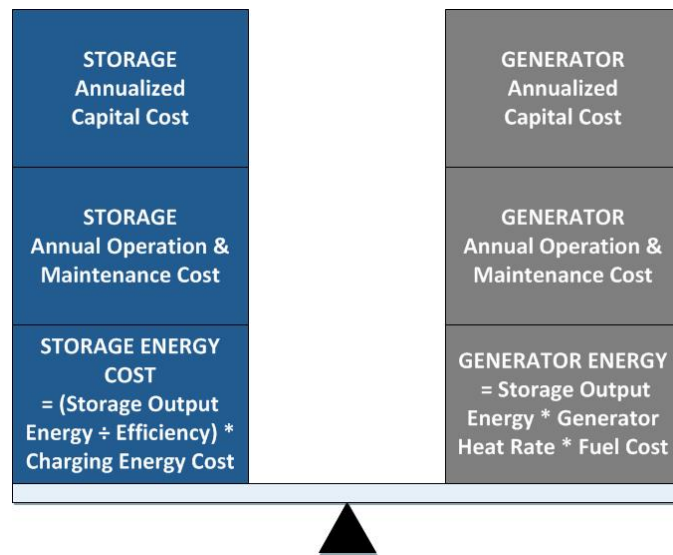


Figure J-2. Energy Storage Economics for Capacity

In this comparison, the energy storage device is compared on a one-for-one basis as a substitute for a generator. A levelized utility revenue requirements factor is applied to the total capital cost of the storage and the generator to determine the annual capital costs. The O&M costs associated with the two alternatives are determined. And finally, the cost of the energy output from each of the assets is computed. In the case of the storage technology, the round trip efficiency must be taken into account, because more energy is required to charge the energy storage asset than is usefully delivered from the same energy storage asset. If the total cost of the energy storage asset were less than the cost of the generator, energy storage would be the most economical alternative<sup>31</sup>. Note that in the case where capacity is not needed, the capacity cost of the generator would be

<sup>29</sup> Denholm, Jorgenson et. al.

<sup>30</sup> Storage is a finite energy resource. When used as a capacity resource, the storage must be carefully designed for the appropriate duration, and the storage energy must be utilized in an appropriate manner. The Companies' criteria require that a resource be able to deliver energy for 3 continuous hours in order to qualify as capacity.

<sup>31</sup> In a proper analysis, any differences in ancillary service costs or benefits associated with the alternatives being compared will also be included.

zero, because existing generation (whose capital cost is sunk) would be able to provide amount of energy required by the system.

### Managing Curtailment

Energy storage used to manage variable renewable energy curtailment is an example of a time shifting application for storage, and may have use in the Companies' systems. Energy storage can absorb variable renewable energy that is produced when it is not needed, and return that energy (less round trip losses) to the system at a later time. Figure J-3 conceptually depicts the economics of energy storage in managing curtailment.

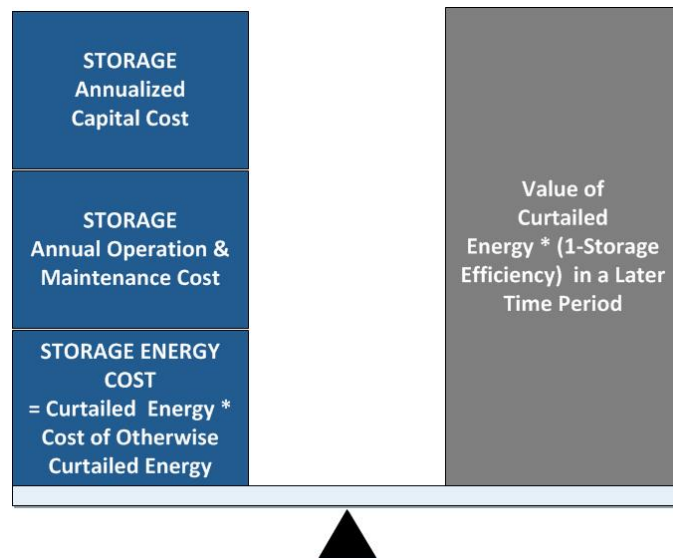


Figure J-3. Energy Storage Economics for Managing Curtailment

The basic economic equation in Figure J-2 is a comparison of the cost of the energy storage versus the value of energy in a later time period of energy that would have otherwise been curtailed (less the round trip efficiency losses since that those losses will not be returned to the system). Note that in Figure J-2 there is a cost associated with the curtailed energy used to charge the energy storage device. Absent the energy storage asset, the payment for the curtailed energy would have been avoided. Thus, this is a cost that is borne by the ratepayer that would otherwise have not been incurred. Further study of Figure J-2 will reveal that the cost comparison includes the capital cost of the energy storage, but it does not explicitly include any capacity value (that is, capital cost) associated with use of the energy in a later time period. Unless there are severe capacity constraints in the system where new capacity is required, the capacity value of the energy used at a later time is essentially zero. At current Company system marginal cost levels, it would almost never be economical to build energy storage exclusively for the purpose of managing energy curtailment. Rather, it is more likely that an energy storage asset already installed for another purpose could also be used to manage curtailment.



### Ancillary Services

Energy storage can be used to provide ancillary services, provided that it can respond in the time frames necessary and operate in a coordinated fashion with other generation and demand response resources on the system. Using energy storage to provide ancillary services slightly increases total amount of energy that must be generated in the system due to the round trip losses associated with the energy storage asset. The charging energy may come from thermal resources or from variable renewable resources. However, energy storage may allow energy production costs to be reduced if provision of ancillary services is causing a constraint on the economic commitment and dispatch of generating units. These economics are depicted in Figure J-4.

The value of the energy storage asset in this situation is based on production cost savings (fuel and O&M) that are incurred by storage supplying the ancillary services. Calculation of these benefits requires production simulations.

If capacity is required in the system, short duration energy storage may be more cost effective than adding new generating capacity. If that is the case, the capital cost of the new generation must be added into the benefits that storage can provide.

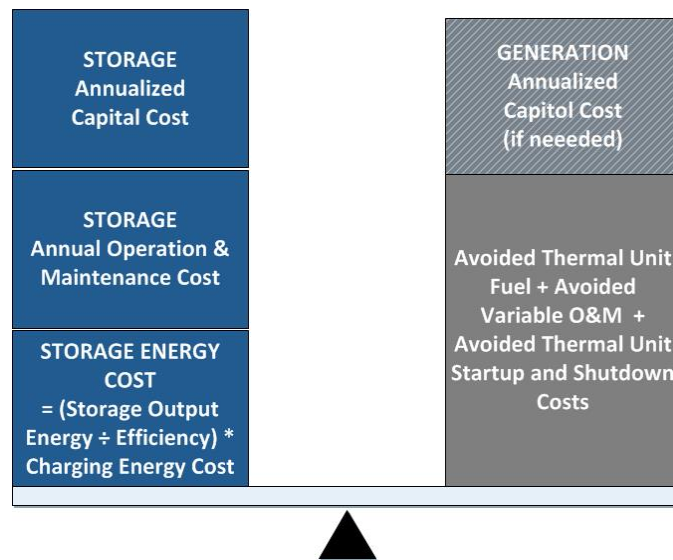


Figure J-4. Energy Storage Economics for Ancillary Services

### Integration of Renewables

Another possible use of energy storage in conjunction with renewable energy is to combine the installation of a variable renewable generator with the installation of energy storage. This has been accomplished in the all three of the Companies' main operating systems. The value of this configuration for customers is that it essentially allows the storage to be leveraged to minimize the ancillary service requirements created by the variable generator that would otherwise have to be provided by other resources on the

## J. Energy Storage for Grid Applications

### Economics of Energy Storage

system. Location of storage at the plant allows the sizing to be designed for the plant needs; co-location also simplifies the communications control interface. From a system standpoint, the storage/generation combination is treated as a plant with the combined operational/technical capabilities of the turbines and storage. The economic evaluation is essentially the same as that portrayed for ancillary services in Figure J-4.

It should be noted that in several cases, the installation of the energy storage was feasible only because it was bundled with generation in a way that allowed the project developer to obtain tax advantages for the energy storage that would not be available for a standalone energy storage asset. In other words, energy storage added value to the generation.

Unless marginal thermal generation costs were much higher than they are today, the converse is not true (that is, adding generation does not add value to storage). It does not make economic sense to build excess renewable generators exclusively to provide energy to charge storage assets since in doing so, the marginal capital cost would be the sum of the generator capital cost and the storage capital cost. Rather, it is important that the system be planned to optimize all resources, including generation, demand response, and storage to achieve the lowest cost.

## K. Capital Investments

This information represents the 2015–2030 capital expenditure budget for the Maui Electric Company.

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### TRANSFORMATIONAL INVESTMENTS

The transformation of the Maui, Lanai, and Molokai electric grids to reliably and cost effectively enable more renewable generation requires significant investment in virtually every aspect of the business. Investments ranging from new renewable generation resources to enabling technologies for demand side resources and from DGPV enabling grid reinforcements to infrastructure for lower-cost LNG fuel will transform the islands' grids. These transformative investments are described below more in depth.

#### Liquefied Natural Gas (LNG)

In an effort to reduce customer costs, the Hawaiian Electric Companies are pursuing two non-exclusive approaches to import lower-cost LNG to Hawai'i: importation of LNG via ISO (International Organization for Standardization) containers (containerized LNG); and/or importation of LNG via bulk LNG carriers (bulk LNG).

The concept of containerized LNG would involve using conventional container ships and trucks equipped to handle ISO containers. The LNG ISO containers would be delivered directly to the generating stations where the LNG would be regasified and consumed. Shipping and distribution of containerized LNG to Hawai'i in volumes sufficient for power generation may possibly be commercialized within three years or less.

## K. Capital Investments

### Transformational Investments

The bulk LNG concept would involve transporting LNG across the ocean via LNG carriers and/or articulated tug barges, and receiving it at a bulk LNG import and regasification terminal (likely located in Pearl Harbor). Once regasified, natural gas would be distributed by pipeline to generating stations where it would be consumed<sup>1</sup>. It is anticipated that development, permitting, and implementation of a bulk LNG import and regasification terminal for Hawai'i will take up to eight years to complete, and could possibly be placed in service in 2020 to 2022.

Regarding containerized LNG, the Hawaiian Electric Companies solicited offers from third parties for containerized LNG deliveries via a March 11, 2014 request for proposals (RFP) and final bids from three potential suppliers were received on May 24, 2014. The responses to the RFP indicate that containerized LNG could be delivered to generating stations on O'ahu and neighbor islands up to an approximate 30% discount below current petroleum fuel prices. Based on these proposals, the Companies intend to move forward as quickly as it can to bring containerized LNG to Hawai'i and to use it in existing and future replacement generating units.

It appears that importing containerized LNG will have the potential of saving the Companies' customers throughout the state substantial amounts on fuel costs. The amount of the savings will depend on the prices for the fuels that are displaced once LNG is available, and the final prices from the on-going RFP. It is uncertain at this time whether a bulk LNG delivery solution would provide as much, the same or more of a cost benefit to customers. Therefore, the Hawaiian Electric Companies will continue to pursue the bulk LNG concept as long as there is a potential that it will provide additional benefits and value to our customers.

## System Security Investments

To reliably operate a grid rich in variable renewable generation requires the grid operator to manage a new, and to some extent not fully known, set of electrical system security issues. When such a grid is a small islanded system such as on Maui, Molokai, and Lanai, the criticality of these issues is further heightened, as compared to the large, interconnected grids of North America. The Company's system security analyses, coupled with the PSIP planning processes, have defined a number of new investments required to meet these system security challenges. These investments, related to both energy storage and communications, enable the Company to comply with its system security and reliability standards and maintain compliance with these standards through the remainder of the study period.

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<sup>1</sup> LNG would continue to be delivered in ISO containers to the neighbor islands.

## Facilitation of New or Renewable Energy

Battery Energy Storage Systems (BESS) for Molokai and Lanai, including transmissions and distribution upgrades to accommodate them, are included to facilitate additional renewable energy on those islands. The BESS will allow for the addition of utility scale as-available generation as well as accommodate additional customer sited DG. For Maui, modifications to units M14 and M16 at Maalaea Power Plant are included to reduce the units minimum operating load. These modifications will lower the amount of generation by Maui Electric in order to increase the as-available generation accepted to the Maui system.

## DG Enabling Investments

The Distributed Generation Improvement Plan (DGIP) lays out an aggressive plan to enable the integration of significant amounts of new distributed resources, which are expected to be primarily rooftop PV. This plan calls for investments to enable “clearing the existing queue” within the next 18 months, and investments enabling total interconnected DGPV to reach approximately 135 MW for Maui County by 2030. This will continue to provide our customers with an important option to manage their electricity costs and contribute to meeting State RPS goals.

The DGIP includes a Distribution Circuit Improvement Implementation Plan (DCIIP) that summarizes specific strategies and action plans, including associated costs and schedules, for circuit upgrades and other mitigation measures to increase the capacity of the Companies’ electrical grids and enable the interconnection of additional DG.

In evaluating each company, by circuit and substation transformer, improvements to allow for greater interconnection of DG include: (1) updating LTC and voltage regulator controls to be capable of operating properly under reverse-flow conditions; (2) upgrading substation transformer capacity when load and DG are greater than 50% of capacity in the reverse direction; (3) upgrading primary circuit capacity when load and DG are greater than 50% of capacity in the reverse direction; (4) upgrading customer service transformer capacity when load and DG are greater than 100% of capacity, which also mitigates high voltage; (5) adding a grounding transformer to circuits when 33% of DML is exceeded for applicable circuits; and (6) adding a grounding transformer of 46-kV lines when 50% DML is exceeded. Each of these mitigation measures provides different values to both the utility and the distributed PV owner.

## Smart Grid and Demand Response

At the Hawaiian Electric Companies, we are committed to achieving modern and fully integrated electric grids on each of the islands we serve – grids that harness advances in

## K. Capital Investments

### Transformational Investments

networking and information technology and, as a result, deliver tangible benefits to our customers and the state of Hawai'i. To accomplish this, we plan to invest in smart grid.

#### Two-Way Communications System

The backbone of our Telecom System (fully owned by the Hawaiian Electric Companies) acts as an enabler for all of our operational and corporate business applications, including the smart grid applications. The Hawaiian Electric Companies enterprise telecommunications network or backbone is commonly referred to as our Wide Area Network (WAN) and Field Area Network (FAN). The smart grid applications and end devices (such as the smart meters), fault circuit indicators (FCIs), SCADA-enabled distribution line transformers and switches, reside in the Neighborhood Area Network (NAN), which is located beyond the WAN and FAN networks. The foundation of the smart grid platform (the NAN) we intend to implement is a two way communications network that connects points along the distribution grid to our back office software. Smart grid applications run on that network providing detailed information about the performance of the distribution grid.

AMI uses the secure IPv6 network that employs wireless 900MHz radio frequency mesh technology. This wireless technology consists of: access points; routers enabling devices communicating over the radio frequency mesh network to connect to our IT infrastructure through wired or cellular connections; relays, which are repeater devices that extend the reach of the radio frequency signal; and intelligent endpoints (such as third-party smart meters outfitted with network interface cards from Silver Spring Networks).

All Silver Spring Networks devices contain a one watt, two way radio. These devices connect with each other to form a mesh that makes up the Neighborhood Area Network (NAN). Access points and relays will be designed to have multiple paths through the NAN and the utility's WAN to provide high-performance, redundant connections between endpoints and our back office systems and data center. The network interface cards inside smart meters also act as relays (repeaters), further extending the mesh.

The radio frequency mesh network aggregates smart meter data and transmits it to us either through the utility-owned WAN or cellular connection. The mesh network can also transmit other information (such as remote service connects or disconnects) from us to customers. A back office head end system (such as UtilityIQ) collects, measures, and analyzes energy consumption, interval and time-of-use data, power quality measures, status logs and other metering data, and manages smart grid devices. Other back office systems manage meter data and integrate that data with customer and billing information.

## Customer Engagement

Although this component represent a small portion of costs of Hawaiian Electric’s Smart Grid program, the Hawaiian Electric Companies believe in a proactive, transparent, and sustained communication effort to educate and engage our customers is critical to successfully rolling out our smart grid plans. Our efforts to engage our customers underscore our commitment to continually improve customer service, modernize the grid, and integrate renewable energy.

We intend to inform customers about installing smart meters, educate them about smart grid benefits, and address their related concerns. Key to this is helping customers understand that, at its core, smart grid technology will offer them more information about their energy use than ever before and give them tools and programs to help them control their energy use, which they can then use to help lower their electricity bills.

Through a multi-pronged approach for the duration of our smart grid roadmap, we intend to build interest from the onset, address questions and concerns, and engage customers in understanding the benefits of smart grid. Our communication program is based on tested and proven industry best practices, and is customized based on research conducted in this market on how to best reach our customers. Our approach seeks to engage our customers with information tailored to their specific needs and questions. Working with trusted third-party groups, we plan to engage customers in direct conversations wherever they are – at home, in their neighborhoods, and online.

## Replacement Dispatchable Generation Capacity

### New Generation

The Commission provided Hawaiian Electric explicit guidance to expeditiously “modernize the generation system to achieve a future with high penetrations of renewable resources.” Decision and Order No. 32052, filed April 28, 2014, in Docket No. 2012-0036 (Regarding Integrated Resource Planning), Exhibit A: Commission’s Inclinations on the Future of Hawai’i’s Electric Utilities (Commission’s Inclinations) at 4. The Commission recognized that act of “serving load” at all times of the day is becoming less focused on energy provision, and more focused on providing or ensuring the reliability of the grid. Proposed New, Flexible Generation projects would be a firm generation resource with attributes and optionality consistent with this guidance, including the following abilities:

- Start, synchronize to the grid, and ramp to full load in a few minutes;
- Ramp generation output up and down at fast rates for frequency regulation;
- Operate over a very wide range of loads when synchronized to the grid (that is, more than 12 to 1 turndown);

## K. Capital Investments

### Foundational Investments

- Execute multiple starts and stops throughout any operating period;
- Control Volt-Amp Reactive (VAR) output for voltage regulation;
- Provide an automatic inertial response during major grid contingencies to help stabilize system frequency;
- Efficiently convert fuels to electric power (that is, to operate at low heat rates) over its full range of power output;
- Utilize multiple liquid and gaseous fuels; and
- Black start and “island a defined energy district” at a unique location in central O’ahu, adjacent to a major air field.

These attributes will contribute to increased grid stability, security, and resiliency as more variable renewable generation is interconnected.

### Retirement of Existing Generation Assets

We will aggressively pursue the retirement and replacement of existing generating units. We “deactivated” Kahului units 1 and 2 at the end of February 2014. These units were deactivated but are laid up in a manner that they could be returned to service in an emergency condition. The Kahului Power Plant is scheduled to be retired in 2019.

We intend to further retire/deactivate generating units as new generation and load situations allow. An aggressive plan for deactivation was created and can be adjusted as situations dictate.

Units that are scheduled to be deactivated will require capital additions in order to prepare them for deactivation. This allows reactivation should it be required. The plans are very specific and be strictly adhered to in order to be in compliance with the environmental operating permits and regulations.

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## FOUNDATIONAL INVESTMENTS

The success of the transformational investments discussed above is dependent on a strong foundation. The Company must continue to deliver safe, reliable, and efficient service to all customers. The foundational investments required to sustain operations are described below.



## Reliability

The Reliability category consists of production and transmission and distribution capital projects to ensure that the Company's existing generation assets and transmission and distribution grids are available to reliably generate and deliver power to customers. Major projects in this category include overhauls for existing generation assets and the reconductoring and relocation of existing transmission facilities. This category also includes the MPP Tsunami Mitigation project to install infrastructure to mitigate risks to the Maalaea Power Plant, which is in the tsunami inundation zone, and the Waena T&D project, to relocate the Maui Operations Center (Dispatch, Data Center, and Communications) to a facility outside of the tsunami inundation zone.

## Asset Management

The asset management category includes costs for the replacement of switchgear, circuit breakers, cable, and batteries. Asset management principles aim to minimize corrective replacement costs, for both O&M expense and capital, by implementing preventive strategies. Work performed on a planned basis, in the normal course of business, can usually be executed at lower, more predictable overall costs and with greater degree of safety to Company employees and the public.

## Customer Connections

The Company will need to connect new customers throughout the 2015–2030 period. The work in this category includes meter installations.

## Customer Projects

The Company will need to complete customer projects throughout the 2015–2030 period. This category of work includes preparing the design and relocations of services to existing customers for both overhead and underground services. The projects included in this category fall under the baseline category. Note -Fully Funded Customer Projects will not appear since numbers are net of CIAC.

## Enterprise

This category consists of information technology project and program hardware and software costs.

## **K. Capital Investments**

### Foundational Capital Investment Project Descriptions

#### Facilities

Ongoing utility operations require efficient and effective business facilities infrastructure to meet customer and workforce needs. The foundational capital investments required to support these needs include routine investments for building facilities sustenance and vehicle replacements.

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## FOUNDATIONAL CAPITAL INVESTMENT PROJECT DESCRIPTIONS

#### Reliability

##### **M000107: Kuihelani Substation**

Install a new 10/12.5 MVA, 69-12kV transformer, 12kV switchgear and related equipment at a new substation site in Kahului designed to accommodate future load growth.

##### **M0001039: Kaonoulu Sub**

Design and construct a new substation to be located between Ma'alaea Power Plant and Kihei Substation 35 to accommodate current and future load growth. The substation will initially be installed with two 10/12.5 MVA transformers, switchgear and related equipment.

##### **M0001051: Kaonoulu Substation T&D Feeder**

Design and construct a new substation to be located between Ma'alaea Power Plant and Kihei Substation 35 to accommodate current and future load growth. The substation will initially be installed with two 10/12.5 MVA transformers, switchgear and related equipment.

##### **M0001251: M19 Capital Overhaul**

50,000 hour combustion turbine overhaul.

##### **M0001304: Kuihelani T&D**

Install a new 10/12.5 MVA, 69-12kV transformer, 12kV switchgear and related equipment at a new substation site in Kahului designed to accommodate future load growth.

**M0001305: Kuihelani Comm**

Install a new 10/12.5 MVA, 69-12kV transformer, 12kV switchgear and related equipment at a new substation site in Kahului designed to accommodate future load growth.

**M0001543: MI4 Capital Overhaul**

50,000 hour combustion turbine overhaul.

**M0001705: MPP Tsunami Mitigation**

Install infrastructure to mitigate risks to the Ma'alaea Power Plant, which is in the tsunami inundation zone.

**M0001711: Waiinu-Kanaha 69kV Upgrade**

The Company continues to explore non-transmission alternatives to address the need to provide voltage support for Central Maui, and has included the costs for these projects as a placeholder. The placeholder projects are for the upgrade of 4.2 miles of an existing 23kV transmission line to 69kV and upgrade the Waiinu, Kahului and Kanaha substations; upgrade 9 miles of an existing 69kV transmission line conductors starting at MPP to Pu'unene Substation 4; upgrade 7.4 miles of an existing 69kV transmission line conductors starting at Ma'alaea Power Plant to Waiinu Substation 36.

**M0001718: MI7 50K Capital Overhaul**

50,000 hour combustion turbine overhaul.

**M0001719: MI6 50K Capital Overhaul**

50,000 hour combustion turbine overhaul.

**M0001720: MPP-Pu'unene Substation 4 Reconduct**

The Company continues to explore non-transmission alternatives to address the need to provide voltage support for Central Maui, and has included the costs for these projects as a placeholder. The placeholder projects are for the upgrade of 4.2 miles of an existing 23kV transmission line to 69kV and upgrade the Waiinu, Kahului and Kanaha substations; upgrade 9 miles of an existing 69kV transmission line conductors starting at MPP to Pu'unene Substation 4; upgrade 7.4 miles of an existing 69kV transmission line conductors starting at Ma'alaea Power Plant to Waiinu Substation 36.

## K. Capital Investments

### Transformational Capital Investment Project Descriptions

#### M0001721: MPP-Waiinu Substation 36 Reconduct

The Company continues to explore non-transmission alternatives to address the need to provide voltage support for Central Maui, and has included the costs for these projects as a placeholder. The placeholder projects are for the upgrade of 4.2 miles of an existing 23kV transmission line to 69kV and upgrade the Waiinu, Kahului and Kanaha substations; upgrade 9 miles of an existing 69kV transmission line conductors starting at MPP to Pu'unene Substation 4; upgrade 7.4 miles of an existing 69kV transmission line conductors starting at Ma'alaea Power Plant to Waiinu Substation 36.

#### M0001890: Kaonoulu Substation Land/Easement

Design and construct a new substation to be located between Ma'alaea Power Plant and Kihei Substation 35 to accommodate current and future load growth. The substation will initially be installed with two 10/12.5 MVA transformers, switchgear and related equipment.

#### M14 50K Overhaul

50,000 hour combustion turbine overhaul.

#### M19 50K Overhaul

50,000 hour combustion turbine overhaul.

#### Waena T&D

Relocate the Operations Center (Dispatch, Data Center, and Communications) to a facility outside of the tsunami inundation zone. The new facility will meet current "best practice" control center and disaster resiliency standards.

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## TRANSFORMATIONAL CAPITAL INVESTMENT PROJECT DESCRIPTIONS

### Liquefied Natural Gas

#### M0001805: M14 LNG Modifications

Plan, design, and construct modifications to the Ma'alaea units to enable operation with liquefied natural gas (LNG).

#### M0001806: M16 LNG Modifications

Plan, design, and construct modifications to the Ma'alaea units to enable operation with liquefied natural gas (LNG).

**M0001807: MI7 LNG Modifications**

Plan, design, and construct modifications to the Ma'alaea units to enable operation with liquefied natural gas (LNG).

**M0001808: MI9 LNG Modifications**

Plan, design, and construct modifications to the Ma'alaea units to enable operation with liquefied natural gas (LNG).

**Moloka'i LNG**

Plan, design, and construct modifications to the Moloka'i units to enable operation with liquefied natural gas (LNG).

**Waena Gas Pipeline**

Install a gas pipeline to transport liquefied natural gas (LNG) from the Company's Waena site to its Ma'alaea Power Plant.

**Waena LNG Infrastructure**

Install a LNG receiving station, vaporization infrastructure, storage tanks, pumping station, and supporting facilities at the Company's Waena site, to enable the Company to use LNG as a replacement fuel for power generation.

**Facilitates New or Renewable Energy****Lana'i Battery**

Design, plan, and install a battery energy storage system to address system security requirements identified by Electric Power Systems and to support integration of renewable energy resources.

**Lana'i Transmission**

Design, plan, and implement transmission and/or distribution infrastructure improvements or additions to integrate the battery energy storage system.

**M0001875: MI4 Low Load Modifications**

Modify Ma'alaea Dual Train Combine Cycle One (DTCC1) to enable reliable operation at lower minimum load, as described in Maui Electric's System Improvement and Curtailment Reduction Plan filed September 3, 2013.

## K. Capital Investments

Transformational Capital Investment Project Descriptions

### M0001876: M16 Low Load Modifications

Modify Ma'alaea Dual Train Combine Cycle One (DTCC1) to enable reliable operation at lower minimum load, as described in Maui Electric's System Improvement and Curtailment Reduction Plan filed September 3, 2013.

### Moloka'i Battery

Design, plan, and install a battery energy storage system to address system security requirements identified by Electric Power Systems and to support integration of renewable energy resources.

### Moloka'i Transmission

Design, plan, and implement transmission and/or distribution infrastructure improvements or additions to integrate the battery energy storage system.

## Replace Dispatch Generation Levelized Capacity Costs

### Maui Kahului 1–4

Retirement costs for removal and remediation.

### Maui Ma'alaea 13

Retirement costs for removal and remediation.

### Maui Ma'alaea 7, 4, 5, 6, 9, 8

Retirement costs for removal and remediation.

## Smart Grid and Demand Response

### M0001839: Smart Grid

The Smart Grid Full Implementation Project will 1) install devices in the field, such as meters, remote controllable switches, fault circuit indicators, capacitors, and load controlling switches, 2) install central office software designed to collect information from the field devices and/or then execute commands or tasks by a system operator for the purposes of managing the grid or managing the utilities' meter reading and field services business processes and 3) provide the Hawaiian Electric Companies' customers with tools which enables them to understand and manage their energy use and energy bill. The benefits for implementing the Smart Grid Full Implementation Project is to 1) lower electricity bills through savings and productivity improvements in utility operations, 2) increase renewable energy through integrated distributed generation, 3)

provides tools to the customers to enable them to utilize their energy more effectively/efficiently, and 4) increase reliability through outage notification and distribution automation which can lower SAIFI and CAIDI.

## System Security Investments

### M0001827: TMP West Sites-F/O Miki-Pu'u

Upgrade telecommunications to support efficient, secure, and reliable business and utility operations by improving the speed of service between Miki Basin and Pu'u Kilea.

### M0001836: TMP Edge Packet-F/O Kahe-Lah

Extend the packet network to the Lahainaluna Switching Station to support efficient, secure, and reliable business and utility operations.

### Maui 20MW Contin BESS (2019)

Install contingency BESS in combination with quick starting generation in South Maui as a non-transmission alternative.

### Maui 20MW Reg BESS (2019)

Install Regulating Reserve BESS to maintain system security after Kahului Power Plant is retired.

## K. Capital Investments

Capital Expenditures by Category and Project

### CAPITAL EXPENDITURES BY CATEGORY AND PROJECT

#### Capital Expenditures: 2015–2019

Table K-1 lists the budgeted, annualized dollar amount for each project; with totals by project group and by category, for the years 2015–2019. Table K-2 lists the budgeted, annualized dollar amount for each project; with totals by project group and by category, for the years 2020–2030 with project totals.

| Project                                    | 2015              | 2016              | 2017              | 2018              | 2019              |
|--|-------------------|-------------------|-------------------|-------------------|-------------------|
| <b>Foundational</b>                        | <b>30,224,122</b> | <b>50,535,944</b> | <b>51,236,291</b> | <b>43,095,221</b> | <b>68,403,965</b> |
| Asset Management                           | 3,398,769         | 3,065,255         | 987,721           | 2,662,061         | 527,953           |
| Baseline                                   | 3,398,769         | 3,065,255         | 987,721           | 2,662,061         | 527,953           |
| Customer Connections                       | 1,682,020         | 1,709,592         | 871,904           | 898,103           | 926,179           |
| Baseline                                   | 1,682,020         | 1,709,592         | 871,904           | 898,103           | 926,179           |
| Customer Projects                          | 1,888,772         | 9,001,582         | 4,977,049         | 5,329,360         | 4,424,774         |
| Baseline                                   | 1,888,772         | 9,001,582         | 4,977,049         | 5,329,360         | 4,424,774         |
| Enterprise IT Framework                    | 928,097           | 381,901           | 157,881           | 191,161           | 188,277           |
| Baseline                                   | 928,097           | 381,901           | 157,881           | 191,161           | 188,277           |
| Facilities                                 | 1,896,131         | 2,227,735         | 1,733,500         | 1,830,518         | 1,771,225         |
| Baseline                                   | 1,896,131         | 2,227,735         | 1,733,500         | 1,830,518         | 1,771,225         |
| Reliability                                | 19,705,474        | 33,970,980        | 42,364,365        | 32,034,934        | 60,395,971        |
| M0000102: Kamalii Substation               | –                 | –                 | –                 | –                 | –                 |
| M0000107: Kuihelani Substation             | 228,547           | 8,269,709         | 888,445           | –                 | –                 |
| M0000986: Ma'alea-Kamalii 69 kV Line       | –                 | –                 | –                 | –                 | –                 |
| M0000988: Ma'alea Substation 69kV Bkr Addn | –                 | –                 | –                 | –                 | –                 |
| M0001039: Kaonoulu Substation              | 194,324           | 1,018,484         | 7,515,511         | –                 | –                 |
| M0001040: Wahikuli Substation Unit #1      | –                 | –                 | –                 | –                 | –                 |
| M0001051: Kaonoulu Substation T&D Feeder   | 6,107             | 3,710,817         | 230,200           | –                 | –                 |
| M0001247: Kihei-Kamalii 69kv Ln            | –                 | –                 | –                 | –                 | –                 |
| M0001248: Wailea-Kamalii 69kv Ln           | –                 | –                 | –                 | –                 | –                 |
| M0001251: M19 Capital Overhaul             | –                 | –                 | –                 | 3,173,768         | –                 |
| M0001304: Kuihelani T&D                    | 83,198            | 1,728,673         | –                 | –                 | –                 |
| M0001305: Kuihelani Comm                   | 5,246             | 1,559,626         | 140,120           | –                 | –                 |
| M0001543: M14 Capital Overhaul             | –                 | –                 | 3,096,659         | –                 | –                 |
| M0001705: MPP Tsunami Mitigation           | –                 | –                 | –                 | 347,393           | 1,036,688         |
| M0001711: Wainu-Kanaha 69kV Upgrade        | 659,618           | 1,260,494         | 12,439,611        | 14,350,144        | –                 |
| M0001718: M17 50K Capital Overhaul         | –                 | –                 | 3,084,426         | –                 | –                 |



## K. Capital Investments

Capital Expenditures by Category and Project

| Project                                       | 2015              | 2016              | 2017              | 2018              | 2019             |
|---|-------------------|-------------------|-------------------|-------------------|------------------|
| M0001719: M16 50K Capital Overhaul            | –                 | –                 | –                 | 1,078,383         | 2,148,560        |
| M0001720: MPP-Pu'unene Substation 4 Reconduct | 299,068           | 2,176,256         | 298,546           | –                 | –                |
| M0001721: MPP-Waiinu Substation 36 Reconduct  | 83,079            | 285,546           | 2,331,932         | –                 | –                |
| M0001890: Kaonoulu Substation Land/Easement   | –                 | 58,022            | 559,104           | –                 | –                |
| M14 50K Overhaul                              | –                 | –                 | –                 | –                 | –                |
| M19 50K Overhaul                              | –                 | –                 | –                 | –                 | –                |
| Maui Waiinu to Kanaha                         | –                 | –                 | –                 | –                 | 39,874,657       |
| Waena T&D                                     | –                 | –                 | –                 | –                 | –                |
| Baseline                                      | 18,146,287        | 13,903,353        | 11,779,811        | 13,085,246        | 17,336,066       |
| Safety, Security and Environmental            | 724,859           | 178,899           | 143,871           | 149,084           | 169,586          |
| <b>Transformational</b>                       | <b>19,553,501</b> | <b>85,774,836</b> | <b>86,902,099</b> | <b>58,360,147</b> | <b>8,303,876</b> |
| DG Enabling Investments                       | 1,303,886         | 1,303,886         | 634,856           | 634,856           | 634,856          |
| Baseline                                      | 1,303,886         | 1,303,886         | 634,856           | 634,856           | 634,856          |
| Liquefied Natural Gas                         | 9,844,575         | 46,046,957        | 39,217,277        | –                 | –                |
| Lana'i LNG conversion                         | –                 | 3,129,572         | –                 | –                 | –                |
| M0001804: MPP LNG Infrastructure              | –                 | –                 | –                 | –                 | –                |
| M0001805: M14 LNG Modifications               | 500,856           | 1,051,066         | 980,985           | –                 | –                |
| M0001806: M16 LNG Modifications               | 500,856           | 1,051,066         | 980,985           | –                 | –                |
| M0001807: M17 LNG Modifications               | 500,856           | 1,051,066         | 980,985           | –                 | –                |
| M0001808: M19 LNG Modifications               | 500,856           | 1,051,066         | 980,985           | –                 | –                |
| Maui DTCC1 LNG conversion                     | –                 | –                 | –                 | –                 | –                |
| Maui DTCC2 LNG conversion                     | –                 | –                 | –                 | –                 | –                |
| Maui LNG Pipeline (Ma'alaea-Waena)            | –                 | –                 | –                 | –                 | –                |
| Maui LNG Regas. – Waena                       | –                 | –                 | –                 | –                 | –                |
| Moloka'i LNG                                  | –                 | 3,651,168         | –                 | –                 | –                |
| Waena Gas Pipeline                            | 2,883,455         | 22,054,776        | 23,432,243        | –                 | –                |
| Waena LNG Infrastructure                      | 2,073,810         | 8,873,639         | 7,833,645         | –                 | –                |
| Baseline                                      | 2,883,885         | 4,133,537         | 4,027,450         | –                 | –                |
| New or Renewable Energy                       | 3,450,103         | 11,287,563        | 17,947,426        | –                 | –                |
| Lana'i Battery                                | –                 | 1,462,945         | 8,748,813         | –                 | –                |
| Lana'i Transmission                           | –                 | 2,347,179         | 224,900           | –                 | –                |
| M0001385: Moloka'i Bess                       | –                 | –                 | –                 | –                 | –                |
| M0001875: M14 Low Load Modifications          | 1,573,652         | 1,496,803         | –                 | –                 | –                |
| M0001876: M16 Low Load Modifications          | 1,573,172         | 1,473,523         | –                 | –                 | –                |
| Moloka'i Battery                              | –                 | 1,462,945         | 8,748,813         | –                 | –                |
| Moloka'i Transmission                         | –                 | 2,347,179         | 224,900           | –                 | –                |
| Baseline                                      | 303,279           | 696,989           | –                 | –                 | –                |

## K. Capital Investments

Capital Expenditures by Category and Project

| Project                                       | 2015              | 2016               | 2017               | 2018               | 2019              |
|---|-------------------|--------------------|--------------------|--------------------|-------------------|
| Replace Dispatch Gen Levelized Capacity Costs | –                 | –                  | –                  | –                  | 0                 |
| Maui Kahului 1–4                              | –                 | –                  | –                  | –                  | 0                 |
| Maui Ma'ālaea 13                              | –                 | –                  | –                  | –                  | –                 |
| Maui Ma'ālaea 7, 4, 5, 6, 9, 8                | –                 | –                  | –                  | –                  | –                 |
| Smart Grid and Demand Response                | 20,000            | 13,450,189         | 10,923,350         | 1,512,805          | 1,499,053         |
| M0001839: Smart Grid                          | –                 | 13,450,189         | 10,923,350         | 1,512,805          | 1,479,053         |
| Baseline                                      | 20,000            | –                  | –                  | –                  | 20,000            |
| System Security Investments                   | 4,934,938         | 13,686,242         | 18,179,189         | 56,212,486         | 6,169,967         |
| M0001827: TMP West Sites-F/O Miki-Pu'u        | –                 | –                  | –                  | 2,690,354          | –                 |
| M0001836: TMP Edge Packet-F/O Kahe-Lah        | –                 | 4,340,932          | –                  | –                  | –                 |
| Maui 20MW Contin BESS (2019)                  | –                 | –                  | 3,408,542          | 19,315,074         | –                 |
| Maui 20MW Reg BESS (2019)                     | –                 | –                  | 4,755,466          | 26,947,643         | –                 |
| Baseline                                      | 4,934,938         | 9,345,310          | 10,015,181         | 7,259,415          | 6,169,967         |
| <b>Grand Totals</b>                           | <b>49,777,623</b> | <b>136,310,780</b> | <b>138,138,390</b> | <b>101,455,368</b> | <b>76,707,841</b> |

Table K-1. Capital Expenditures by Category and Project: 2015–2019

**Capital Expenditures: 2020–2030 with Project Totals**

Table K-2 lists the budgeted, annualized dollar amount for each project; with totals by project group and by category, for the years 2020–2030 with project totals.

| Project                                       | 2020              | 2021–2025          | 2026–2030          | Totals             |
|---|-------------------|--------------------|--------------------|--------------------|
| <b>Foundational</b>                           | <b>42,349,549</b> | <b>356,143,829</b> | <b>220,465,410</b> | <b>862,454,338</b> |
| Asset Management                              | 2,876,973         | 15,090,245         | 16,336,719         | 44,945,698         |
| Baseline                                      | 2,876,973         | 15,090,245         | 16,336,719         | 44,945,698         |
| Customer Connections                          | 1,645,820         | 8,632,627          | 9,345,693          | 25,711,939         |
| Baseline                                      | 1,645,820         | 8,632,627          | 9,345,693          | 25,711,939         |
| Customer Projects                             | 10,172,351        | 53,355,829         | 57,763,089         | 146,912,806        |
| Baseline                                      | 10,172,351        | 53,355,829         | 57,763,089         | 146,912,806        |
| Enterprise IT Framework                       | 369,650           | 2,068,884          | 2,299,038          | 6,584,889          |
| Baseline                                      | 369,650           | 2,068,884          | 2,299,038          | 6,584,889          |
| Facilities                                    | 2,421,170         | 12,699,479         | 13,748,473         | 38,328,233         |
| Baseline                                      | 2,421,170         | 12,699,479         | 13,748,473         | 38,328,233         |
| Reliability                                   | 24,507,327        | 262,428,128        | 118,949,409        | 594,356,590        |
| M0000102: Kamalii Substation                  | –                 | –                  | –                  | –                  |
| M0000107: Kuihelani Substation                | –                 | –                  | –                  | 9,386,701          |
| M0000986: Ma'alaea-Kamalii 69 kV Line         | –                 | –                  | –                  | –                  |
| M0000988: Ma'alaea Substation 69kV Bkr Addn   | –                 | –                  | –                  | –                  |
| M0001039: Kaonoulu Substation                 | –                 | –                  | –                  | 8,728,318          |
| M0001040: Wahikuli Substation Unit #1         | –                 | –                  | –                  | –                  |
| M0001051: Kaonoulu Substation T&D Feeder      | –                 | –                  | –                  | 3,947,124          |
| M0001247: Kihei-Kamalii 69kv Ln               | –                 | –                  | –                  | –                  |
| M0001248: Wailea-Kamalii 69kv Ln              | –                 | –                  | –                  | –                  |
| M0001251: M19 Capital Overhaul                | –                 | –                  | –                  | 3,173,768          |
| M0001304: Kuihelani T&D                       | –                 | –                  | –                  | 1,811,870          |
| M0001305: Kuihelani Comm                      | –                 | –                  | –                  | 1,704,992          |
| M0001543: M14 Capital Overhaul                | –                 | –                  | –                  | 3,096,659          |
| M0001705: MPP Tsunami Mitigation              | 1,113,059         | 66,816,176         | –                  | 69,313,316         |
| M0001711: Waiinu-Kanaha 69kV Upgrade          | –                 | –                  | –                  | 28,709,868         |
| M0001718: M17 50K Capital Overhaul            | –                 | –                  | –                  | 3,084,426          |
| M0001719: M16 50K Capital Overhaul            | –                 | –                  | –                  | 3,226,944          |
| M0001720: MPP-Pu'unene Substation 4 Reconduct | –                 | –                  | –                  | 2,773,870          |
| M0001721: MPP-Waiinu Substation 36 Reconduct  | –                 | –                  | –                  | 2,700,558          |
| M0001890: Kaonoulu Substation Land/Easement   | –                 | –                  | –                  | 617,125            |
| M14 50K Overhaul                              | –                 | –                  | 3,700,000          | 3,700,000          |

## K. Capital Investments

Capital Expenditures by Category and Project

| Project                                       | 2020             | 2021–2025         | 2026–2030        | Totals             |
|---|------------------|-------------------|------------------|--------------------|
| MI9 50K Overhaul                              | –                | –                 | 3,700,000        | 3,700,000          |
| Maui Waiinu to Kanaha                         | –                | –                 | –                | 39,874,657         |
| Waena T&D                                     | –                | 91,000,000        | –                | 91,000,000         |
| Baseline                                      | 23,394,268       | 104,611,952       | 111,549,409      | 313,806,394        |
| Safety, Security and Environmental            | 356,258          | 1,868,637         | 2,022,989        | 5,614,183          |
| <b>Transformational</b>                       | <b>5,023,080</b> | <b>20,040,412</b> | <b>5,534,269</b> | <b>289,492,221</b> |
| DG Enabling Investments                       | 634,856          | 613,533           | 613,533          | 6,374,262          |
| Baseline                                      | 634,856          | 613,533           | 613,533          | 6,374,262          |
| Liquefied Natural Gas                         | –                | –                 | –                | 95,108,808         |
| Lana'i LNG conversion                         | –                | –                 | –                | 3,129,572          |
| M0001804: MPP LNG Infrastructure              | –                | –                 | –                | –                  |
| M0001805: M14 LNG Modifications               | –                | –                 | –                | 2,532,907          |
| M0001806: M16 LNG Modifications               | –                | –                 | –                | 2,532,907          |
| M0001807: M17 LNG Modifications               | –                | –                 | –                | 2,532,907          |
| M0001808: M19 LNG Modifications               | –                | –                 | –                | 2,532,907          |
| Maui DTCC1 LNG conversion                     | –                | –                 | –                | –                  |
| Maui DTCC2 LNG conversion                     | –                | –                 | –                | –                  |
| Maui LNG Pipeline (Ma'ala'ea-Waena)           | –                | –                 | –                | –                  |
| Maui LNG Regas. – Waena                       | –                | –                 | –                | –                  |
| Moloka'i LNG                                  | –                | –                 | –                | 3,651,168          |
| Waena Gas Pipeline                            | –                | –                 | –                | 48,370,474         |
| Waena LNG Infrastructure                      | –                | –                 | –                | 18,781,094         |
| Baseline                                      | –                | –                 | –                | 11,044,873         |
| New or Renewable Energy                       | 120,324          | 631,121           | 683,252          | 34,119,787         |
| Lana'i Battery                                | –                | –                 | –                | 10,211,758         |
| Lana'i Transmission                           | –                | –                 | –                | 2,572,079          |
| M0001385: Moloka'i Bess                       | –                | –                 | –                | –                  |
| M0001875: M14 Low Load Modifications          | –                | –                 | –                | 3,070,454          |
| M0001876: M16 Low Load Modifications          | –                | –                 | –                | 3,046,695          |
| Moloka'i Battery                              | –                | –                 | –                | 10,211,758         |
| Moloka'i Transmission                         | –                | –                 | –                | 2,572,079          |
| Baseline                                      | 120,324          | 631,121           | 683,252          | 2,434,964          |
| Replace Dispatch Gen Levelized Capacity Costs | –                | 0                 | 0                | 0                  |
| Maui Kahului I–4                              | –                | –                 | –                | 0                  |
| Maui Ma'ala'ea I3                             | –                | –                 | 0                | 0                  |
| Maui Ma'ala'ea 7, 4, 5, 6, 9, 8               | –                | 0                 | 0                | 0                  |
| Smart Grid and Demand Response                | 1,366,878        | 7,731,755         | 3,320,246        | 39,824,276         |
| M0001839: Smart Grid                          | 1,366,878        | 7,731,755         | 3,320,246        | 39,784,276         |

**K. Capital Investments**

Capital Expenditures by Category and Project

| Project                                | 2020              | 2021–2025          | 2026–2030          | Totals               |
|--|-------------------|--------------------|--------------------|----------------------|
| Baseline                               | –                 | –                  | –                  | 40,000               |
| System Security Investments            | 2,901,022         | 11,064,003         | 917,238            | 114,065,087          |
| M0001827: TMP West Sites-F/O Miki-Pu'u | –                 | –                  | –                  | 2,690,354            |
| M0001836: TMP Edge Packet-F/O Kahe-Lah | –                 | –                  | –                  | 4,340,932            |
| Maui 20MW Contin BESS (2019)           | –                 | –                  | –                  | 22,723,616           |
| Maui 20MW Reg BESS (2019)              | –                 | –                  | –                  | 31,703,110           |
| Baseline                               | 2,901,022         | 11,064,003         | 917,238            | 52,607,075           |
| <b>Grand Totals</b>                    | <b>47,372,629</b> | <b>376,184,241</b> | <b>225,999,679</b> | <b>1,151,946,559</b> |

Table K-2. Capital Expenditures: 2020–2030 with Project Totals

**K. Capital Investments**

Capital Expenditures by Category and Project

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# L. Preferred Plan Development

Sensitivity analyses are performed to test how a particular condition would affect the Base Plan and if it should be considered for incorporation into the Preferred Plan. The analyses were conducted by the three independent modeling teams (Hawaiian Electric, Black & Veatch, and PA Consulting) and the results are described in this appendix.

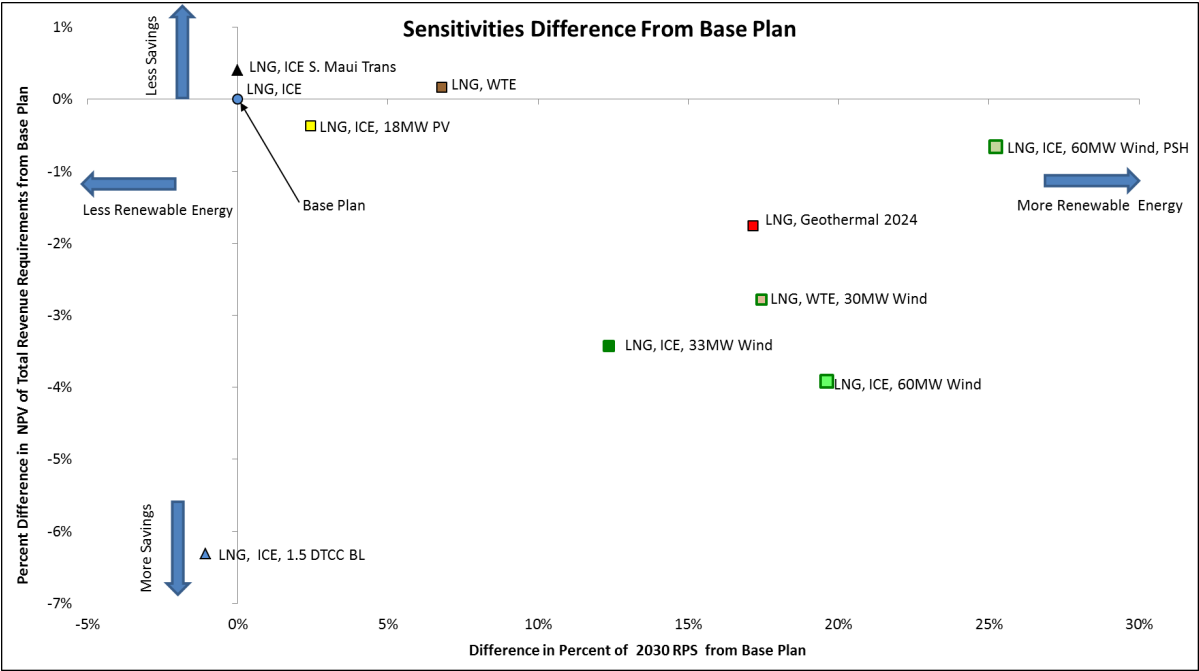


Figure L-1. Sensitivity Difference from Base Plan

## Development of Preferred Plan – Maui Only

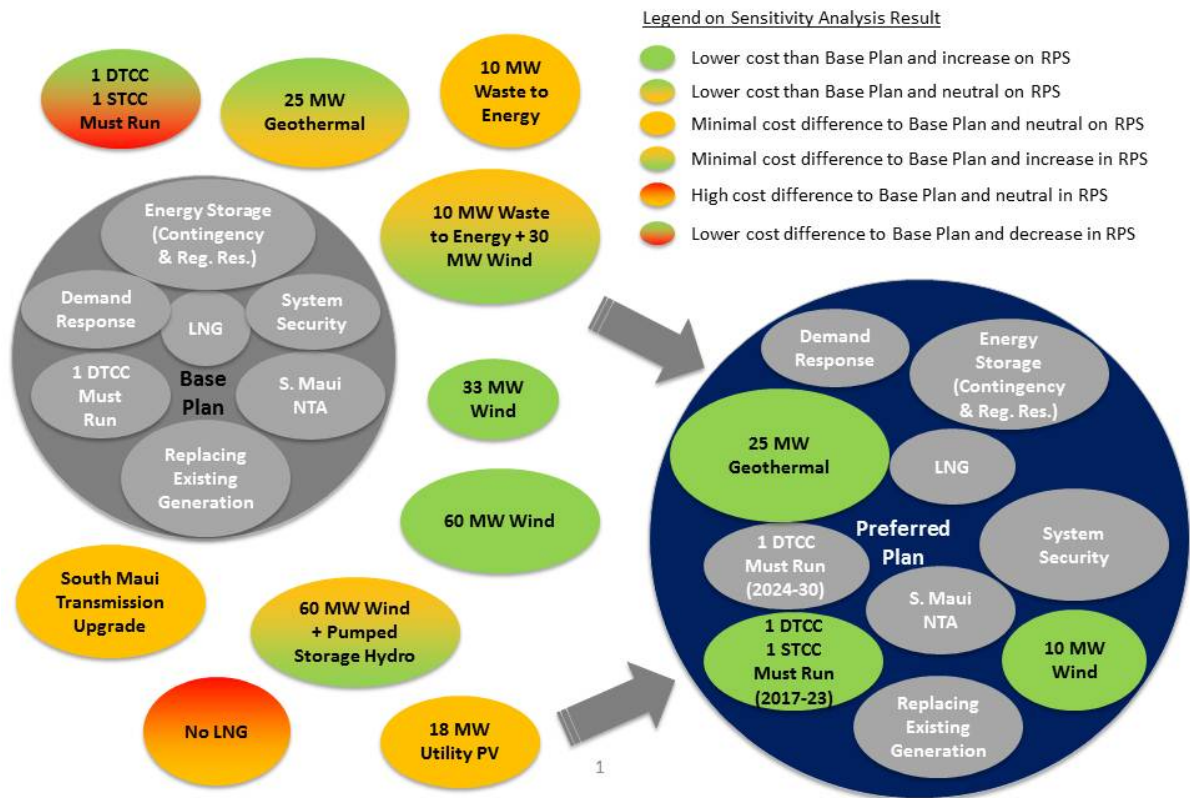


Figure L-2. Process for Developing the Preferred Plan

### BASE PLAN

As a platform to work from the Base Plan for Maui incorporated the usage of lower-cost LNG fuel for the most efficient must-run units currently on the Maui system as well as in new generation to reduce customer bills. The Base Plan adds new flexible internal combustion engines (ICE) units to replace the older units at Kahului Power Plant. Removing the must-run status from units while maintaining system security is made possible by including energy storage technology. Non-transmission alternatives to building the Ma’alaea to Kamali’i transmission line also incorporated the use of energy storage systems (ESS) and new quick-starting ICE units. The Base Plan includes the following:

- Conversion of dual-train combined cycles from diesel to LNG.
- Retirement of Kahului Power Plant.



- HC&S contract extended till replacement capacity added.
- Firm generation and contingency ESS in South Maui as a non-transmission alternative.
- Wai'inu to Kanaha Transmission upgraded for system security.
- Lower minimum load modification of Ma'alaea 14-15-16 combined-cycle.
- Internal combustion engines operating on LNG added for replacement capacity and additional capacity as needed.
- Regulating ESS added for system security.
- DR for demand behavior modification and capacity.

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## EXISTING GENERATING UNITS

The Base Plan included some assumptions that warranted sensitivity analyses to test their robustness. The sensitivity analyses to test the future of existing generating units included must-run units.

### Must-Run Units

The current operation of must-run units include Kahului Units 3 & 4 thermal steam units at Kahului Power Plant and one dual-train combined cycle (DTCC) unit at Ma'alaea Power Plant. In the Base Plan, we assumed only one DTCC unit would be must-run once Kahului Power Plant was retired. Sensitivity analyses performed included the addition of a single-train combined cycle unit at Ma'alaea Power Plant as a must-run unit in the Base Plan. In comparison to the Base Plan the analysis showed the must-run unit addition of a single-train combined cycle unit decreased the overall system costs by about 6 to 7% and decreased the RPS percentage in 2030 by about 0 to 1 %.

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## SOUTH MAUI TRANSMISSION LINE

In the Base Plan, it was assumed that the required 20 MW contingency ESSs would be placed in South Maui and would be accompanied by three LNG-fired ICE thermal units (at 8.14 MW each) that were needed for capacity when Kahului Power Plant is retired as a non-transmission alternative. This sensitivity analysis assumed that the Ma'alaea to Kamali'i transmission line was installed instead of locating the three ICE units in South Maui and building an LNG regasification plant there. In comparison to the Base Plan the analysis showed that the transmission line increased the overall system costs by about

## L. Preferred Plan Development

### Additional Renewable Energy Resources

one percent, and there would be no change in RPS. It is important to note the contingency ESS and the ICE's have to be located on the same circuit in order to realize the benefits.

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## ADDITIONAL RENEWABLE ENERGY RESOURCES

The Base Plan includes solar distributed generation (DG-PV) which was incrementally added over time. Sensitivity analyses looked at the effect of adding additional renewable energy resources such as:

- Wind
- Utility-Scale PV

### Wind

In the Base Plan, it was assumed that the 72 MW of existing wind farms continued to operate and no additional wind farms were added. Sensitivities around the wind farms include the addition of 33 MW and 60 MW of additional wind farms.

#### 33 MW Wind

This sensitivity analysis assumed that 33 MW of wind farms were added to the existing 72 MW of existing wind farms. In comparison to the Base Plan the analysis showed that the additional wind farms decreased the overall system costs by about 3 to 4% and increased the RPS percentage in 2030 by about 12 to 13 %.

#### 60 MW Wind

This sensitivity analysis assumed that 60 MW of wind farms were added to the existing 72 MW of existing wind farms. In comparison to the Base Plan the analysis showed that the additional wind farms also decreased the overall system costs by about 3 to 4% and increased the RPS percentage in 2030 by about 25 to 26 %.

### Utility-Scale PV

In the Base Plan, no utility-scale PV farm was assumed to be added to the system. For sensitivity an 18 MW utility-scale PV farm is added. In comparison to the Base Plan the analysis showed that the additional PV farm decreased the overall system costs by about 0 to 1% and increased the RPS percentage in 2030 by about 2 to 3%.

## Pumped Storage Hydro

Pumped storage hydro has operating characteristics similar to a load-shifting energy storage system. This resource was assumed to provide firm capacity that can defer future generation and increase renewable energy utilization during excess energy periods. Sensitivity analyses were conducted to examine the effect of adding a pumped storage hydro resource on the system.

### 25 MW Pumped Storage Hydro and 60 MW Wind

This sensitivity analysis coupled a 60 MW Wind Farm with a 25 MW pumped storage hydro. The energy provided by the 60 MW Wind Farm was used to charge the pumped storage hydro during the morning and day periods when curtailment occurred. The stored energy was then discharged at night during the evening peak. In comparison to the Base Plan the addition of the 25 MW pumped storage hydro and the 60 MW Wind Farm decreased the overall system costs by about 0 to 1% and increased the RPS percentage in 2030 by about 25 to 26%.

When comparing the 60 MW Wind Farm Plan with the 60 MW Wind Farm Plan plus the addition of the 25 MW pumped storage hydro, the result showed pumped storage increased the overall system costs by about 3 to 4% and increased the RPS percentage in 2030 by about 5 to 6%.

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## FUTURE FIRM RENEWABLE GENERATION MIX

Sensitivity analyses looked at the effect of adding firm renewable energy resources such as:

- Geothermal
- Waste-to-Energy

### 25 MW Geothermal

This sensitivity analysis assumed a must-run 25MW geothermal plant was added to the system. In comparison to the Base Plan the analysis showed that the geothermal plant decreased the overall system costs by about 1 to 2% and increased the RPS percentage in 2030 by about 17 to 18 %.

### 10 MW Waste-to-Energy

This sensitivity analysis assumed a must-run 10MW waste-to-energy plant was added to the system. In comparison to the Base Plan the analysis showed that the waste-to-energy

**L. Preferred Plan Development**  
Utilizing Renewable Energy Resources

plant increased the overall system costs by about 0 to 1%, but increased the RPS percentage in 2030 by about 6 to 7 %.

**10 MW Waste-to-Energy and 30 MW Wind**

This sensitivity analysis assumed a must-run 10MW waste-to-energy plant and a 30 MW wind farm was added to the system. In comparison to the Base Plan the analysis showed that the combination of the waste-to-energy plant and new wind farm decreased the overall system costs by about 2 to 3% and increased the RPS percentage in 2030 by about 17 to 18 %.

**UTILIZING RENEWABLE ENERGY RESOURCES**

Each sensitivity analysis looked at the effect of adding renewable energy resources. Along with cost evaluation, utilization of renewable energy with respect to excess energy was also evaluated. Maui Electric’s plan to increase operational flexibility through modifications of existing generation, retirement of existing generation, and addition of new flexible generation, allows us to optimize utilization of renewable energy to avoid curtailment.

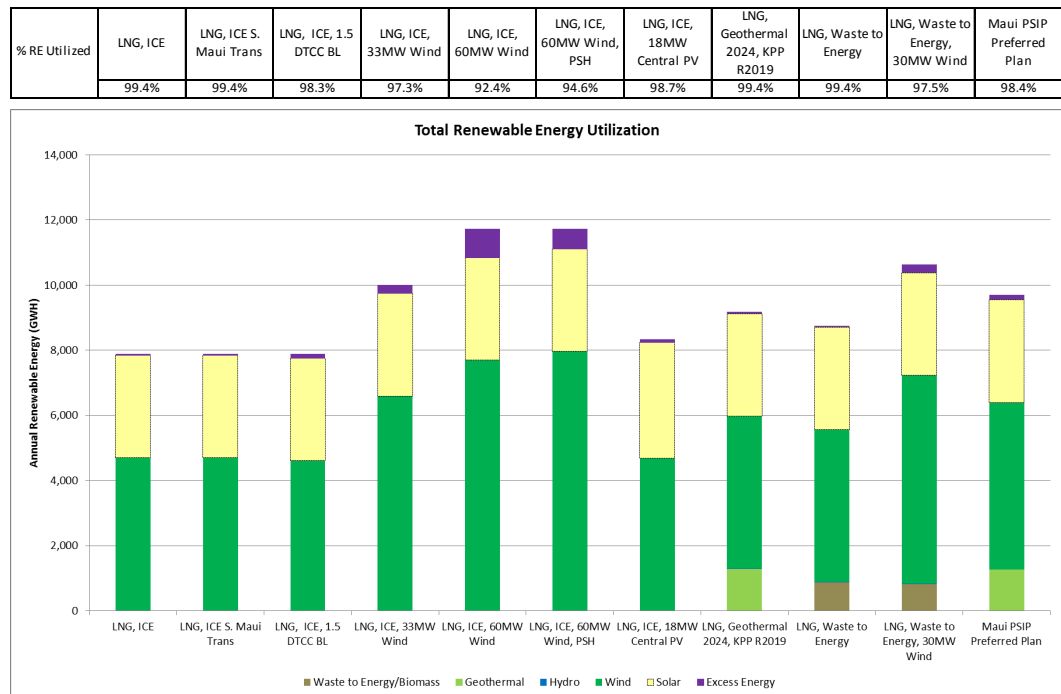


Figure L-3. Total Renewable Energy Utilization by Sensitivity

## PREFERRED PLAN

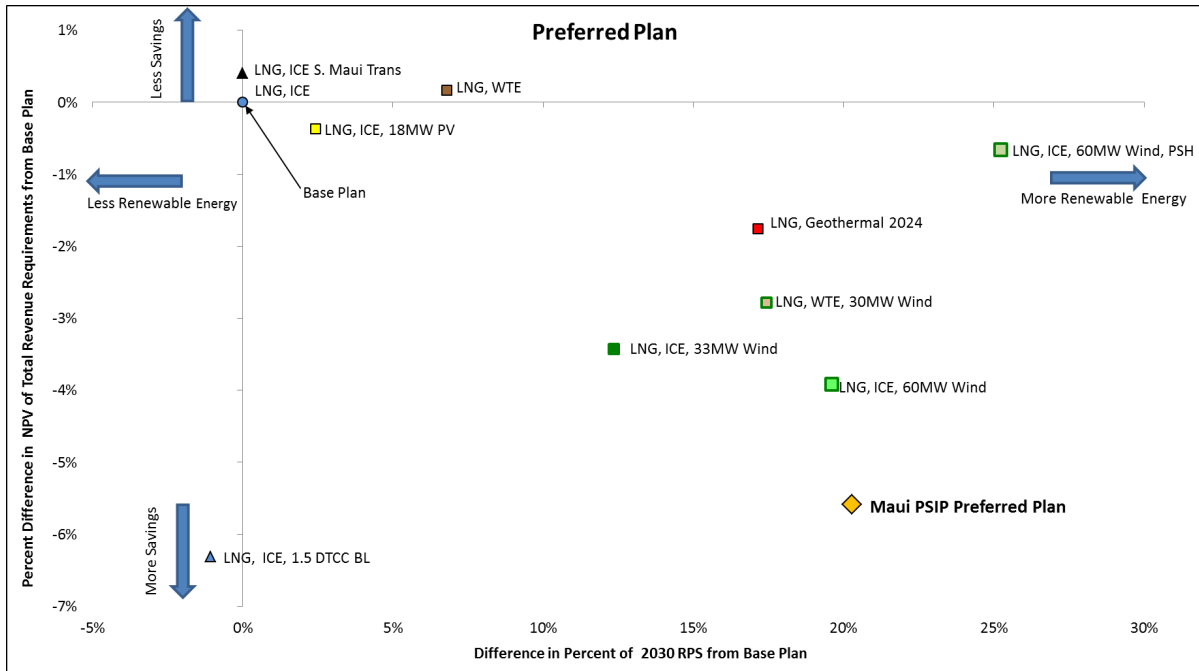


Figure L-4. Preferred Plan

The preferred plan was the culmination of benefits from the individual sensitivities to provide the customers of Maui the largest cost savings while still increasing the amount of clean renewable energy into the mix of system resources.

- Non-transmission alternative in South Maui
- LNG
- Must-run 1½ DTCC
- Reduce fossil fueled must-run units when possible
- 10 MW Wind
- 5 MW Geothermal

The Preferred Plan incorporated demand response programs demand behavior modification, capacity, ramping, offline reserve, and load shifting. The analysis assumed the ICE units fueled by diesel together with the 20 MW contingency ESS were used as the non-transmission alternative in South Maui until the need could be satisfied by geothermal. 1½ DTCC must-run units fueled with LNG to take advantage of the cheaper fuel in earlier years until geothermal could be implemented to provide renewable must-run energy. Fossil fueled must-run units were removed with the decommissioning of Kahului Power Plant and then further reduced from 1½ DTCC to 1 DTCC units when geothermal is

## **L. Preferred Plan Development**

### Preferred Plan

available for system security. Additional wind energy was incorporated to further reduce expensive diesel consumption.

**When compared to the Base Plan, the Preferred Plan decreased the overall system costs by about 5 to 6% and increased the RPS percentage in 2030 by about 20% to 21%.**

## M. Planning Standards

This appendix contains the details of the planning standards TPL-001 and BAL-052.

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### TPL-001-0: TRANSMISSION PLANNING PERFORMANCE REQUIREMENTS

The starting document for HI-TPL-001-0 was NERC standard TPL-001-2 dated August 4, 2011. The standard includes the merging of TPL-001-0, TPL-002-0, TPL-003-0, and TPL-004-0 into one, single comprehensive, coordinated standard and retirement of TPL-005-0 and TPL-006-0.

The only added complexity was that the differently sized power systems that are in Hawai'i would need different levels of system reliability. The Hawai'i standard has three groups to address the different sizes of the various Balancing Areas.

#### Definitions of Terms Used in Standard

*This section includes all newly defined or revised terms used in the proposed standard. Terms already defined in the Reliability Standards Working Group Glossary of Terms, Version 1 – 20120304 are not repeated here. New or revised definitions listed below become approved when the proposed standard is approved. When the standard becomes effective, these defined terms will be removed from the individual standard and added to the Glossary.*

**Balancing Authority (BA):** The responsible entity that integrates resource plans ahead of time, maintains load-generation balance within a Balancing Authority Area, and governs the real time operation and control of the Balancing Area. (Source: Modified from Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

## M. Planning Standards

TPL-001-0: Transmission Planning Performance Requirements

**Balancing Authority Area:** The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority. The Balancing Authority maintains load-resource balance within this area. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012)

**Base Year:** The 2011 BA's transmission and generation system shall be used as the base year to establish performance standards utilized with this standard. (Source: Proposed RSWG proposed definition.)

**Cascading:** The uncontrolled successive loss of system elements triggered by an incident at any location. Cascading results in widespread electric service interruption that cannot be restrained from sequentially spreading beyond an area predetermined by studies. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Corrective Action Plan:** A list of actions and an associated timetable for implementation to remedy a specific problem. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Equipment Rating:** The maximum and minimum voltage, current, frequency, real and reactive power flows on individual equipment under steady state, short-circuit and transient conditions, as permitted or assigned by the equipment owner. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Facility:** A set of electrical equipment that operates as a single Bulk Electric System Element (for example, a line, a generator, a shunt compensator, transformer, etc.). (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Long-Term Transmission Planning Horizon:** Transmission planning period that covers years six through ten or beyond when required to accommodate any known longer lead time projects that may take longer than ten years to complete. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Near-Term Transmission Planning Horizon:** The transmission planning period that covers Year One through five. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Non-Consequential Load Loss:** Non-Interruptible Load loss that does not include: (1) Consequential Load Loss, (2) the response of voltage sensitive load, or (3) load that is disconnected from the system by end-user equipment. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Off-Peak:** Those hours or other periods defined by NAESB business practices, contract, agreements, or guides as periods of lower electrical demand. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)



**Operating Procedure:** A document that identifies specific steps or tasks that should be taken by one or more specific operating positions to achieve specific operating goal(s). The steps in an Operating Procedure should be followed in the order in which they are presented, and should be performed by the position(s) identified. A document that lists the specific steps for a system operator to take in removing a specific transmission line from service is an example of an Operating Procedure. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Planning Assessment:** Documented evaluation of future Transmission system performance and Corrective Action Plans to remedy identified deficiencies. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Protection System:** Protection Systems are:

- Protective relays which respond to electrical quantities,
- Communications systems necessary for correct operation of protective functions
- Voltage and current sensing devices providing inputs to protective relays,
- Station dc supply associated with protective functions (including batteries, battery chargers, and non-battery-based dc supply), and
- Control circuitry associated with protective functions through the trip coil(s) of the circuit breakers or other interrupting devices.

(Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Protection Reserves:** The resources under the control of the Under Frequency Load Shedding System designed to protect the system against single or multiple contingency events. (Source: RSWG proposed definition.)

**Special Protection System (SPS) or Remedial Action Scheme:** An automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability. Such action may include changes in demand, generation (MW and MVAR), or system configuration to maintain system stability, acceptable voltage, or power flows. An SPS does not include (a) underfrequency or undervoltage load shedding or (b) fault conditions that must be isolated or (c) out-of-step relaying (not designed as an integral part of an SPS). Also called Remedial Action Scheme. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Stability:** The ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

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**System:** A combination of generation, transmission, and distribution components. (Source: Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Transmission:** An interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers. (Source: Modified Glossary of Terms Used in NERC Reliability Standards February 8, 2012.)

**Year One:** Year One is the first year of planning studies for future planning and evaluation requirements. (Source: Modified Glossary of Terms Used in NERC Reliability Standards February 8, 2012, Reliability First Regional Definitions.)

## Introduction

**Purpose:** Establish Transmission system planning performance requirements within the planning horizon to develop a system that will operate reliably over a broad spectrum of conditions and following a wide range of probable Contingencies.

**Applicability:** Balancing Authorities (BA)

**Facilities:** The Facilities are divided into three groups A, B and C. All groups are divided based on the annual system peak demand.

- Group A - Annual system peak is greater than or equal to 500 MW.
- Group B - Annual system peak is greater than or equal to 50 MW and less than 500 MW.
- Group C - Annual system peak is less than 50 MW.

**Effective Date:** To be determined

## B. Requirements

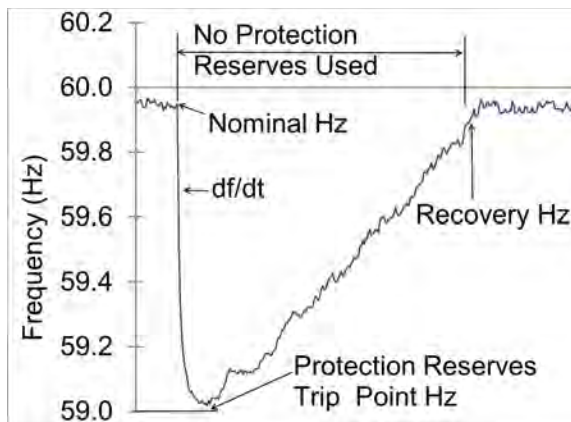
**R1.** The BA must maintain system models for performing the studies needed to complete its Planning Assessment. The models must use data consistent with that provided in accordance with the HI-MOD-010 Development and Reporting of Steady State System Models and Simulations and HI-MOD-012 Development and Reporting of Dynamic System Models and Simulations standards, supplemented by other sources as needed, including items represented in the Corrective Action Plan, and must represent projected system conditions. This establishes Category P0 as the normal system condition in Table 1.

R1.1. System models must represent:

R1.1.1. Actual steady-state characteristics of system resources and loads as defined in HI-MOD-010 Development and Reporting of Steady State System Models and Simulations.

- R1.1.2. Actual dynamic characteristics of system resources and loads as defined in HI-MOD-012 Development and Reporting of Dynamic System Models and Simulations.
- R1.1.3. Planned Facilities and changes to existing Facilities
- R1.2. The Generation resources must maintain or better the following characteristics unless the change can be verified by study that the results will provide acceptable reliability. The characteristics of the system that meet the acceptable reliability criteria will be used as the new benchmark for future planning until the reliability criteria is changed.
  - R1.2.1. Each Balance Authority system will be planned to meet the requirements Disturbance Recovery performance in HI-BAL-002 Disturbance Control Performance.
  - R1.2.2. The loss of the largest single contingency may result in a loss of load within the acceptable reliability criteria defined in BAL-002 Disturbance Control Performance.
  - R1.2.3. Each resource will have frequency ride-through designed such that all generation, reserves, regulation and voltage control resources will withstand single and excess contingency events defined in HI-BAL-002 Disturbance Control Performance. The ride-through capability will meet the criteria designed to be protected under HI-PRC-006 Underfrequency Load Shedding, without the loss of, or damage to any resource.
  - R1.2.4. The system will be planned such that the resultant impacts of inertia, unit response or reserve response will meet the system frequency response characteristics following the loss of the largest single contingency as defined below.

Frequency Response - For all BA systems the loss of the largest unit(s) or any single contingency should not result in activation of the protection reserves. In addition, the rate of change of frequency  $df/dt$  is not to increase over historical levels, without prior review of impacts on system protection operation and critical resources. A sample system performance characteristic is shown in the graph below:

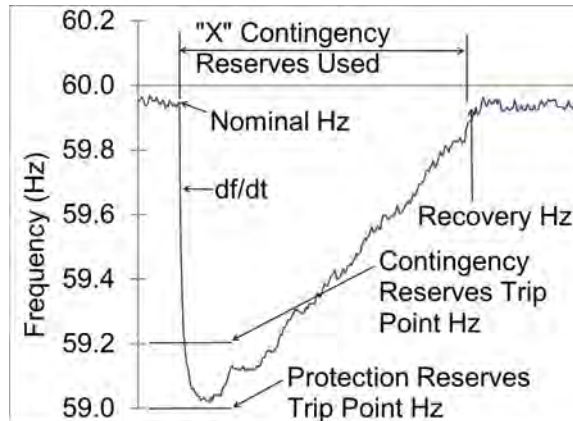


System using no Protection Reserves

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An example characteristic graph of a system that utilizing the protection reserves is indicated below:



System using Protection Reserves

- R1.2.5. The system will be planned such that all generation, reserves, regulation and voltage control resources will withstand the most severe voltage ride-thru requirement for a single contingency event, including both transmission and distribution events and distribution and transmission fault reclose cycles, through the duration of their reclosing cycle, without the loss of or damage to any resource.
- R1.2.6. The system will be designed such that all generation, reserves, regulation and voltage control resources will withstand excess contingency events defined in HI-BAL-002 Disturbance Control Performance for voltage ride-thru requirement for an excess contingency event and designed to be protected under HI-PRC-006 Underfrequency Load Shedding, without the loss of or damage to any resource.
- R1.2.7. The system will be planned to be transiently and dynamically stable following any single contingency event or any excess contingency event designed to be protected under HI-PRC-006 Underfrequency Load Shedding. Stability will be defined that the system will survive the first swing stability and the second swing and each subsequent swing will be lesser in magnitude than its predecessor (damped response). All swings will be effectively eliminated within 20 seconds of the initiating event.
- R1.2.8. The system shall be designed to supply the required ancillary services necessary to provide voltage and frequency response to meet the reliability requirements of each BA's service tariff and R1.2.2.
- R2.** The BA must prepare an annual Planning Assessment of its system. This Planning Assessment must use current or qualified past studies (as indicated in R2.6), document assumptions, and document summarized results of the steady state analyses, short circuit analyses, and Stability analyses.

- R2.1. For the Planning Assessment, the Near-Term Transmission Planning Horizon portion of the steady state analysis must be assessed annually and be supported by current annual studies or qualified past studies as indicated in R2.6. Qualifying studies need to include the following conditions:
- R2.1.1. System peak load for either Year One or year two, and for year five.
  - R2.1.2. System minimum with maximum and minimum variable renewables (night-time load) load for one of the five years.
  - R2.1.3. System minimum day load, maximum variable renewable for one of the five years.
  - R2.1.4. System day-peak load with maximum variable renewable and minimum variable renewable for one of the five years.
  - R2.1.5. System peak load, no variable renewable for one of the five years.
  - R2.1.6. For each of the studies described in R2.1.1 through R2.1.5, sensitivity case(s) must be utilized to demonstrate the impact of changes to the basic assumptions used in the model. To accomplish this, the sensitivity analysis in the Planning Assessment must vary one or more of the following conditions by a sufficient amount to stress the system within a range of credible conditions that demonstrate a measurable change in system response:
    - Real and reactive forecasted load.
    - Expected transfers.
    - Expected in-service dates of new or modified Transmission Facilities.
    - Planned or unplanned outages of critical resources for ancillary services
    - Typical generation scenarios including outage of the typically operated generation sources
    - Reactive resource capability.
    - Generation additions, retirements, or other dispatch scenarios.
    - Controllable loads and Demand Side Management.
  - R2.1.7. When an entity’s spare equipment strategy could result in the unavailability of major Transmission equipment that has a lead time of one year or more (such as a transformer), the impact of this possible unavailability on system performance must be studied. The studies must be performed for the P0, P1, and P2 categories identified in Table 1 with the conditions that the system is expected to experience during the possible unavailability of the long lead time equipment.
- R2.2. For the Planning Assessment, the Long-Term Transmission Planning Horizon portion of the steady state analysis must be assessed annually and be supported by the following annual current study, supplemented with qualified past studies as indicated in R2.6:

## M. Planning Standards

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- R2.2.1. A current study assessing expected system peak load conditions for one of the years in the Long-Term Transmission Planning Horizon and the rationale for why that year was selected.
- R2.3. The short circuit analysis portion of the Planning Assessment must be conducted annually addressing the Near-Term Transmission Planning Horizon and can be supported by current or past studies as qualified in R2.6. The analysis must be used to determine whether circuit breakers have interrupting capability for Faults that they will be expected to interrupt using the system short circuit model with any planned generation and Transmission Facilities in service which could impact the study area.
- R2.4. For the Planning Assessment, the Near-Term Transmission Planning Horizon portion of the Stability analysis must be assessed annually and be supported by current or past studies as qualified in R2.6. The following studies are required:
- R2.4.1. System peak load for one of the five years. System peak load levels must include a load model which represents the expected dynamic behavior of loads that could impact the study area, considering the behavior of induction motor loads or other load characteristics, including the model of distributed generation, Demand Response and other programs that impact system load characteristics. An aggregate system load model which represents the overall dynamic behavior of the load is acceptable.
- R2.4.2. System minimum load for one of the five years.
- R2.4.3. System minimum with maximum and minimum variable renewables (night-time load) load for one of the five years.
- R2.4.4. System minimum day load, maximum variable renewable for one of the five years.
- R2.4.5. System day-peak load, maximum and minimum variable renewable for one of the five years.
- R2.4.6. System peak load, no variable renewable for one of the five years.
- R2.4.7. For each of the studies described in R2.4.1 through R2.4.6, sensitivity case(s) must be utilized to demonstrate the impact of changes to the basic assumptions used in the model. To accomplish this, the sensitivity analysis in the Planning Assessment must vary one or more of the following conditions by a sufficient amount to stress the system within a range of credible conditions that demonstrate a measurable change in performance:
- Load level, load forecast, or dynamic load model assumptions.
  - Expected transfers.
  - Expected in service dates of new or modified Transmission Facilities.
  - Reactive resource capability
  - Maintenance periods of generation resources and alternative resources providing ancillary services.
  - Generation additions, retirements, or other dispatch scenarios.

- R2.5. For the Planning Assessment, the Long-Term Transmission Planning Horizon portion of the Stability analysis must be assessed to address the impact of proposed material generation additions or changes in that time frame and be supported by current or past studies as qualified in R2.6 and must include documentation to support the technical rationale for determining material changes.
- R2.6. Past studies may be used to support the Planning Assessment if they meet the following requirements:
- R2.6.1. For steady state, short circuit, or Stability analysis: the study must be five calendar years old or less, unless a technical rationale can be provided to demonstrate that the results of an older study are still valid.
- R2.6.2. For steady state, short circuit, or Stability analysis: no material changes have occurred to the system represented in the study. Documentation to support the technical rationale for determining material changes must be included.
- R2.7. For planning events shown in Table 1, when the analysis indicates an inability of the system to meet the performance requirements in Table 1, the Planning Assessment must include Corrective Action Plan(s) addressing how the performance requirements will be met. Revisions to the Corrective Action Plan(s) are allowed in subsequent Planning Assessments but the planned system must continue to meet the performance requirements in Table 1. The Corrective Action Plan(s) must:
- R2.7.1. List system deficiencies and the associated actions needed to achieve required system performance. Examples of such actions include:
- Installation, modification, retirement, or removal of Transmission and generation Facilities and any associated equipment
  - Installation, modification, or removal of Protection Systems or Special Protection Systems
  - Installation or modification of automatic generation tripping as a response to a single or multiple Contingency to mitigate Stability performance violations
  - Installation or modification of manual and automatic generation runback or tripping as a response to a single or multiple Contingency to mitigate steady state performance violations
  - Use of Operating Procedures specifying how long they will be needed as part of the Corrective Action Plan
  - Use of rate applications, DSM, alternative resources and technologies, or other initiatives
- R2.7.2. Include actions to resolve performance deficiencies identified in multiple sensitivity studies or provide a rationale for why actions were not necessary.
- R2.7.3. If situations arise that are beyond the control of the BA that prevent the implementation of a Corrective Action Plan in the required

## M. Planning Standards

TPL-001-0: Transmission Planning Performance Requirements

time frame, then the BA is permitted to utilize Non-Consequential Load Loss to correct the situation that would normally not be permitted in Table 1, provided that the BA documents that they are taking actions to resolve the situation. The BA must document the situation causing the problem, alternatives evaluated, and the use of Non-Consequential Load.

- R2.7.4. Be reviewed in subsequent annual Planning Assessments for continued validity and implementation status of identified system Facilities and Operating Procedures.
- R2.8. For short circuit analysis, if the short circuit current interrupting duty on circuit breakers determined in R2.3 exceeds their Equipment Rating, the Planning Assessment must include a Corrective Action Plan to address the Equipment Rating violations. The Corrective Action Plan must:
- R2.8.1. List system deficiencies and the associated actions needed to achieve required system performance.
- R2.8.2. Be reviewed in subsequent annual Planning Assessments for continued validity and implementation status of identified System Facilities and Operating Procedures.
- R3.** For the steady state portion of the Planning Assessment, the BA must perform studies for the Near-Term and Long-Term Transmission Planning Horizons in R2.1, and R2.2. The studies must be based on computer simulation models using data provided in R1.
- R3.1. Studies must be performed for planning events to determine whether the system meets the performance requirements in Table 1 based on the Contingency list created in R3.4.
- R3.2. Studies must be performed to assess the impact of the extreme events which are identified by the list created in R3.5.
- R3.3. Contingency analyses for R3.1 & R3.2 must:
- R3.3.1. Simulate the removal of all elements that the Protection System and other automatic controls are expected to disconnect for each Contingency without operator intervention. The analyses must include the impact of subsequent:
- Tripping of generators where simulations show generator bus voltages or high side of the generation step up (GSU) voltages are less than known or assumed minimum generator steady state or ride through voltage limitations. Include in the assessment any assumptions made.
  - Tripping of Transmission elements where relay loadability limits are exceeded.
  - Tripping of generation and other resources (including distributed resources) where ride-thru capabilities are exceeded
- R3.3.2. Simulate the expected automatic operation of existing and planned devices designed to provide steady state control of electrical system quantities when such devices impact the study area. These devices may include equipment such as phase-shifting transformers, load tap changing transformers, and switched capacitors and inductors.



- R3.4. Those planning events in Table 1, that are expected to produce more severe system impacts must be identified and a list of those Contingencies to be evaluated for system performance in R3.1 created. The rationale for those Contingencies selected for evaluation must be available as supporting information.
- R3.5. Those extreme events in Table 1 that are expected to produce more severe system impacts must be identified and a list created of those events to be evaluated in R3.2. The rationale for those Contingencies selected for evaluation must be available as supporting information. If the analysis concludes there is Cascading caused by the occurrence of extreme events, an evaluation of possible actions designed to reduce the likelihood or mitigate the consequences and adverse impacts of the event(s) must be conducted.
- R4.** For the Stability portion of the Planning Assessment, as described in Requirement R2, Parts 2.4 and 2.5, the BA must perform the Contingency analyses listed in Table 1. The studies must be based on computer simulation models using data provided in Requirement R1.
  - R4.1. Studies must be performed for planning events to determine whether the system meets the performance requirements in Table 1 based on the Contingency list created in R4.4.
    - R4.1.1. For planning event P1: No generating unit must pull out of synchronism. A generator being disconnected from the system by fault clearing action or by a Special Protection System is not considered pulling out of synchronism.
    - R4.1.2. For planning events P2 through P7: When a generator pulls out of synchronism in the simulations, the resulting apparent impedance swings must not result in the tripping of any Transmission system elements other than the generating unit and its directly connected Facilities.
    - R4.1.3. For planning events P1 through P7: Power oscillations must exhibit acceptable damping as established by the BA.
  - R4.2. Studies must be performed to assess the impact of the extreme events which are identified by the list created in R4.5.
  - R4.3. Contingency analyses for R4.1 and R4.2 must:
    - R4.3.1. Simulate the removal of all elements that the Protection System and other automatic controls are expected to disconnect for each Contingency without operator intervention. The analyses must include the impact of subsequent:
      - Successful high speed (less than one second) reclosing and unsuccessful high-speed reclosing into a Fault where high speed reclosing is utilized.
      - Tripping of generators where simulations show generator bus voltages or high side of the GSU voltages are less than known or assumed generator low voltage ride through capability. Include in the assessment any assumptions made.
      - Tripping of Transmission lines and transformers where transient swings cause Protection System operation based on generic or actual relay models.

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- Tripping of all generation sources whose ride-thru capabilities are exceeded.
- R4.3.2. Simulate the expected automatic operation of existing and planned devices designed to provide dynamic control of electrical system quantities when such devices impact the study area. These devices may include equipment such as generation exciter control and power system stabilizers, static var compensators and power flow controllers.
- R4.4. Those planning events in Table 1 that are expected to produce more severe system impacts on its portion of the system, must be identified, and a list created of those Contingencies to be evaluated in R4.1. The rationale for those Contingencies selected for evaluation must be available as supporting information.
- R4.5. Those extreme events in Table 1 that are expected to produce more severe system impacts must be identified and a list created of those events to be evaluated in R4.2. The rationale for those Contingencies selected for evaluation must be available as supporting information. If the analysis concludes there is Cascading caused by the occurrence of extreme events, an evaluation of possible actions designed to reduce the likelihood or mitigate the consequences of the event(s) must be conducted.
- R5. The BA must have criteria for acceptable system steady state voltage limits, post-Contingency voltage deviations, and the transient voltage response for its system. For transient voltage response, the criteria must at a minimum, specify a low voltage level and a maximum length of time that transient voltages may remain below that level.
- R6. The BA must define and document, within their Planning Assessment, the criteria or methodology used in the analysis to identify system instability for conditions such as Cascading, voltage instability, or uncontrolled islanding.
- R7. The BA must distribute its Planning Assessment results to the Hawai'i PUC (or designee) within 30 calendar days upon a written request for the information.

Table I – Steady State & Stability Performance Planning Events

Steady State & Stability:

1. The system must remain stable. Cascading and uncontrolled islanding must not occur.
2. Consequential Load Loss as well as generation loss is acceptable as a consequence of any event excluding P0.
3. Simulate the removal of all elements that Protection Systems and other controls are expected to automatically disconnect for each event.
4. Simulate Normal Clearing unless otherwise specified.
5. Planned System adjustments such as Transmission configuration changes and re-dispatch of generation are allowed if such adjustments are executable within the time duration applicable to the Facility Ratings
6. Phase angle separation for line contingency must not preclude automatic reclosing for BA groups B and C, unless system Adjustments can be performed within fifteen minutes.

Steady State Only:

7. Applicable Facility Ratings must not be exceeded.
8. System steady state voltages and post-Contingency voltage deviations must be within acceptable limits as established by the BA.
9. Planning event P0 is applicable to steady state only.
10. The response of voltage sensitive load that is disconnected from the system by end-user equipment associated with an event must not be used to meet steady state performance requirements.

Stability Only:

11. Transient voltage response must be within acceptable limits established by the BA.

| Category                 | Initial Condition | Event <sup>1</sup>   | Fault(s) Type <sup>2</sup>                      | Non-Consequential Load Loss Allowed | Range of Customers Loss Allowed | Applicable BA Group(s) <sup>3</sup> |
|--------------------------|-------------------|--|---|-------------------------------------|---------------------------------|-------------------------------------|
| P0<br>No Contingency     | Normal system     | None   | NA  | No                                  | None                            | A, B and C                          |
| P1<br>Single Contingency | Normal system     | Loss of one of the following:<br>1. Generator<br>2. Transmission Circuits<br>3. Transformer <sup>4</sup><br>4. Shunt Device-Ancillary Service Device <sup>5</sup><br>5. Generator – no fault | 3Ø and SLG for Events 1 through 4, NA for Event | Yes                                 | up to 12% gen only              | A                                   |
|                          |                   |  |   | Yes                                 | up to 15% gen only              | B                                   |
|                          |                   |  |   | Yes                                 | up to 15% gen only              | C                                   |

**M. Planning Standards**

TPL-001-0: Transmission Planning Performance Requirements

| Table I – Steady State & Stability Performance Planning Events -Continued |  |  |                            |                                     |                                 |                                     |
|---|--|--|----------------------------|-------------------------------------|---------------------------------|-------------------------------------|
| Category  | Initial Condition  | Event <sup>1</sup>   | Fault(s) Type <sup>2</sup> | Non-Consequential Load Loss Allowed | Range of Customers Loss Allowed | Applicable BA Group(s) <sup>3</sup> |
| <b>P2</b><br>Single Contingency   | Normal system  | 1. Opening a line section w/o fault <sup>6</sup>   | N/A                        | No                                  | None                            | A, B and C                          |
|   |  | 2. Bus Section fault   | SLG                        | Yes                                 | none                            | A                                   |
|   |  |  |                            | Yes                                 | none                            | B                                   |
|   |  |  |                            | Yes                                 | none                            | C                                   |
|   |  | 3. Internal Breaker Fault <sup>7</sup><br>(Transmission line breaker)  | SLG                        | Yes                                 | none                            | A                                   |
|   |  |  |                            | Yes                                 | none                            | B                                   |
| Yes   | none   |  |                            | C                                   |                                 |                                     |
| <b>P3</b><br>Single Contingency   | Loss of generator unit followed by System adjustments <sup>8</sup> | Loss of one of the following:<br>1. Generator<br>2. Transmission Circuits<br>3. Transformer <sup>4</sup><br>4. Shunt Device/ Ancillary Service Device <sup>5</sup> | 3Ø and SLG                 | No                                  | up to 12%                       | A                                   |
|   |  |  |                            | Yes                                 | up to 40%                       | B                                   |
|   |  |  |                            | Yes                                 | up to 40%                       | C                                   |

Table I – Steady State & Stability Performance Planning Events -Continued

| Category  | Initial Condition | Event <sup>1</sup>  | Fault(s) Type <sup>2</sup> | Non-Consequential Load Loss Allowed | Range of Customers Loss Allowed | Applicable BA Group(s) <sup>3</sup> |
|---|-------------------|---|----------------------------|-------------------------------------|---------------------------------|-------------------------------------|
| <b>P4</b><br>Multiple Contingency (Fault plus stuck breaker <sup>10</sup> ) | Normal system     | Loss of multiple elements caused by a stuck breaker <sup>10</sup> (non-Bus-tie Breaker) attempting to clear a Fault on one of the following:<br><br>1. Generator<br>2. Transmission Circuits<br>3. Transformer <sup>4</sup><br>4. Shunt Device <sup>5</sup><br>5. Bus Section | SLG                        | Yes                                 | up to 65%                       | A                                   |
|   |                   |   |                            | Yes                                 | up to 65%                       | B <sup>13</sup>                     |
|   |                   |   | Yes                        | up to 65%                           | C <sup>13</sup>                 |                                     |
|   |                   | 6. Loss of multiple elements caused by a stuck breaker <sup>10</sup> (Bus-tie Breaker) attempting to clear a Fault on the associated bus  | SLG                        | Yes                                 | up to 65%                       | A <sup>13</sup>                     |
|   |                   |   |                            | Yes                                 | up to 65%                       | B <sup>13</sup>                     |
|   |                   |   |                            | Yes                                 | up to 65%                       | C <sup>13</sup>                     |

**M. Planning Standards**

TPL-001-0: Transmission Planning Performance Requirements

| Table I – Steady State & Stability Performance Planning Events -Continued |   |  |                         |                                     |                                 |                                     |
|---|---|--|-------------------------|-------------------------------------|---------------------------------|-------------------------------------|
| Category  | Initial Condition   | Event <sup>1</sup>   | Fault Type <sup>2</sup> | Non-Consequential Load Loss Allowed | Range of Customers Loss Allowed | Applicable BA Group(s) <sup>3</sup> |
| <b>P5</b><br>Multiple Contingency (Fault plus relay failure to operate)   | Normal system   | Delayed Fault Clearing due to the failure of a non-redundant relay <sup>12</sup> protecting the Faulted element to operate as designed, for one of the following:<br><br>1. Generator<br>2. Transmission Circuits<br>3. Transformer <sup>4</sup><br>4. Shunt Device <sup>5</sup><br>5. Bus Section | SLG                     | No                                  | None                            | A                                   |
|   |   |  |                         | Yes                                 | up to 15%                       | B                                   |
|   |   |  |                         | Yes                                 | up to 15%                       | C                                   |
| <b>P6</b><br>Multiple Contingency (Two overlapping singles)               | Loss of one of the followed by system adjustments <sup>8</sup><br><br>1. Transmission Circuits<br>2. Transformer <sup>4</sup><br>3. Shunt Device <sup>5</sup> | Loss of one of the following:<br><br>1. Transmission Circuits<br>2. Transformer <sup>4</sup><br>3. Shunt Device <sup>5</sup>   | 3Ø                      | No                                  | up to 40%                       | A                                   |
|   |   |  |                         | Yes                                 | up to 65%                       | B <sup>13</sup>                     |
|   |   |  |                         | Yes                                 | up to 65%                       | C <sup>13</sup>                     |
| <b>P7</b><br>Multiple Contingency (Common Structure)                      | Normal system   | The loss of any two adjacent (vertically or horizontally ) circuits on common wood structure <sup>10</sup> :   | SLG                     | No                                  | up to 40%                       | A                                   |
|   |   |  |                         | Yes                                 | up to 65%                       | B                                   |
|   |   |  |                         | Yes                                 | up to 65%                       | C                                   |

**Table I – Steady State & Stability Performance Extreme Events**

**Steady State & Stability**

For all extreme events evaluated:

1. Simulate the removal of all elements that Protection systems and automatic controls are expected to disconnect for each Contingency.
2. Simulate Normal Clearing unless otherwise specified.

**Steady State**

1. Loss of a single generator, Transmission Circuit, shunt device, or transformer force out of service followed by another single generator, Transmission Circuit, shunt device, or transformer forced out of service prior to system adjustments.
2. Local area events affecting the transmission system such as:
  - a. Loss of a tower line with three or more circuits<sup>10</sup>.
  - b. Loss of all Transmission lines on a common Right-of-Way<sup>10</sup>.
  - c. Loss of a switching station or substation (loss of one voltage level plus transformers).
  - d. Loss of all generating units at a generating station.
  - e. Loss of a large load or major load center.
3. Wide area events affecting the Transmission System based on system topology such as:
  - a. Loss of two generating stations resulting from conditions such as:
    - i. Loss of a large fuel line into an area.
    - ii. Loss of the use of a large body of water as the cooling source for generation.
    - iii. Wildfires
    - iv. Severe weather, for example, hurricanes
    - v. A successful cyber attack
    - vi. Large earthquake, tsunami or volcanic eruption
  - b. Other events based upon operating experience that may result in wide area disturbances.

**Stability**

1. Loss of a single generator, Transmission circuit, shunt device, or transformer force out of service apply a 3Ø fault on another single generator, Transmission circuit, shunt device, or transformer prior to system adjustments.
2. Local area events affecting the transmission system such as:
  - a. 3Ø fault on generator with stuck breaker<sup>9</sup> or a relay failure<sup>12</sup> resulting in Delayed Fault Clearing.
  - b. 3Ø fault on Transmission circuit with stuck breaker<sup>9</sup> or a relay failure<sup>12</sup> resulting in Delayed Fault Clearing.
  - c. 3Ø fault on transformer with stuck breaker<sup>9</sup> or a relay failure<sup>12</sup> resulting in Delayed Fault Clearing.
  - d. 3Ø fault on bus section with stuck breaker<sup>9</sup> or a relay failure<sup>12</sup> resulting in Delayed Fault Clearing.
  - e. 3Ø internal breaker fault.
  - f. Other events based upon operating experience, such as consideration of initiating events that experience suggests may result in wide area disturbances.

## M. Planning Standards

TPL-001-0: Transmission Planning Performance Requirements

**Table I – Steady State & Stability Performance Footnotes  
(Planning Event and Extreme Events)**

1. If the event analyzed involves system elements at multiple system voltage levels, the lowest system voltage level of the element(s) removed for the analyzed event determines the stated performance criteria regarding allowances for interruptions of Non-Consequential Load Loss.
2. Unless specified otherwise, simulate Normal Clearing of faults. Single line to ground (SLG) or three-phase (3 $\emptyset$ ) are the fault types that must be evaluated in Stability simulations for the event described. A 3 $\emptyset$  or a double line to ground fault study indicating the criteria are being met is sufficient evidence that a SLG condition would also meet the criteria.
3. The Applicable BA Groups (A, B or C) is defined under Facilities and is determined by the annual system peak demand.
4. For non-generator step up transformer outage events, the reference voltage, as used in footnote 1, applies to the low-side winding (excluding tertiary windings). For generator and Generator Step Up transformer outage events, the reference voltage applies to the system connected voltage (high-side of the Generator Step Up transformer). Requirements which are applicable to transformers also apply to variable frequency transformers and phase shifting transformers.
5. Requirements which are applicable to shunt devices also apply to FACTS devices that are connected to ground.
6. Opening one end of a line section without a fault on a normally networked Transmission circuit such that the line is possibly serving load radial from a single source point.
7. An internal breaker fault means a breaker failing internally, thus creating a system fault which must be cleared by protection on both sides of the breaker.
8. An objective of the planning process should be to minimize the likelihood and magnitude of interruption of Transmission following Contingency events. System adjustment (as identified in the column entitled 'Initial Condition') when achieved through the appropriate re-dispatch of resources obligated to re-dispatch, where it can be demonstrated that Facilities remain within applicable Facility Ratings and the re-dispatch does not result in any Non-Consequential Load Loss. Where limited options for re-dispatch exist, sensitivities associated with the availability of those resources should be considered.
9. A stuck breaker means that for a gang-operated breaker, all three phases of the breaker have remained closed. For an independent pole operated (IPO) or an independent pole tripping (IPT) breaker, only one pole is assumed to remain closed. A stuck breaker results in Delayed Fault Clearing.
10. Excludes circuits that share a common structure (Planning event P7, Extreme event steady state 2a) or common Right-of-Way (Extreme event, steady state 2b) for 1 mile or less.
11. An objective of the planning process should be to minimize the likelihood and magnitude of Non-Consequential Load Loss following Contingency events. However, in limited circumstances Non-Consequential Load Loss may be needed to address System performance requirements. When Non-Consequential Load Loss is utilized within the planning process to address system performance requirements, such interruption is limited to circumstances where the Non-Consequential Load Loss is documented, including alternatives evaluated.
12. Applies to the following relay functions or types: pilot (#85), distance (#21), differential (#87), current (#50, 51, and 67), voltage (#27 & 59), directional (#32, & 67), and tripping (#86, & 94).
13. Indicates that the system level for the Category is an extreme event for the Group.



## C. Measures

- M1.** The BA must provide evidence, in electronic or hard copy format, that it is maintaining system models within their respective area, using data consistent with HI-MOD-010 Development and Reporting of Steady State System Models and Simulations and HI-MOD-012 Development and Reporting of Dynamic System Models and Simulations, including items represented in the Corrective Action Plan, representing projected system conditions, and that the models represent the required information in accordance with R1.
- M2.** The BA must provide dated evidence, such as electronic or hard copies of its annual Planning Assessment, that it has prepared an annual Planning Assessment of its portion of the system in accordance with Requirement R2.
- M3.** The BA must provide dated evidence, such as electronic or hard copies of the studies utilized in preparing the Planning Assessment, in accordance with Requirement R3.
- M4.** The BA must provide dated evidence, such as electronic or hard copies of the studies utilized in preparing the Planning Assessment in accordance with Requirement R4.
- M5.** The BA must provide dated evidence such as electronic or hard copies of the documentation specifying the criteria for acceptable system steady state voltage limits, post-Contingency voltage deviations, and the transient voltage response for its system in accordance with Requirement R5.
- M6.** The BA must provide dated evidence, such as electronic or hard copies of documentation specifying the criteria or methodology used in the analysis to identify system instability for conditions such as Cascading, voltage instability, or uncontrolled islanding that was utilized in preparing the Planning Assessment in accordance with Requirement R6.
- M7.** The BA must provide evidence, such as email notices, postal receipts showing recipient and date that it has distributed its Planning Assessment results to the Hawai'i PUC (or designee) within 30 calendar days upon a written request for the information in accordance with Requirement R7.

## D. Compliance

### I. Compliance Monitoring Process

#### 1.1 Compliance Enforcement Authority

Hawai'i Public Utilities Commission (PUC) or its designee.

#### 1.2 Data Retention

The BA must each retain data or evidence to show compliance as identified unless directed by its Hawai'i PUC (or designee) to retain specific evidence for a longer period of time as part of an investigation:

- The models utilized in the current in-force Planning Assessment and one previous Planning Assessment in accordance with Requirement R1 and Measure M1.
- The Planning Assessments performed since the last compliance audit in accordance with Requirement R2 and Measure M2.
- The studies performed in support of its Planning Assessments since the last compliance audit in accordance with Requirement R3 and Measure M3.
- The studies performed in support of its Planning Assessments since the last compliance audit in accordance with Requirement R4 and Measure M4.
- The documentation specifying the criteria for acceptable system steady state voltage limits, post-contingency voltage deviations, and transient voltage response since the last compliance audit in accordance with Requirement R5 and Measure M5.
- The documentation specifying the criteria or methodology utilized in the analysis to identify system instability for conditions such as cascading, voltage instability, or uncontrolled islanding in support of its Planning Assessments since the last compliance audit in accordance with Requirement R6 and Measure M6.
- Three calendar years of the notifications employed in accordance with Requirement R7 and Measure M7.

If the BA is found non-compliant, it must keep information related to the non-compliance until found compliant or the time periods specified above, whichever is longer.

#### 1.3 Compliance Monitoring and Enforcement Processes:

- Compliance Audits - The Hawai'i PUC (or designee) will give notice to the BA within 30 days of years' end for a compliance audit and will complete such audit within 90 days of such information being supplied by the BA.

- Self-Certifications
  - Spot Checking
  - Compliance Violation Investigations
  - Self-Reporting
  - Complaints
2. Levels of Non-Compliance for Requirement R1, Measure M1
    - 2.1 Level 1 - The BA's system model failed to represent one of the Requirement R1, Parts 1.1.1 through 1.1.5. for Requirement R1 and Measurement M1.
    - 2.2 Level 2 - The BA failed to meet all the requirements of Level 1 for Requirement R1 and Measurement M1.
  3. Levels of Non-Compliance for Requirement R2, Measure M2
    - 3.1 Level 1 - The BA failed to comply with Requirement R2, Part 2.6. for Requirement R2 and Measurement M2
    - 3.2 Level 2 - The BA failed to meet all the requirements of Level 1 for Requirement R2 and Measurement M2.
  4. Levels of Non-Compliance for Requirement R3, Measure M3
    - 4.1 Level 1 - The BA did not identify planning events as described in Requirement R3, Part 3.4 or extreme events as described in Requirement R3, Part 3.5. for Requirement R3 and Measurement M3.
    - 4.2 Level 2 - The BA failed to meet all the requirements of Level 1 for Requirement R3 and Measurement M3.
  5. Levels of Non-Compliance for Requirement R4, Measure M4
    - 5.1 Level 1 - The BA did not identify planning events as described in Requirement R4, Part 4.4 or extreme events as described in Requirement R4, Part 4.5 for Requirement R4 and Measurement M4.
    - 5.2 Level 2 - The BA failed to meet all the requirements of Level 1 for Requirement R4 and Measurement M4.
  6. Levels of Non-Compliance for Requirement R5, Measure M5
    - 6.1 Level 1 - N/A
    - 6.2 Level 2 - The BA does not have criteria for acceptable system steady state voltage limits, post-Contingency voltage deviations, or the transient voltage response for its system for Requirement R5 and Measurement M5.

## **M. Planning Standards**

TPL-001-0: Transmission Planning Performance Requirements

### **7. Levels of Non-Compliance for Requirement R6, Measure M6**

7.1 Level 1 - N/A

7.2 Level 2 - The BA failed to define and document the criteria or methodology for system instability used within its analysis as described in Requirement R6 for Requirement R6 and Measurement M6.

### **8. Levels of Non-Compliance for Requirement R7, Measure M7**

8.1 The BA distributed its Planning Assessment results to Hawai'i PUC (or designee) but it was more than 30 days but less than or equal to 40 days following the request as described in Requirement R7 for Requirement R7 and Measurement M7.

8.2 The BA failed to meet all the requirements of Level 1 for Requirement R7 and Measurement M7.

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## BAL-502-0: RESOURCE ADEQUACY ANALYSIS, ASSESSMENT, AND DOCUMENTATION

### A. Introduction

**Purpose:** To establish common criteria for each Balancing Authority (BA) based on “one day in “X” year” (determined by study) loss of load expectation principles or as an alternative a planning methodology based on the single largest unit contingency and an appropriate reserve margin or reserve criteria. The analysis, assessment and documentation of Resource Adequacy, will include Planning Reserve Margins for meeting system load for the BA’s system. The analysis will also include resource adequacy analysis for frequency response, spinning reserve, off-line reserves and other resource characteristics required to meet the reliability criteria.

**Applicability:** Balancing Authorities (BA) are divided into two groups based on the annual system Peak Demand.

- *Group A:* Annual system peak is greater than 50 MW.
- *Group B:* Annual system peak is less than or equal to 50 MW.

**Effective Date:** To be determined

## B. Requirements

**RI.** The Group A utilities will establish at their discretion whether to use Resource Adequacy analysis using requirements defined in either R1.1 or R1.2 for each planning year. Group B will use the planning methodology defined in R1.2 for each planning year.

**RI.1.** Group A - “one day in X year criteria”. The utility will establish the methodology and procedures used to establish the “one day in X year” criteria to meet the system peak load to be served by the BA. The methodology should evaluate the reliability of the generating resources, the capacity and system requirements of the BA and the alternatives to resource commitment available to meet the desired reliability criteria for each of the BA’s utility loss of load expectations methodologies. In addition the methodology should include the consideration of, renewable capacity from variable renewable resources using the reliability based methods described in R1.2 for  $L_{QC}$ . Consideration will also be given to ensure that the enough generating resources are installed on system that have the capability to provide the operating ancillary services such as frequency response, spinning reserve, voltage regulation, frequency regulation and other services during the same time periods included in HI-TPL-001 Transmission Planning Performance Requirements as follows:

**RI.1.1.** Minimum day load with no variable renewable generation

**RI.1.2.** Minimum day load with variable maximum renewable generation

**RI.1.3.** Maximum load with no variable renewable generation

**RI.1.4.** Maximum load with maximum variable renewable generation.

**RI.2.** Group A and Group B - “reserve margin of XX% criteria”. The utility will maintain a minimum XX% Reserve Margin ( $F_{RM}$ ) over the annual system peak.

$$\frac{\sum_{i=1}^N N_i + L_{DR} + L_{QC} - L_{Peak}}{L_{Peak} - L_{DR}} \geq F_{RM}$$

Where:

- $F_{RM}$  is the Reserve Margin.
- $N_i$  is the Normal Net Capability of all firm units.
- $L_{DR}$  is the amount of Interruptible Demand and Direct Control Load Management (DCLM) exclusively available and measureable for the BA’s interruption for the entire period of the expected capacity shortfall. Such Interruptible Demand and DCLM will not infringe on the protective reserve for system security required by HI-BAL-006 Underfrequency Load Shedding.
- $L_{QC}$  is the estimated capacity value of grid-side variable renewable and stored energy generation on the system. The estimated capacity value of grid-side variable generation and stored energy will be determined by the utility using reliability or statistical based calculation methods depending upon the available data. Reliability based methods that may be used

include the effective load carrying capability (ELCC), equivalent conventional power (ECP), or equivalent firm capacity (EFC) methods. Statistical based methods may consist of the relevant time period of the system peak and renewable energy over a time series of data. For example, the estimated capacity  $L_{QC}$  is the level where over that system peak period in which 90% of the data points are available to serve the system peak. For existing installations, the capacity value will be calculated using three years of actual data for each group of similar variable renewables such as wind, hydro, PV, etc. For future installations the estimated capacity value will be based on estimated capacity value calculations for similarly located resources installed in Hawai'i. For future variable resources where no Hawai'i historical data is available, the best available data shall be used for calculations. For the first year of data, the estimated capacity value shall be adjusted by 0.7 followed by 0.8 after gathering the second year of data. Following the third year of data, the actual data shall be used to determine the capacity value.

- $L_{Peak}$  is the forecasted annual system peak load.

The Reserve Margin analysis will also consider as a secondary planning criteria that the BA's total Normal Net Capability of all firm units of the system less the capacity of the unit(s) scheduled for maintenance less the capacity that would be lost by the Forced Outage of the largest single contingency plus the total amount of interruptible loads plus the estimated capacity value of grid-side variable renewable and stored energy generation on the system, if appropriate, and dedicated for serving the entire period of the peak ,must be equal to or greater than the forecasted system peak load.

$$\sum_{i=1}^N N_i - \sum_{m=1}^N N_m - N_{FO} + L_{DR} + L_{QC} \geq L_{Peak}$$

Where:

- $N_m$  is the Normal Net Capability of units on scheduled maintenance.
- $N_{FO}$  is the Normal Net Capability of the largest single contingency lost by Forced Outage.

**RI.3.** The BA for each Group A system will stipulate the use of either R1.1. or R1.2. for planning. The Resource Adequacy analysis must calculate a Planning Reserve Margin for the applicable group that will either result from the sum of the probabilities for Loss of Load for the system Peak Demand for all days of each planning year analyzed (per R1.1) being equal to \_\_\_\_ (This is comparable to a "one day in x year" criterion) or document that the applicable Balance Authority has developed a resource plan that encompasses a xx% Reserve Margin for Group A (per R1.2). Group B will use the Reserve Margin criteria (per R1.2). The reserve margin target will be utilized until such a time that a new study determines a change in the reserve margin is warranted.

**RI.4.** The BA will develop criteria to ensure the generation characteristics address the following system requirements:

- RI.4.1.** Starting and loading time if resources are to be used as Contingency Reserves as required in HI-BAL-002 Disturbance Control Standard.

## M. Planning Standards

BAL-502-0: Resource Adequacy Analysis, Assessment, and Documentation

- RI.4.2.** The Frequency and Inertia response characteristics as required in HI-BAL-001 Transmission System Planning Performance Requirements.
  - RI.4.3.** The Voltage and Frequency ride-through characteristics as required in HI-BAL-001 Transmission System Planning Performance Requirements.
  - RI.4.4.** Short circuit current requirements.
  - RI.4.5.** Dispatch characteristics (starting time, ramp rate, minimum values, regulation, etc.) as required to meet the requirements of the planning period.
  - RI.4.6.** Any other ancillary resources required to meet system security requirements which have been identified as necessary through analysis of the planning period.
- RI.5.** Be performed or verified separately for each of the following planning years:
- RI.5.1.** Perform an analysis for Year One.
  - RI.5.2.** Perform an analysis or verification when changes in measured non-dispatchable generation or net load changes more than \_ MW/year or \_ MW (amount established by each BA) from Year One or there are planned or unplanned changes in resource development other than non-dispatchable generation or DG.
- RI.6.** Include the following subject matter and documentation of its use:
- RI.6.1.** Criteria for including planned resource additions in the analysis.
  - RI.6.2.** Load forecast characteristics:
    - Median forecast peak load.
    - Load forecast uncertainty (reflects variability in the load forecast due to weather and regional economic forecasts).
    - Load diversity.
    - Seasonal load variations.
    - Daily demand modeling assumptions (firm, interruptible).
    - Contractual arrangements concerning curtailable or Interruptible Demand.
    - Historic resource performance and any projected changes.Seasonal resource ratings.
    - Historic resource performance and any projected changes.Seasonal resource ratings.
    - Resource planned outage schedules, deratings, and retirements.
    - Intermittent and energy limited resources such as wind, PV, and cogeneration may be considered holistically using time synchronized data with load. The relevant time period of the system peak must be defined using a minimum of three years of data.



- RI.6.3.** Transmission limitations that prevent the delivery of generation reserves
  - RI.6.3.1.** Criteria for including planned Transmission Facility additions in the analysis.
  - RI.6.3.2.** Criteria for remedial action systems employed in lieu of Transmission improvements.
- RI.7.** Consider the following resource availability characteristics and document how and why they were included in the analysis or why they were not included:
  - Common mode outages that affect resource availability.
  - Environmental or regulatory restrictions of resource availability.
  - Any other demand (load) response programs not included in R1.3.1.
  - Sensitivity to resource outage rates.
  - Impacts of extreme weather or drought conditions that affect unit availability.
- RI.8.** Document that capacity resources are appropriately accounted for in its Resource Adequacy analysis.
- R2.** The BA must annually document the projected load and resource capability, for each area or Transmission constrained sub-area identified in the Resource Adequacy analysis.
  - R2.1.** This documentation must cover each of the years in Year One through ten.
  - R2.2.** This documentation must include the Planning Reserve Margin calculated per requirement R1.1 for each of the three years in the analysis.
  - R2.3.** The documentation as specified per requirement R2.1 and R2.2 must be publicly posted no later than 30 days after the close of the year.

## C. Measures

- M2.** The BA must possess the documentation that a valid Resource Adequacy analysis was performed or verified in accordance with R1.
- M3.** The BA must possess the documentation of its projected load and resource capability, for each area or Transmission constrained sub-area identified in the Resource Adequacy analysis on an annual basis in accordance with R2.

## D. Compliance

### 1. Compliance Monitoring Process

#### 1.1. Compliance Enforcement Authority

1.1.1. Hawai'i PUC (or designee)

#### 1.2. Compliance Monitoring Period and Reset Timeframe

1.2.1. One calendar year

#### 1.3. Data Retention

1.3.1. The BA must retain information from the most current and prior two years. The Hawai'i PUC (or designee) will retain any audit data for five years.

### 2. Levels of Non-Compliance for Requirement R1, Measure M1

2.1. **Level 1** - The BA met one of the following conditions for Requirement R1 and Measurement M1.

2.1.1. The BA Resource Adequacy analysis failed to consider 1 or 2 of the Resource availability characteristics subcomponents under R1.4 and documentation of how and why they were included in the analysis or why they were not included.

2.1.2. The BA Resource Adequacy analysis failed to consider Transmission maintenance outage schedules and document how and why they were included in the analysis or why they were not included per R1.6.

2.2. **Level 2** - The BA failed to meet all the requirements of Level 1 for Requirement R1 and Measurement M1.

### 3. Levels of Non-Compliance for Requirement R2, Measure M2

3.1. **Level 1** - The BA failed to publicly post the documents as specified per requirement R2.1 and R2.2 later than 30 calendar days prior to the beginning of Year One per R2.3 for Requirement R2 and Measurement M2.

3.2. **Level 2** - The BA failed to meet all the requirements of Level 1 for Requirement R2 and Measurement M2. The PUC or its designee will give notice to the BA within 30 days of years' end for a compliance audit and will complete such audit within 90 days of such information being supplied by the BA.

# N. System Operation and Transparency of Operations

## PRUDENT DISPATCH AND OPERATIONAL PRACTICES

The Companies' unit commitment and economic dispatch policies are based on safe and reliable operation of the system, minimizing operating costs, and complying with contractual and regulatory obligations. The daily generation dispatch process is illustrated in Figure N-1.

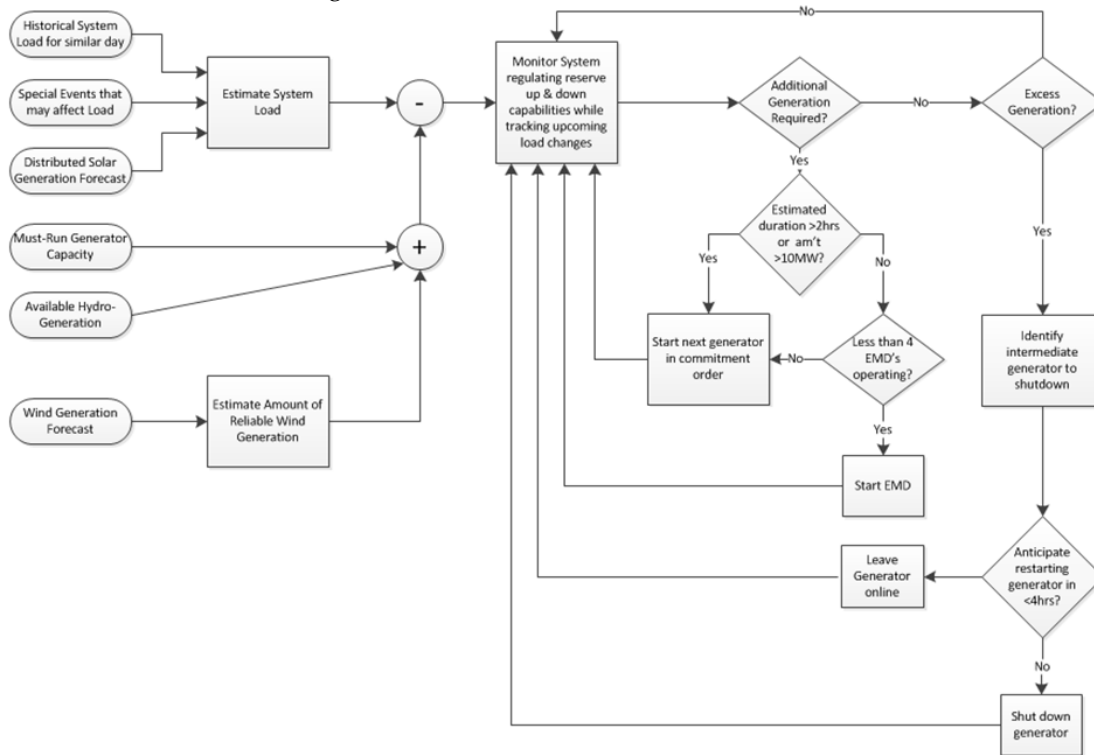


Figure N-1. Daily Generation Dispatch Process

## N. System Operation and Transparency of Operations

### Prudent Dispatch and Operational Practices

In the future, the goal is for the System Operator to be able to incorporate a more automated approach to unit commitment and dispatch with increased amounts of variable renewable generation (wind and solar), quick-starting engines, energy storage, and demand response resources on the grid. The Energy Management Systems (EMS) would likely be interfaced/integrated with corresponding Demand Response Management Systems (DRMS) and Energy Storage Management Systems (ESMS). This would also include integrating the demand forecast, with wind and solar forecasts to achieve a net demand to be used for unit commitment.

### Minimization of Ancillary Services Costs

The process to identify system security constraints, and the combinations of resources which can be used to meet them, is summarized as follows:

- Determine system constraints.
- Identify the resource mix that meets each of them.
- Select the lowest cost combination of resources to operate.

For all three operating companies, additional security constraints are imposed with increased concentrations of variable renewable resources. Therefore, the projected increase in distributed PV may have an impact on ancillary service costs. The Companies will continually evaluate the economics of using existing resources to meet ancillary service and system security requirements versus meeting those needs with alternative resources including energy storage and demand response.

### Maximizing the Use of Available Renewable Energy

The commitment and dispatch of renewable energy resources depends upon the contract terms for those resources and whether or not the system operator has visibility and control over the generation. If the resource can be economically dispatched, it is put under automatic generation control (AGC), and its output is determined by its marginal cost relative to the marginal cost of other resources. Examples of this type of renewable resource includes geothermal, generating units using renewable biofuels, waste-to-energy projects, and other “firm” renewable projects.

To date, variable renewable energy projects are contractually treated as “must-take,” variable energy. These resources are accepted regardless of cost, but their output is reduced as needed when all intermediate units are off line and there remains excess energy production. In this case the system operator limits, or “curtails” the output of variable energy providers to the degree necessary to keep the system in balance and provide response reserves. Most curtailments are partial – the output is limited but the

resource is not restricted to zero output. When curtailment is necessary due to excess energy, it is performed in a manner consistent with the purchased power agreements associated with the affected resources and in accordance with a priority order established by the system operator.

In addition to excess energy situations, curtailments can also be required for system constraints such as line loading, phase angle separation, line maintenance, and frequency impact from power fluctuations. Curtailments for system constraints are applied to the resources as needed to address these constraints and are not subject to the priority order used for excess energy curtailments. Curtailments are also performed at the request of wind plants for wind conditions, and equipment issues. The number of curtailment events, the reason, and their duration are reported monthly through various reports to the Commission such as the monthly report filed by the Hawaiian Electric Companies in Docket No. 2011-0206 (RSWG).

The vast majority of distributed solar PV is not visible or controllable by the system operator. These resources serve demand ahead of all other resources. Additional growth in distributed solar PV these resources is forecast to cause increased curtailments of utility-scale variable renewable resources, unless distributed solar PV is required to provide the visibility and control to the system operator.

## Energy Management Systems (EMS)

The operation of the system is facilitated by use of a centralized Energy Management System (EMS). The EMS provides the system operator with constantly updated, real-time information about the operational state of the system. There are three key program applications within the EMS:

- Supervisory Control and Data Acquisition (SCADA)
- Real-time Automatic Generation Control (AGC)
- Real-time State Estimator

The Companies routinely update the EMS hardware and software platforms for each system in order to ensure reliable operation, to incorporate new industry developments such as protocols and system security measures, and to maintain support from EMS vendors<sup>1</sup>. The most recent migration to a new platform was completed in late 2013.

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<sup>1</sup> The Companies operate EMS systems from two different vendors, *Alstom* at Hawai'i Electric Light and Maui Electric, and *Siemens* at Hawaiian Electric.

## System Dispatch and Unit Commitment

Unit commitment and dispatch decisions are based upon:

**Safety.** The Companies' dispatch of generating resources is always subject to ensuring the safety of Company personnel and the general public.

**Reliability.** Dispatch and unit commitment must adhere to system security and generation adequacy requirements.

**Contractual Requirements.** Dispatch and unit commitment must adhere to contractual constraints.

**Cost.** After meeting all the forgoing requirements, the Company commits units and dispatches units based on their marginal cost, with lower cost units being committed and operated before higher cost units.

When determining the unit commitment and dispatch of generating units, the Company does not differentiate between dispatchable IPPs and utility-owned assets. The daily unit commitment modeling tool input data does not differentiate units by ownership. Certain generators do receive a form of priority in terms of energy being accepted onto the system on the basis of the location of the generator, its characteristics, or the contractual obligations unique to the resource. The acceptance of energy is in the following order of preference:

- **Distributed generation:** Distributed generation resources receive preferential treatment as "must take" resources regardless of their economic merit for system dispatch. This includes Standard Interconnection Agreement (SIA) distributed generation and Net Energy Metering (NEM) distributed generation. At the present time, the Companies have no control over, or ability to curtail, distributed generation.
- **Scheduled contractually obligated generation:** These resources are preferentially treated from a dispatch perspective by contract. They are used to serve customer load regardless of their economic merit for system dispatch. Scheduled energy from these resources is taken after distributed generation, but ahead of all other resources including variable energy providers.
- **Contractually must-run, dispatchable generation:** The resources cannot be cycled offline and therefore the minimum dispatch level of these resources are preferentially treated in the system dispatch determination and the energy is accepted from these resources regardless of cost, except during periods of maintenance.
- **Generation to meet system security constraints:** These resources provide energy at least at their minimum dispatch limit, ahead of other resources, similar to contractual must-run and scheduled generation, plus an amount of reserve capability to provide down regulation. However, once dispatched, the continued operating status of these

resources is subject to continual evaluation of their costs relative to other alternative resources that may become available at a lower cost, except where it is required by contract.

- **Variable energy:** As available energy is accepted on the system, regardless of cost, after distributed generation, scheduled energy purchases, and continuously operated generation. This energy is accepted regardless of cost and thus presents a constraint on optimized (lowest) cost. If the energy cannot be accommodated due to low demand, curtailment of the resource is ordered according to an established and approved priority order.
- **Dispatchable resources:** Energy from dispatchable resources is taken on the basis of relative cost (economic dispatch). Resources with the lowest variable energy (fuel and O&M) cost will be committed ahead of resources with higher variable costs. Online resources with lower incremental costs will be dispatched at higher outputs ahead of resources with higher incremental costs. The units operated routinely to meet demand, but cycled offline during minimum demand periods, are described as intermediate units. Short-term (daily) unit commitment decisions do not consider fixed costs associated with these resources because the fixed costs will be incurred regardless of whether or not the unit is operated.

## Utilization of Energy Storage and Demand Response

Energy storage and demand response programs can provide the system operator with a flexible resource capable of providing capacity and ancillary services. In order to provide the system operator with appropriate control and visibility of energy storage assets will be equipped with essentially the same telemetry and controls necessary to operate generating units. Demand response used for providing regulation reserves and contingency reserves will also be equipped with appropriate telemetry and controls. The specific interface requirements depend upon whether the storage device or demand response resource is responding automatically, or is under the control of the system operator. DRMS and/or ESMS may be interfaced with or directly incorporated in an EMS. For storage or demand response that is integrated into the EMS, telemetry requirements include:

- For storage, real-time telemetry indicating charging state, amount of energy being produced, device status.
- Control interface to the EMS to enable the increase and decrease of energy output from the storage asset, and for energy input to the storage device for charging.
- For demand response, real-time telemetry indicating breaker status, switch status, and load.

## N. System Operation and Transparency of Operations

### Prudent Dispatch and Operational Practices

- Control interface to the EMS to enable the triggering of load shed in response to automatic signals (for example, underfrequency) or a command from the system operator.

Depending on the specific application, storage may also be required to respond to local signals. For example, storage may need the capability to respond to a system frequency change in a manner similar to generator governor droop response, which may be used for a contingency reserve response or for frequency responsive regulating reserve.

Another example of local response includes the ability of the storage to change output (or absorb energy) in response to another input signal from a variable renewable energy resource in order to provide “smoothing” of the renewable resource output.

A special consideration of short-duration storage is the fact that it is a limited energy resource. This introduces the need for the system operator to be informed regarding the storage asset’s charging state, and the need to ensure that the integration and operation of these resources allows for replacement energy sources prior to depletion of the storage. This replacement could be in the form of longer-term storage or generation resources. In order for the value of the demand response to be realized in providing a particular grid service, once called, the load cannot return to the system until after a specified time, which is dependent on the type of grid service being provided by the demand response resource. Accordingly, the system operator similarly requires information regarding the status of demand response, particularly as it relates to the state of the response after an event has been triggered.

## Visibility and Transparency in System Dispatch

A high level review of the Renewable Watch websites of various ISOs including PJM, MISO, Cal ISO, and ERCOT shows the following operational information commonly being displayed, along with ISO energy market-specific information such as locational marginal pricing:

- Real time daily demand curve showing actual and forecasted demand, updated at least hourly
- Hourly wind power MW or MWh being produced and forecasted
- Other renewable energy production in MW (California)
- Available generation resources

The Company’s Renewable Watch site currently displays the following information, with data updated approximately every 30 minutes:



**Net Energy System Load.** The system load served by generators on the “utility-side” of the meter including those owned by the utility and by independent power producers (IPP).

**Gross System Load.** The net system load plus estimated load served by “customer-side” of the meter by DG-PV.

**Solar Irradiance Data.** This data is measured in different regions of the island, which are used as input to calculating the estimated load served by customer-side PV.

**Wind Power Production.** Total megawatts of wind power being produced by the various IPP-owned wind farms selling electricity to Hawaiian Electric.

To provide further information to customers about the dispatch of various energy generation resources under the utility’s control, the Company is currently partnering with the Blue Planet Foundation to develop and publicly present real time breakouts of the percentage of net energy system load being served by various fuel types, including coal, oil, wind, waste-to-energy, solar, and biofuel. Hawaiian Electric and Blue Planet believe this information will be useful in raising customer awareness of the use of renewable energy versus fossil fuels. A prototype kiosk was displayed at the Hawai’i Clean Energy Day event on July 22, 2014 with positive public reaction.

In light of this information already being developed for public display, Hawaiian Electric is agreeable to the following enhancements to its website:

- The information on the Renewable Energy watch website will be supplemented with additional information showing for the previous hour the percentage of the energy supplied by the different resources (IPPs, Renewables, Company generating units).
- A historical archive of the percentage of the energy produced by each of the resource groups for the previous 24 hour period will be maintained so that the customer can view the changes over time.

These enhancements will address the Commission’s objectives of showing the significant use of non-utility generation and renewable resources, most of which, with the exception of Hawaiian Electric’s biofueled combustion turbine generation CT-1, are IPP owned.

In addition to the above, Hawaiian Electric will also make public a description of its economic dispatch policies and procedures, via posting on its company website. Combined, the enhancements to the Hawaiian Electric website and the sharing of its dispatch policies and procedures will increase visibility and transparency of how generating resources are being dispatched on the Hawaiian Electric system.

As previously mentioned the Companies generating unit commitment and dispatch of the generating units is based on the objective of incurring the least cost to the customers while continuing to maintain system reliability. With the introduction of increasing

## N. System Operation and Transparency of Operations

### Prudent Dispatch and Operational Practices

amounts of renewable resources on the systems, it has become more important to minimize the use of fossil fuels and contending with the dynamic system changes that occur from the new resources so that reliability can be maintained. A screenshot from the Renewable Watch–O’ahu website is shown below in Figure N-2 to provide an example of the variability of the renewable energy resources.

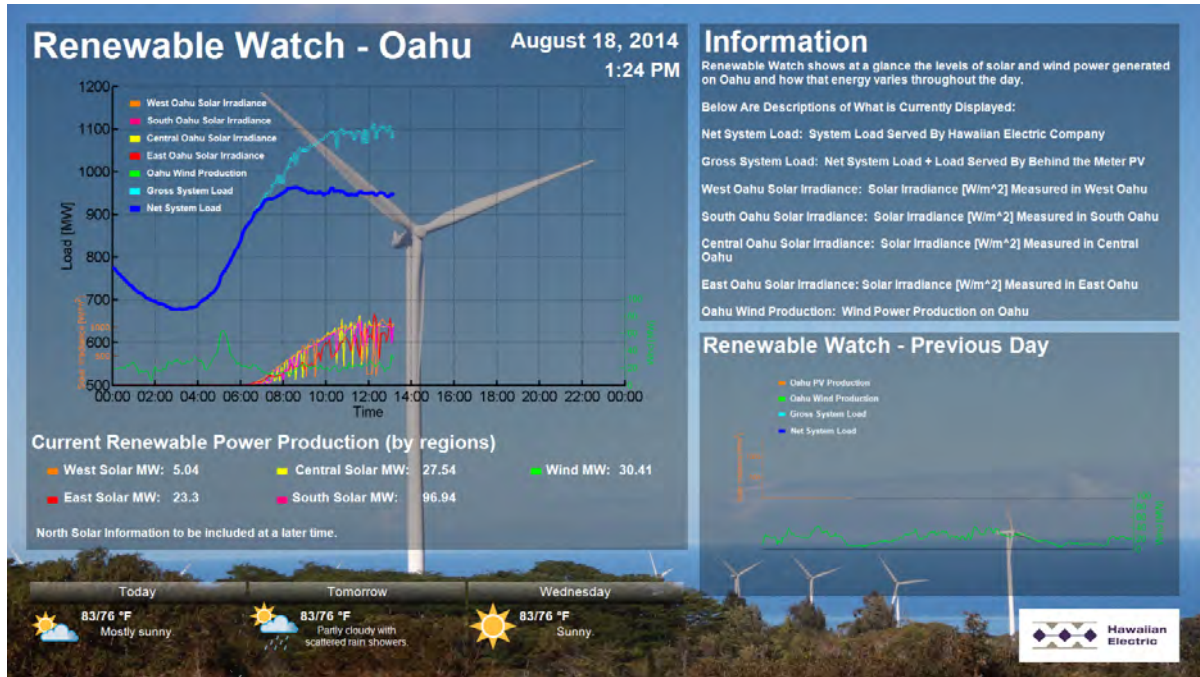


Figure N-2. Renewable Watch–O’ahu Website Screenshot of Information Displayed for August 18, 2014.

Keep in mind that the changes that have been occurring on the Companies’ respective systems have been occurring for a few years but at different rates of change. The neighbor island systems (Maui and Hawai’i Island) have been changing at a far more rapid pace due to the high availability of renewable resources that could be used on each island.

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## CAPACITY VALUE OF VARIABLE GENERATION AND DEMAND RESPONSE

Accurately assessing the capacity value of variable generation and demand response resources are critical components toward meeting customer demand and maintaining system reliability. Because wind and solar are variable resources, determining its capacity value becomes a considerable challenge in order to achieve the confidence required to include variable generation resources to replace firm generation.

### Capacity Value of Wind Generation

#### *Hawaiian Electric*

The contribution of existing and future wind resources to capacity planning is reflected in the Loss of Load Probability (LOLP) analysis. In the modeling determination of when additional firm capacity may be needed based on the application of Hawaiian Electric's generating system reliability guideline (4.5 years per day), the wind resources' contribution to serving load will be reflected in the LOLP calculations. As such, wind resources' contribution to capacity planning is dependent upon the composition and assumptions in each plan.

#### *Hawai'i Electric Light*

The aggregate value of the two existing wind farms (20.5 MW Tawhiri wind generating facility and 10.56 MW Hawi Renewable Development wind farm) contribution to capacity planning is 3.1 MW.

The capacity value of future wind farms in the PSIP is 10% of the nameplate value of the facility to be added.

#### *Maui Electric*

The aggregate value of the three existing wind farms (20 MW Kaheawa Wind Power I, 21 MW Kaheawa Wind Power II, 21 MW Auwahi Wind Energy) contribution to capacity planning is 2 MW.

The capacity value of future wind farms in the PSIP is 3% of the nameplate value of the facility to be added.

### Capacity Value of Solar Generation

The capacity value of existing and future utility-scale and rooftop PV is 0.

## **N. System Operation and Transparency of Operations**

### Conclusions

#### Capacity Value of Demand Response

The estimated megawatt potential from the Residential and Small Business Direct Load Control Program, Commercial and Industrial Direct Load Control Program, and Customer Firm Generation Programs are included in PISP capacity planning.

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## CONCLUSIONS

The Companies understand the importance of visibility and transparency of the economic commitment and economic dispatch to show the customers that a real effort is being made to reduce the use of fossil fuels and to encourage the use of renewable resources. Creating a website with the same information that RTOs or ISOs use to show price of energy for the market may be misleading if the customer is unaware of the system conditions that is dictating how the generating units are being run. The information that is graphically displayed on the existing Renewable Watch websites is a good starting point for creating visibility and transparency. And the Companies recommend that additional information that is being developed by Blue Planet that displays the system load and the percent of power that each resource group is providing to serve that load also be shown to the customers so that they are able to see over time that less fossil fuel generation is being substituted with less costly generation.

## O. Non-Transmission Alternative Studies

Non-transmission alternatives (NTAs) were evaluated to avoid transmission capital investments. Two transmission studies completed by Hawaiian Electric Transmission Planning Department evaluated as possible solutions to address the need for capacity and avoid construction of new transmission lines and substations for the following system issues:

- Under voltages, thermal overloads and voltage stability on the Central Maui 23KV system due to the retirement of KPP.
- Under voltages and voltage stability in South Maui; and Overloading of distribution substations.

Those two studies comprise this appendix.

## Maalaea-Kamalii Transmission Line Alternatives

Prepared by  
Transmission Planning Division  
System Planning Department  
Hawaiian Electric Company

Original Date: October 16, 2013  
Revision Date: February 20, 2014

TPD #2014-03-Rev1

## Maalaea-Kamalii Transmission Line Alternatives

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## Maalaea-Kamalii Transmission Line Alternatives

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### Revision History

| Revision Number | Date       | Reason   |
|-----------------|------------|--|
| 0               | 10/16/2013 | Original TPD #2013-26  |
| 1               | 2/20/2014  | Updated TPD reference number, TPD #2014-03-Rev1, for reissue in 2014. Further explanations of alternatives and reference documents were added with no substantial changes. |



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## Maalaea-Kamalii Transmission Line Alternatives

### INTRODUCTION

Transmission Planning Division has determined that the Kihei and Wailea substations will have low voltage issues and favorable conditions of possible voltage collapse in the event of an N-1 contingency. An N-1 contingency is when there is a planned or unplanned outage of a transmission facility, such as a transmission line, while all other transmission facilities are still in service. Currently, majority of the South Maui load is served by the Maalaea-Kihei transmission line shown in Figure 1 below. The most severe N-1 contingency occurs with the loss of this line. In the event of losing the Maalaea-Kihei line, low voltage quality at substations in the South Maui area could cause a voltage collapse to occur suddenly. A voltage collapse occurs when the system cannot supply enough reactive power to meet the load demand. This could result in a system network collapse, in other words, an island wide blackout which can take hours to be restored. Possible alternatives were considered to address this issue.

The gross system peak load is forecasted to be 248.9 MW in 2024, the year this study focuses on. The system gross load peaks are shown in Appendix A and do not include demand side management (DSM). At this load level, the South Maui load is approximately 62 MW—25% of the system load.

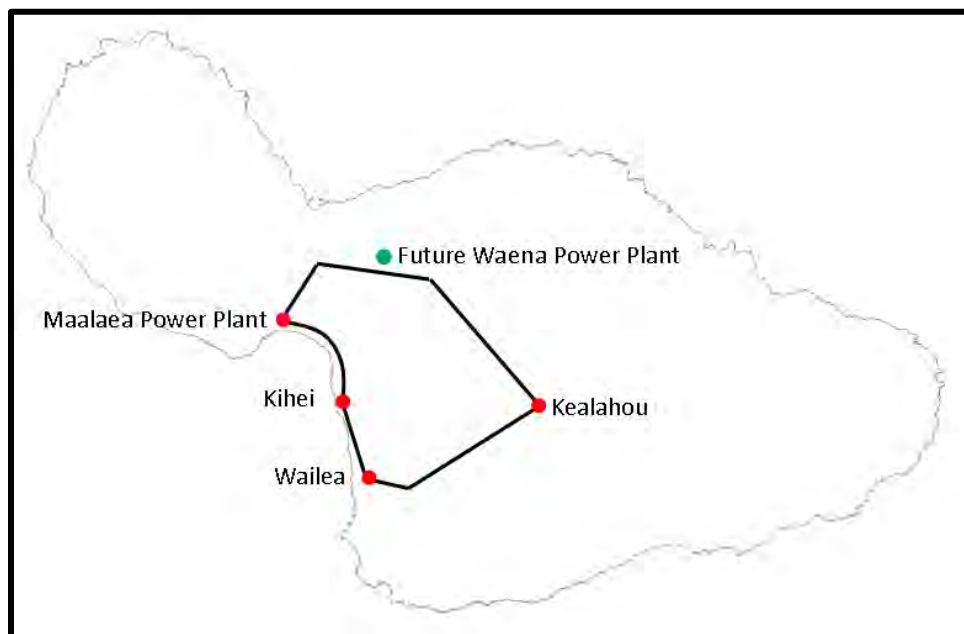


Figure 1: Existing South Maui transmission lines and future Waena Power Plant site

### ASSUMPTIONS

The Siemens PTI Power System Simulator, PSS<sup>®</sup>E, is the program used to study power system transmission networks for steady state and transient conditions. This study uses PSSE powerflow models for the Maui transmission system with following assumptions:

- 2022 peak basecase – Year 2022 model of Maui system at peak load level

- Basecase load scaled uniformly to 248.9 MW—the forecasted load for 2024
- HC&S output—0 MW, end of contract starting January 1, 2015
- Kahului Power Plant retirement starting January 1, 2019
- Conversion of Waiinu-Kanaha 23kV to 69kV in 2018
- Capacitor banks at Kihei—two cap banks at 3.6MVARs each
- Capacitor banks at Wailea—two cap banks at 3.6MVARs each
- Kaheawa Windfarm (KWP) I and II online—with maximum output of 30MW and 21MW respectively
- Auwahi Windfarm—offline (as-available generation)
- Waena Power Plant online with total output of 17 MW (future power plant with a Stage 1 plans have two 8.5 MW internal combustion engines (ICE))
- K1 and K2 available as synchronous condenser—6.25MVARs each

## DISCUSSION

Under the N-1 contingency, voltages drop below 0.90 per unit (pu) and violates Maui Electric Criteria for Transmission Planning, shown in Table 1. N-1 contingencies use emergency conditions when evaluating voltage levels for the planning criteria. These low voltages occur because the system cannot move power from one area to another over the weak transmission lines without incurring major losses. In other words, the generated MWs cannot be transferred through the long and small conductors. This transfer capability depends on the generation, customer demands and system conditions. The system will not be able to meet the load demands of South Maui due to the large amount of power needed. Furthermore, a concern with low voltages is the possibility of a voltage collapse. When a voltage collapse occurs there could possibly be an island wide blackout which may take hours before service can be restored.

The investigation of the low voltages due to transfer capability limits were first address in the *8 Year Transmission Study, 2009-2016, South/Up-Country Maui* report, see Appendix A.

Table 1: Maui Electric Voltage Level Criteria

| Criteria                | Normal Conditions | Emergency Conditions |
|-------------------------|-------------------|----------------------|
| Over voltage violation  | > 1.05 pu         | > 1.05 pu            |
| Under voltage violation | < 0.90 pu         | < 0.90 pu            |

To provide a reliable system, the best option should extend the transfer limits or create a reasonable margin from the transfer limits. Extending the transfer limits can be accomplished by providing a shorter path for power flow under an N-1 condition or reducing the load in South Maui. The following transmission and non-transmission possible solutions are discussed in this study:

- Maalaea-Kamalii line
- Distributed Generation (DG)
- Synchronous Condenser

## Maalaea-Kamalii Transmission Line Alternatives

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- Static Capacitors
- Energy Storage System (ESS)
- Kealahou-Kihei line
- Hybrid (DG & ESS)
- Combined Heat and Power (CHP)
- Load Curtailment
- Demand Response

These alternatives were considered because they could raise the bus voltages in South Maui to meet the planning criteria. This could be accomplished with the installation of new transmission facilities, new reactive devices, or with load reduction.

Transmission facilities will provide a new power flow to the area. During the N-1 contingency the other path to serve the load at Kihei Substation is through the Maalaea-Kealahou line. With this route power must travel a distance of approximately 28 miles to Kihei Substation. To shorten the distance, new transmission lines were considered. Equipment such as the synchronous condenser and static capacitor banks are common devices used for voltage support. These devices provide reactive power and help control voltages at the load. However, during the event of a voltage collapse, these devices become ineffective. The reduction of load in the area could be thru the addition of generation or load shedding. Various power sources such as DG, ESS or CHP was considered as possible generation could be added in South Maui. Load reduction can also be accomplished by shedding load through programs like demand response or with existing under voltage load shedding scheme, installed as an interim solution.

The best solution should extend the transfer limits or allow the system to be a reasonable margin away from the transfer limit. Although some alternatives considered can increase the bus voltages in the area to meet the planning criteria, it cannot provide voltage support during a voltage collapse. If this problem is not addressed a voltage collapse event is possible and would cause a widespread outage.

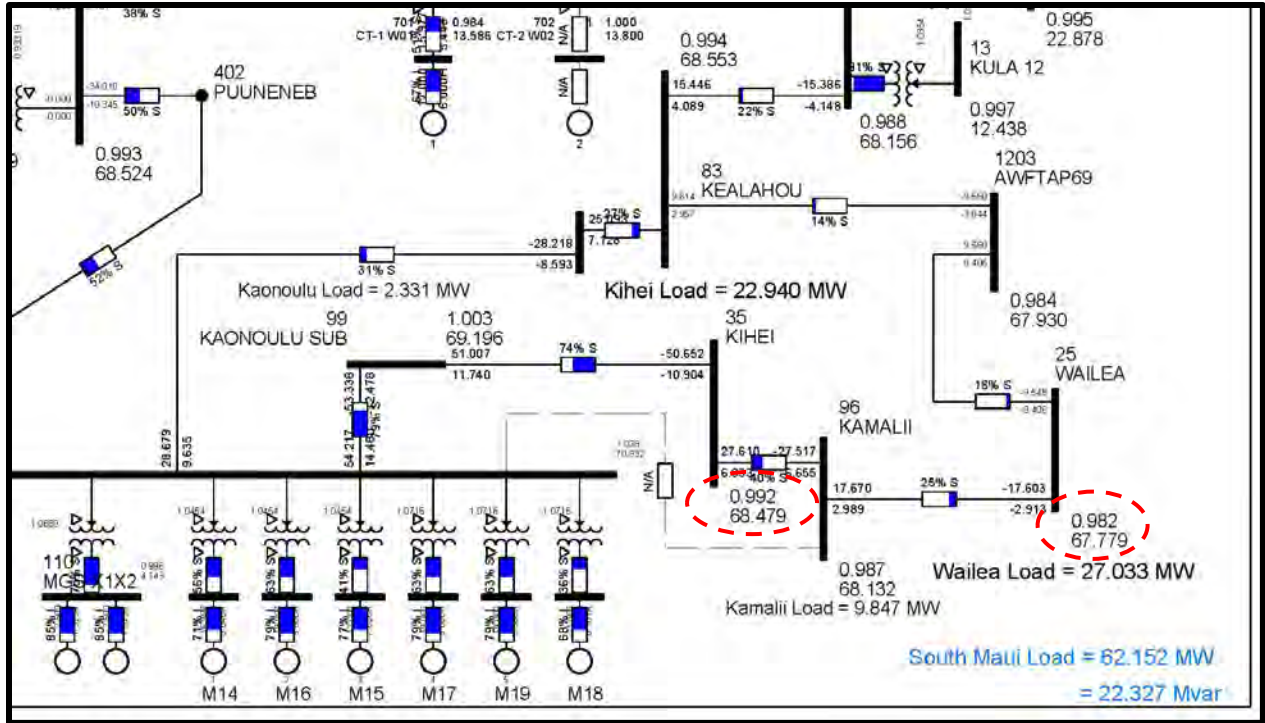


Figure 2: 2024 Normal Conditions

Figure 2 shows 2024 normal conditions without the Maalaea-Kamalii 69kV transmission line. Under normal conditions one capacitor bank at Kihei and one capacitor bank at Wailea are online.

Under the N-1 contingency, voltages drop below 0.90 pu, violating the Transmission Planning criteria, as shown in Figure 3.

## Maalaea-Kamalii Transmission Line Alternatives

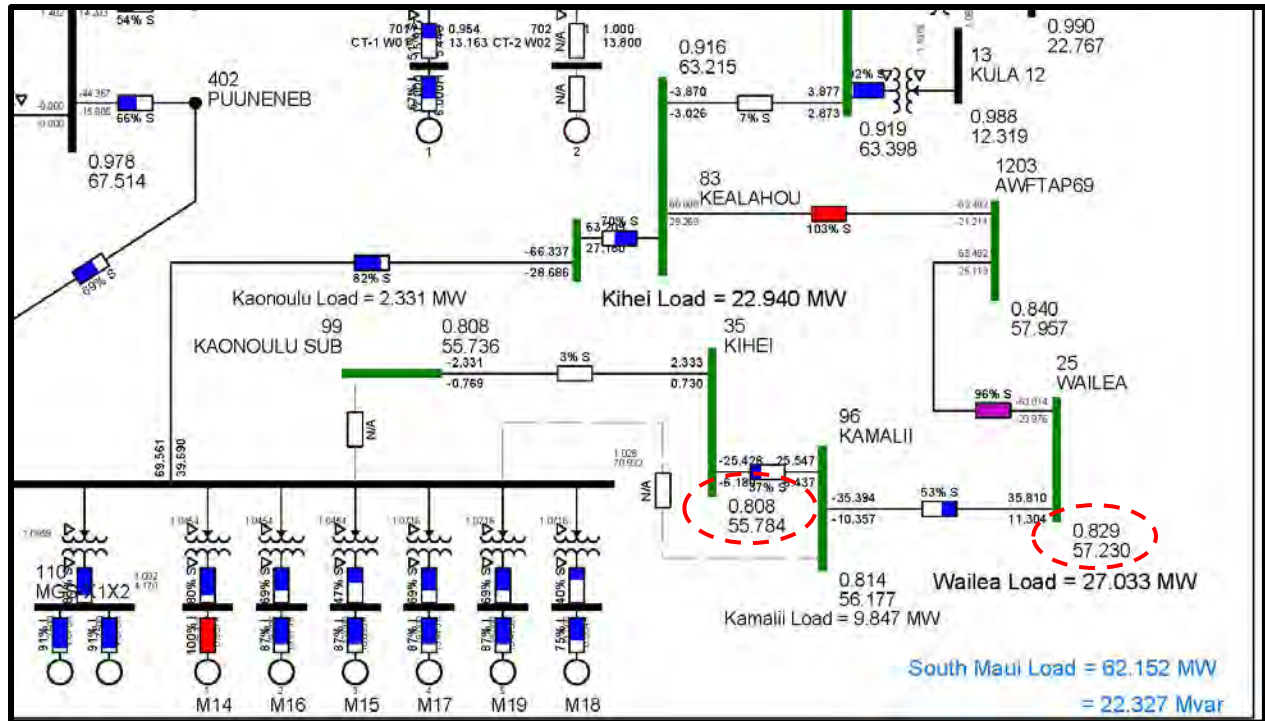


Figure 3: Low voltages under the N-1 contingency of loss of Maalaea-Kihei

### Maalaea-Kamalii Line

Currently the South Maui load is served with four primary transformers at Kihei Substation and four primary transformers at Wailea Substation. To improve the distribution system the construction of two new substations were proposed, the Kaonoulu Substation and Kamalii Substation. The Kamalii substation sited to be midway between Kihei and Wailea Substations, across Kamalii Elementary School along Piilani Highway. Kamalii Substation will use the existing Kihei-Wailea 69kV transmission line to interconnect to the system.

To help extend the power transfer limits, the addition of a new transmission line from Maalaea to Kamalii was considered, shown in Figure 4. With the Maalaea-Kamalii transmission line, under the N-1 contingency the bus voltages are significantly above 0.90 pu. As shown in Figure 5, bus voltages are near the voltages under normal conditions, approximately 0.99 pu. This will reduce the possibility of a voltage collapse.

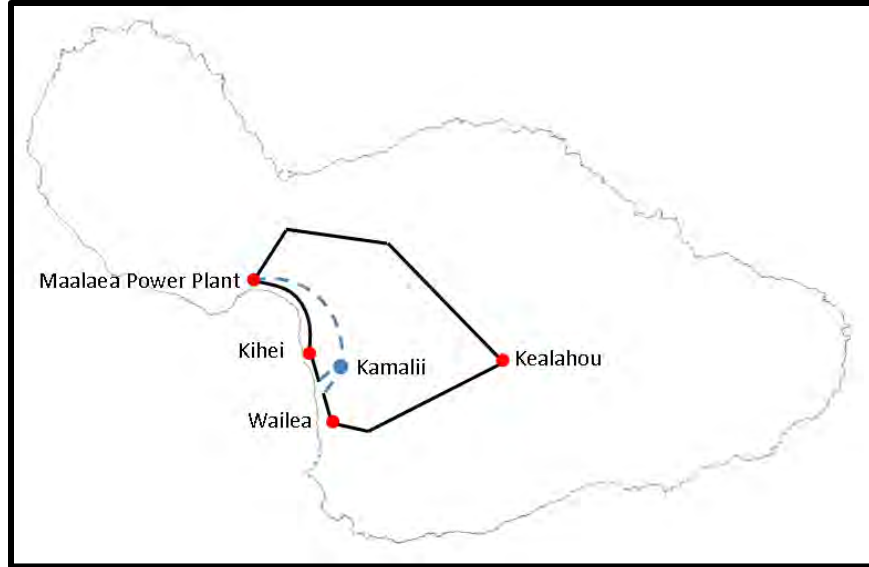


Figure 4: South Maui transmission system with Kamalii Substation and Maalaea-Kamalii 69kV transmission line

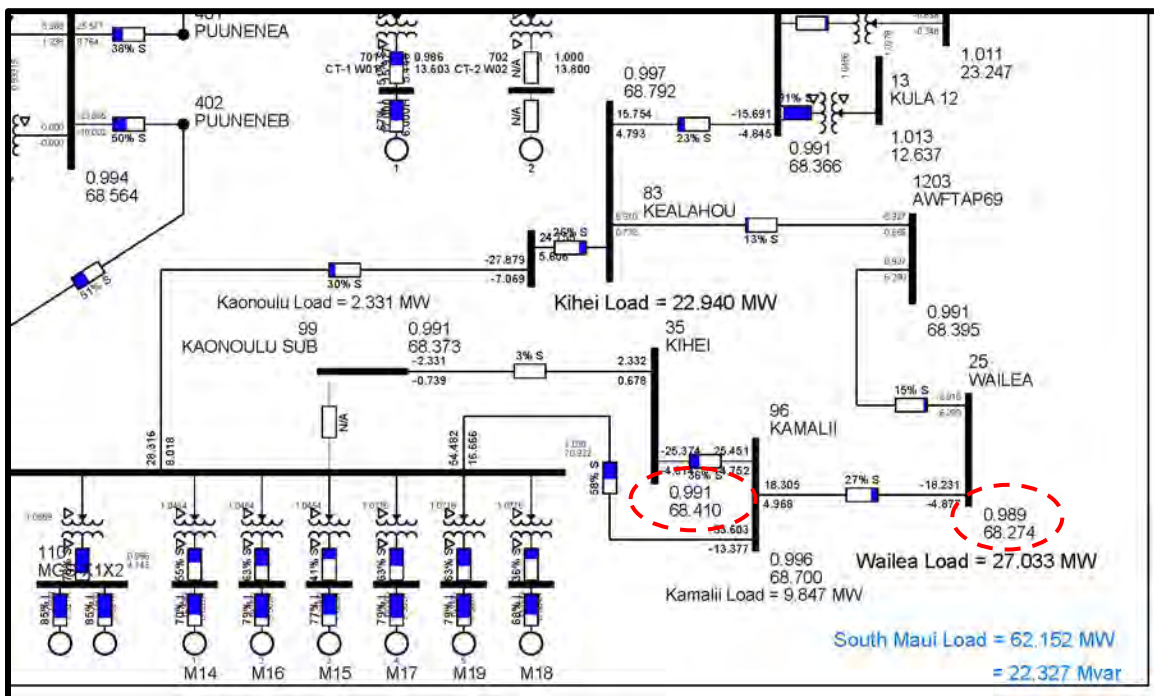


Figure 5: Bus voltages under N-1 contingencies with Maalaea-Kamalii line

### Distributed Generation (DG)

A distributed generation (DG) option was considered as a solution to decrease the load in South Maui create margin away from the transfer limit. Several powerflow simulations were conducted in PSS®E to evaluate various levels of generation added to South Maui. Using the South Maui bus voltages as a guideline a DG unit was modeled at Kihei Substation was viewed

## Maalaea-Kamalii Transmission Line Alternatives

at different levels to increase the bus voltages to a voltage of 0.95 pu, which provides a reasonable margin above the threshold of 0.90 pu. Adding a total of 20MW of DG to South Maui raised the bus voltages to approximately 0.943 pu, shown in Figure 6.

The DG will mainly need to be operated during the N-1 contingency. Currently, an under voltage load shed (UVLS) scheme is in place for various circuits in South Maui and is discussed later in this report. Therefore, the DG can be started after the UVLS to bring the load back online. Considering it could take at least 8 hours to restore the N-1 contingency, the DG would be operated during that time. The 20MW of DG to South Maui does not include redundancy. The daily operation of the DG and any if any redundancy is needed is beyond the scope of this work.

Since there is no space at Kihei Substation the DG can be distributed at various locations South of Kihei Substation. Therefore, with the loss of the Maalaea-Kihei line the DG will still have the ability to reduce the load on the transformers in South Maui. Having DG near residential areas also raise noise and emission concerns, an environmental impact study will need to be conducted to address these issues.

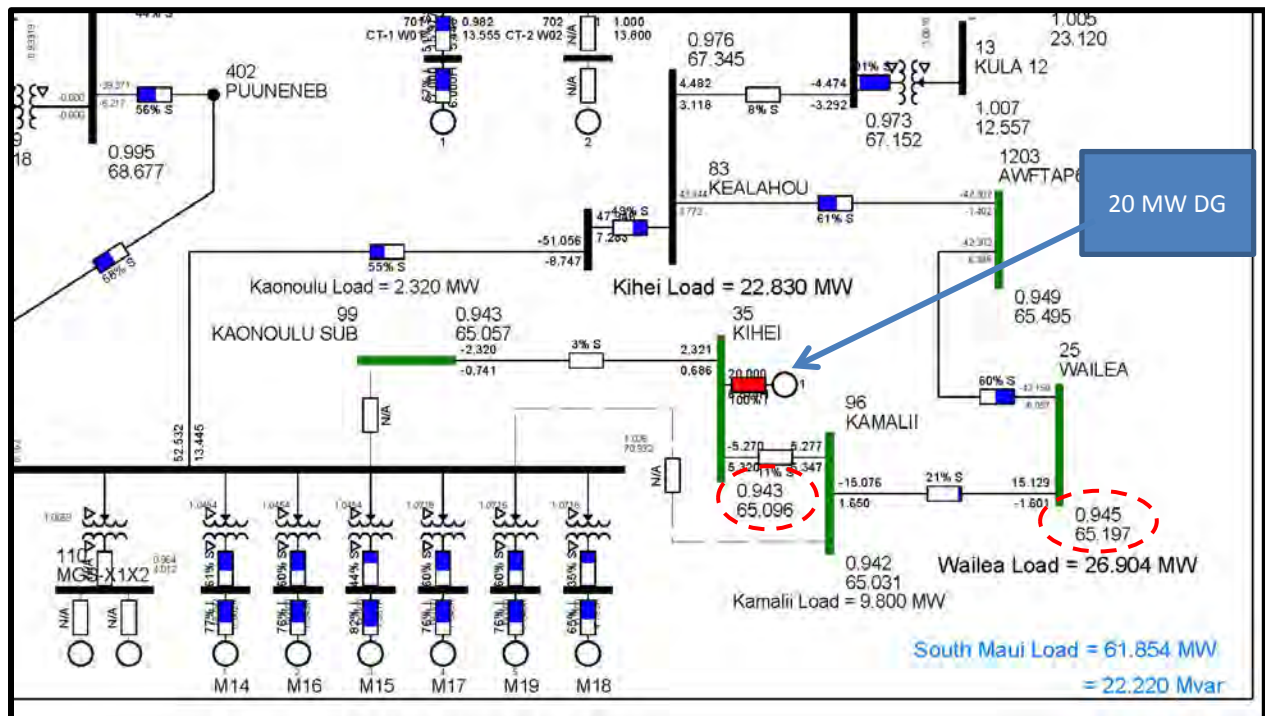


Figure 6: N-1 contingency, loss of Maalaea-Kihei, with a DG alternative



## Synchronous Condenser

A synchronous condenser is a synchronous machine that operates without a prime mover or mechanical load. By controlling the field excitation, it can be used to either absorb or supply reactive power – enabling the capability to control terminal voltage.

A synchronous condenser option is capable of maintaining voltage quality within voltage performance standards as stated in the reliability criteria. A power flow analysis was conducted under the assumption that the K1 and K2 units at Kahului Power Plant, anticipated for deactivation in 2014, will be relocated to South Maui and used as synchronous condensers. This will supply an additional 12.5 MVARs to the system (6.25 MVARs from each unit). Voltage levels will be slightly higher than 0.91 pu under a N-1 contingency, shown in Figure 7. However, a synchronous condenser option will not solve the power transfer limit issues that are present under the N-1 contingency. The possibility of a voltage collapse will still be present.

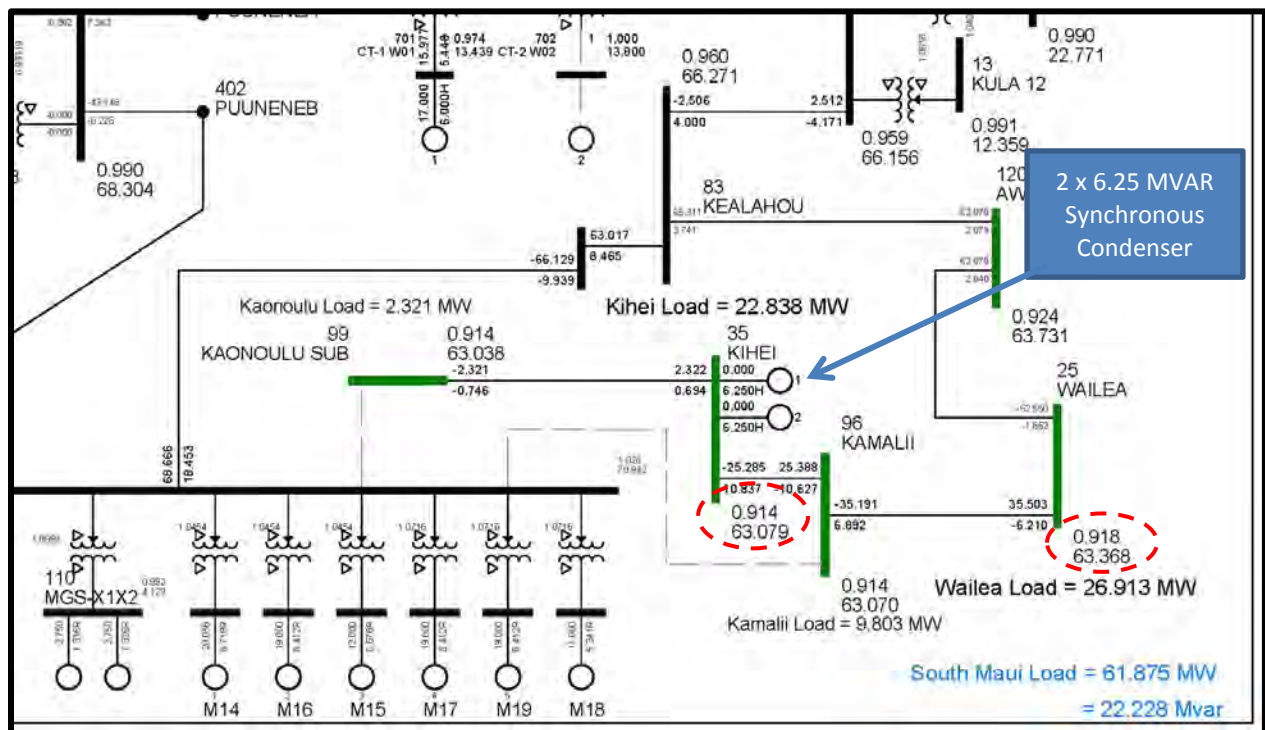


Figure 7: Low voltages with K1 and K2 as synchronous condensers in South Maui

## Static Capacitors

A static capacitor is a device that provides reactive power to a high voltage electricity transmission network. It is an automated impedance matching device (where the generator and load impedance are matched) and is designed to bring the power system as close to unity power factor (1.0) as possible. This is important because a high power factor reduces losses and improves voltage regulation at the load. It is called “static” due to the fact that it has no major moving parts (with the exception of internal switchgear). Static capacitor banks are generally

## Maalaea-Kamalii Transmission Line Alternatives

cheaper, higher-capacity, faster and more reliable than other power factor correction schemes such as synchronous condensers.

Although static capacitors can increase the voltages to meet the planning criteria it will not help the cause of the low voltages—the transfer capabilities. The static capacitors can increase voltages before a voltage collapse; however it will not provide compensation during a voltage collapse. For the reactive power generated by a capacitor, it is proportional to the voltage squared. Thus, when the voltage decreases, the VARS decrease at an exponential rate, making the situation worse.

### Energy Storage System (ESS)

PSSE powerflow simulations were conducted for various MW generation levels to determine the MW needed to raise bus voltages to a reasonable margin above 0.90 pu. With the addition of generation to the area, the possibility of voltage collapse decreases because the system is not at its transfer limits. A 20MW ESS added in South Maui raised bus voltages to 0.943 pu, under the N-1 contingency, as shown below in Figure 8. In anticipation that restoring the line may take at least 8 hours, a 160 MWh ESS would be needed. Similar to the DG, the ESS will need to be interconnected south of Kihei Substation. ESS locations south of Kihei Substation will enable them to have the ability to reduce the load when experiencing an N-1 contingency.

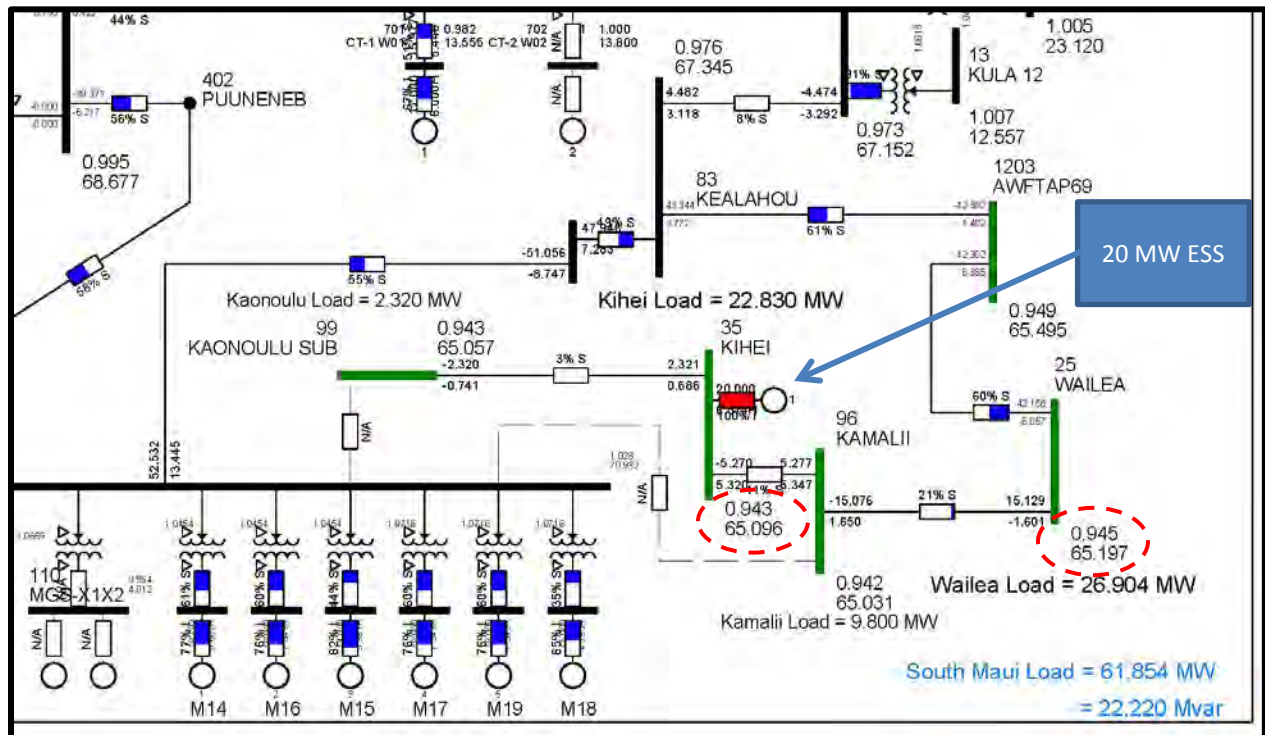


Figure 8: ESS alternative, under N-1 contingency, loss of Maalaea-Kihei

## Hybrid (ESS & DG)

The hybrid of ESS and DG was considered, where the ESS would provide a fast response and will need to serve the load until the DG can be started. Similarly with using the ESS and DG alternatives individually, the hybrid will also require a 20MW ESS and a 20MW DG. The MWhs of the ESS will be dependent on the characteristics of the DG. With a hybrid, the MWhs of the ESS would not need to be 8 hours—the anticipated time to restore the line out. The ESS would only need to serve the load long enough for the DG to be started. A typical start up time of a DG unit is 20 minutes. Therefore, the 20MW ESS will need 6.667MWhs. Similar to the installation of the units individually these units will need to also need to be interconnected south of Kihei Substation. Similar to the DG alternative, an environmental impact study will need to be done due to the noise and emission concerns that arise with DG.

## Combined Heat and Power (CHP)

Combined heat and power (CHP) integrates generating power and recovers the heat for heating or cooling. With the recovery of heat, CHP has fewer emissions compared to DG. This technology is useful for hotels, as it provides a heat source and will therefore reduce costs. CHP is also on-site and will provide quality, economical and reliable power to the hotel load.

Using CHP to reduce the load in the area can help reduce the risk of low voltages under an N-1 contingency. However, a load reduction of 20MW would be needed—no redundancy was assumed. Table 2 shows a list of hotels in South Maui and if there is enough space to accommodate a CHP unit. Further data will need to be gathered for sites that have space for a CHP unit to determine the size of the units that are possible.

Table 2: South Maui Hotels for possible CHP units

| Hotel Name                         | Space for CHP unit |
|------------------------------------|--------------------|
| Four Seasons Resort Maui at Wailea | Yes                |
| Makena Beach & Golf Resort         | Yes                |
| Hotel Wailea                       | Not sure           |
| Wailea Beach Villas                | Not sure           |
| Wailea Beach Marriott Resort & Spa | Yes                |
| Grand Wailea                       | Yes                |
| The Fairmont Kea Lani              | Yes                |
| Andaz Maui at Wailea               | Not sure           |

## Load Curtailment

Currently to avoid a possible voltage collapse, the Kihei and Wailea Substations have an under voltage load shed (UVLS) scheme settings; Table 3 shows the order of the scheme. The UVLS study, see Appendix B, determined a minimum 150MW system load as a threshold for arming the scheme to ensure the local peaking time of South Maui will be included. Under the N-1,

## Maalaea-Kamalii Transmission Line Alternatives

system load may operate near voltage collapse conditions if the system load is greater than 150MW. Therefore, this UVLS scheme has a minimum threshold of system load greater than 150MW to avoid unnecessary load shed.

Customers will need to remain offline until there is no N-1 contingency in effect or if the system load decreases below 150MW. Load curtailment is not intended to defer any system changes or upgrades; it is installed to avoid a whole system collapse.

Table 3: Under Voltage Load Shed Scheme for Kihei and Wailea Substations

| Load Shed Block           | Substation | Unit #  | Feeder #               | Voltage Pick-up |
|---------------------------|------------|---------|------------------------|-----------------|
| 1 <sup>st</sup> load shed | Kihei      | 3       | 1472, 1473             | 0.91 pu         |
| 2 <sup>nd</sup> load shed | Kihei      | 4       | 1515, 1516             | 0.91 pu         |
| 3 <sup>rd</sup> load shed | Kihei      | 1 and 2 | 1253, 1254, 1384, 1385 | 0.91 pu         |
| 4 <sup>th</sup> load shed | Wailea     | 4       | 1517, 1518             | 0.91 pu         |

### Kealahou-Kihei 69kV Transmission Line

The Maalaea-Kealahou line also serves the South Maui load. Due to the long distance to serve power, a new transmission line from Kealahou to Kihei substations was considered to lessen the distance, see Figure 9. The Maalaea-Kealahou line has an approximate distance 15 miles long and the estimated distance for Kealahou-Kihei is 7 miles, for an approximate total distance of 23 miles. The Kealahou-Kihei line will shorten the existing power flow line by 5 miles.

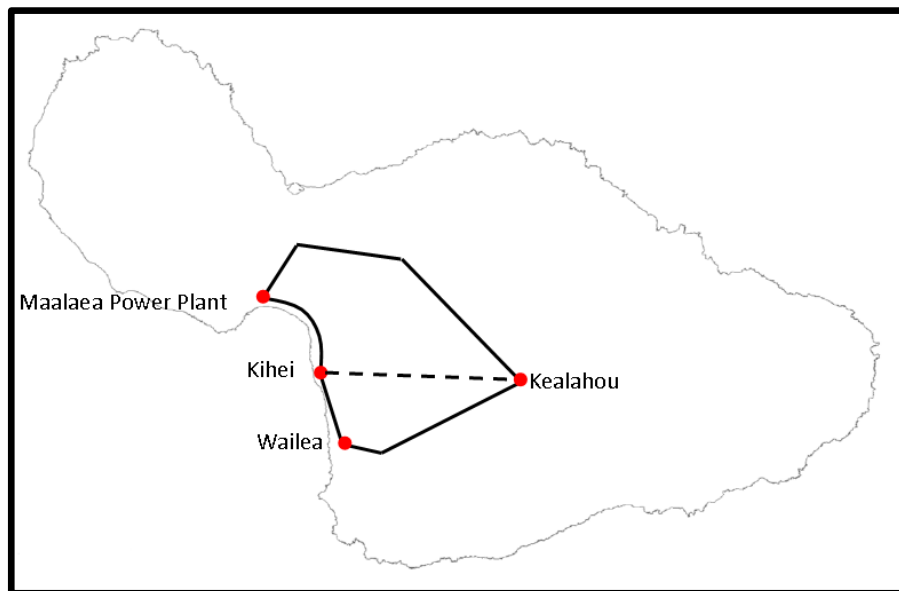


Figure 9: South Maui transmission system with Kamalii Substation and Maalaea-Kamalii 69kV transmission line

A powerflow simulation shows that the installation of a Kealahou-Kihei transmission line, modeled as a 556 AAC, and does not significantly alleviate the low voltage issues in South Maui, as shown in Figure 10. In this case, to raise the voltages to 0.93 pu all capacitor banks in South Maui were needed and no additional support will be available if needed.

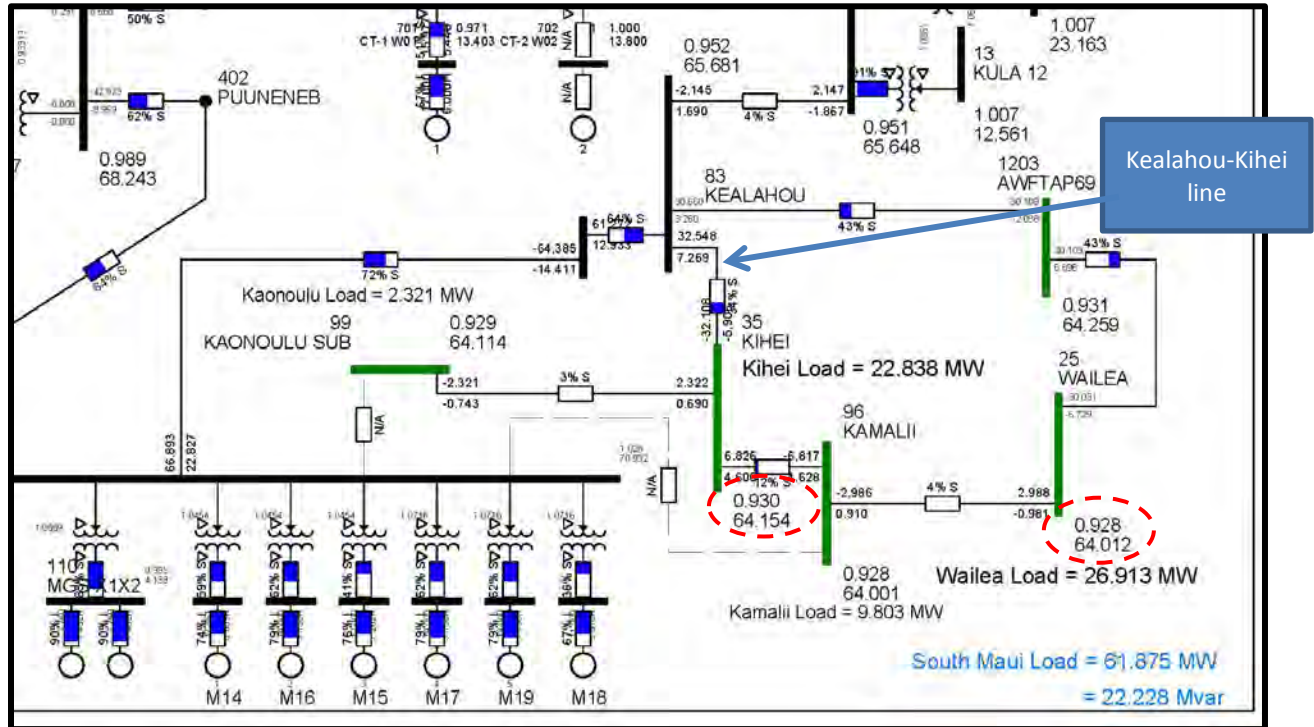


Figure 10: N-1 contingency with Kealahou-Kihei alternative

### Outages

Over the last 5 years, historical data have shown that five unscheduled outages of the Maalaea-Kihei line have occurred. These outages had outage duration times ranging from 0-15 minutes. The duration times during these unscheduled outages have been minimal due to the actions of the load dispatchers or the auto transfer schemes in the area’s substations. Furthermore, the outages did not occur near the system peak time, these outages occurred between 9:00am-3:00pm. The system peak usually occurs around 7:00pm.

Maintenance on the Maalaea-Kihei line over the last 5 years caused the line to be out of service for approximately 60 times. These scheduled outages had durations from 3-12 hours. Proper planning actions were taken in anticipation of these scheduled outages to avoid low voltage issues in South Maui, which includes load shedding.

Fortunately, the scheduled and unscheduled outages had minimum disruption to customers in the last 5 years. As the loads increase the power outages could occur more frequently due to the system operating at the transfer limits. At this point, the addition of loads will decrease

## Maalaea-Kamalii Transmission Line Alternatives

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voltages to a point where the system cannot recover, the voltage collapse. By not addressing the problem, Transmission Planning is also in violation of the transmission planning criteria.

### Demand Response (DR)

With demand response, the program would need to reduce the load South Maui load by at least 20MW. Loads at Kihei and Wailea substations would need to decrease so less power would be transferred to the area. Voltage collapse could occur suddenly under the right conditions; therefore, the DR needs to be able to respond within 10 minutes.

### CONCLUSIONS

Many alternatives were considered to help raise the voltages in South Maui when experiencing an N-1 contingency. However, not all alternatives are viable solutions. Although some alternatives are able to increase voltages to meet the planning criteria for transmission planning, shown in Table 4, not all alternatives can allow the system to operate away from the power transfer limits. These alternatives that were not viable solutions, such as the synchronous condenser and static capacitor, were removed from further consideration. Alternatives that were considered technically viable will need to be economically evaluated.

Table 4: Kihei and Wailea Substations bus voltages

| Scenario  | Kihei (69kV) | Wailea (69kv) |
|---|--------------|---------------|
| 2024 Normal Conditions  | 0.992 pu     | 0.982 pu      |
| N-1 Contingency   | 0.808 pu     | 0.829 pu      |
| Maalaea-Kamalii line with N-1 Contingency                                   | 0.991 pu     | 0.989 pu      |
| Distributed Generation alternative with N-1 Contingency                     | 0.943 pu     | 0.945 pu      |
| Synchronous Condenser alternative with N-1 Contingency                      | 0.914 pu     | 0.918 pu      |
| Energy Storage System alternative with N-1 Contingency                      | 0.943 pu     | 0.945 pu      |
| Kealahou-Kihei line alternative with N-1 Contingency                        | 0.930 pu     | 0.928 pu      |
| N-1 Contingency—outage of Maalaea-Kihei 69kV transmission line              |              |               |
| Green highlight = under voltage violations                                  |              |               |
| Orange highlight= meet voltage criteria but low voltages that cause concern |              |               |

**APPENDIX A**

*8 Year Transmission Study, 2009-2016, South/Up-Country Maui*

## Maalaea-Kamalii Transmission Line Alternatives

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### INTEROFFICE CORRESPONDENCE


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Hawaiian Electric Co., Inc.

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August 6, 2010

To: Chris Reynolds  
From: Marc Matsuura   
Subject: MECO 8 Year Transmission Study, 2009-2016, South/Up-country Maui

Attached is a copy of the MECO 8 Year Transmission Study, 2009-2016, South/Up-country Maui final report. The report recommends a new 69 kV line to be installed from Maalaea Power Plant to the South Maui area via the Kamalii substation. This report also recognizes that if this solution cannot be applied in the near future, an Undervoltage Load Shedding scheme should be used as an interim solution. If you have any questions, please contact Tammy Okubo at ext. 7286 or Gemini Yau at ext. 7888.

#### Attachment

cc: D. Park  
F. Oshiro  
R. Jung  
R. Tamayo  
S. Sano  
Engineering Library  
File





Maui Electric Company (MECO)

**8 YEAR TRANSMISSION STUDY  
2009-2016  
SOUTH/UP-COUNTRY MAUI**

Prepared by  
System Integration Department  
Transmission Planning Division  
Hawaiian Electric Company, Inc.

April 2010

## Maalaea-Kamalii Transmission Line Alternatives

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### Executive Summary:

This study discusses the low voltage problems at Kihei and Wailea with the N-1 condition from Maalaea Generating Station (MGS) to Kihei. The N-1 condition is when there is a single line out contingency while the rest of the lines are all in service. For the purposes of this study, the N-1 condition is for the line out from MGS to Kihei unless specified otherwise. With the N-1 case, voltage levels at Kihei and Wailea were below the accepted 0.90 p.u. for 2009 and throughout the duration of the study, which is in violation of MECO transmission planning criteria. More importantly, these areas of low voltage can also result in a voltage collapse situation, which is also discussed in this study.

Three alternatives were considered to address the planning criteria violations. The first alternative considered was to re-conductor the MGS-Kihei-Wailea-Kealahou line, (referred to as the South Maui line). Re-conducting the South Maui line makes no significant improvement to voltage conditions during an outage of the MGS to Kihei line. Re-conducting the South Maui line will only raise the voltage at Kihei and Wailea by about 0.02 p.u.

The second alternative considered was to add 3.6 MVARs of capacitors at Kihei Substation for a total of 10.8 MVARs. The addition of the capacitor banks would boost voltages only slightly above 0.90 p.u. With the capacitor banks, there is still a significant possibility of a voltage collapse situation.

The third alternative considered was to build an additional 69 kV transmission line from MGS to the Kihei-Wailea service area, terminating at the new Kamalii Substation. The additional line maintains a transmission connection to the Kihei-Wailea service area in the event of the loss of the 69kV MGS to Kihei line and keeps voltages at Kihei and Wailea well above the 0.90 p.u. standard throughout the study period. Of the three solutions, the new line provides the best answer for the voltage collapse situation.

It is recommended that this line is installed as soon as possible due to the fact that the latest load flow analysis shows that the current system conditions hold the potential of the low voltages at Kihei and Wailea as well as a possible voltage collapse with the loss of the MGS to Kihei 69kV line.

## Maalaea-Kamalii Transmission Line Alternatives

### Problem Overview:

There are possible low voltage conditions that exist for the N-1 contingency with the loss of the MGS (39) to Kihei (35) line. This study will evaluate those low voltage conditions as well as evaluate the possible voltage collapse situations that are a result of the low voltage levels.

#### a. Low Voltage:

With current system conditions in the South/Up-Country Maui area, low voltages are anticipated at Kihei (35) and Wailea (25) Substations with the outage of the MGS-Kihei 69kV line. With the loss of the MGS-Kihei 69kV line, the voltage at Kihei will drop from 0.9947 p.u. to 0.8543 p.u. and the voltage will drop at Wailea from 0.9853 p.u. to 0.8709 p.u., as shown in Table 1.

| Year | Projected System Peak Loading (MW) | Kihei (35) Voltage (p.u.) |                          | Wailea (25) Voltage (p.u.) |                          |
|------|------------------------------------|---------------------------|--------------------------|----------------------------|--------------------------|
|      |                                    | Normal Condition          | N-1, MGS-Kihei 69kV line | Normal Condition           | N-1, MGS-Kihei 69kV line |
| 2009 | 201.2 (actual)                     | 0.9947                    | 0.8543                   | 0.9853                     | 0.8709                   |
| 2010 | 187.9                              | 0.9976                    | 0.8757                   | 0.9893                     | 0.8903                   |
| 2011 | 189.1                              | 0.9974                    | 0.8742                   | 0.9890                     | 0.8890                   |
| 2012 | 190.0                              | 0.9973                    | 0.8732                   | 0.9888                     | 0.8880                   |
| 2013 | 191.1                              | 0.9971                    | 0.8717                   | 0.9885                     | 0.8867                   |
| 2014 | 192.5                              | 0.9968                    | 0.8700                   | 0.9882                     | 0.8851                   |
| 2015 | 194.4                              | 0.9965                    | 0.8674                   | 0.9877                     | 0.8828                   |
| 2016 | 196.7                              | 0.9960                    | 0.8645                   | 0.9871                     | 0.8801                   |

Table 1: Normal vs. N-1 (MGS-Kihei) Conditions at Kihei (35) and Wailea (25)

The projected system peak loads typically occur during the months of October, November, and December.

#### b. Voltage Collapse:

A serious consequence of low voltages that currently exists is the possibility of a system wide voltage collapse situation. During system peak conditions, all transmission lines in service, and Kihei (35) as the control bus, there are only approximately 35 MVARs left before the start of a voltage collapse situation, as shown by the QV analysis in Figure 1, and it may start with voltages as high as 0.96 p.u. This means that the system can only handle the addition of 35 more MVARs before the system may start to collapse. Figure 1 also shows the amount of MVARs left drops to approximately 9 MVARs when there is an outage of the MGS-Kihei 69 kV line. The addition of reactive power can occur not only with the addition of loads but also during the transient of a system

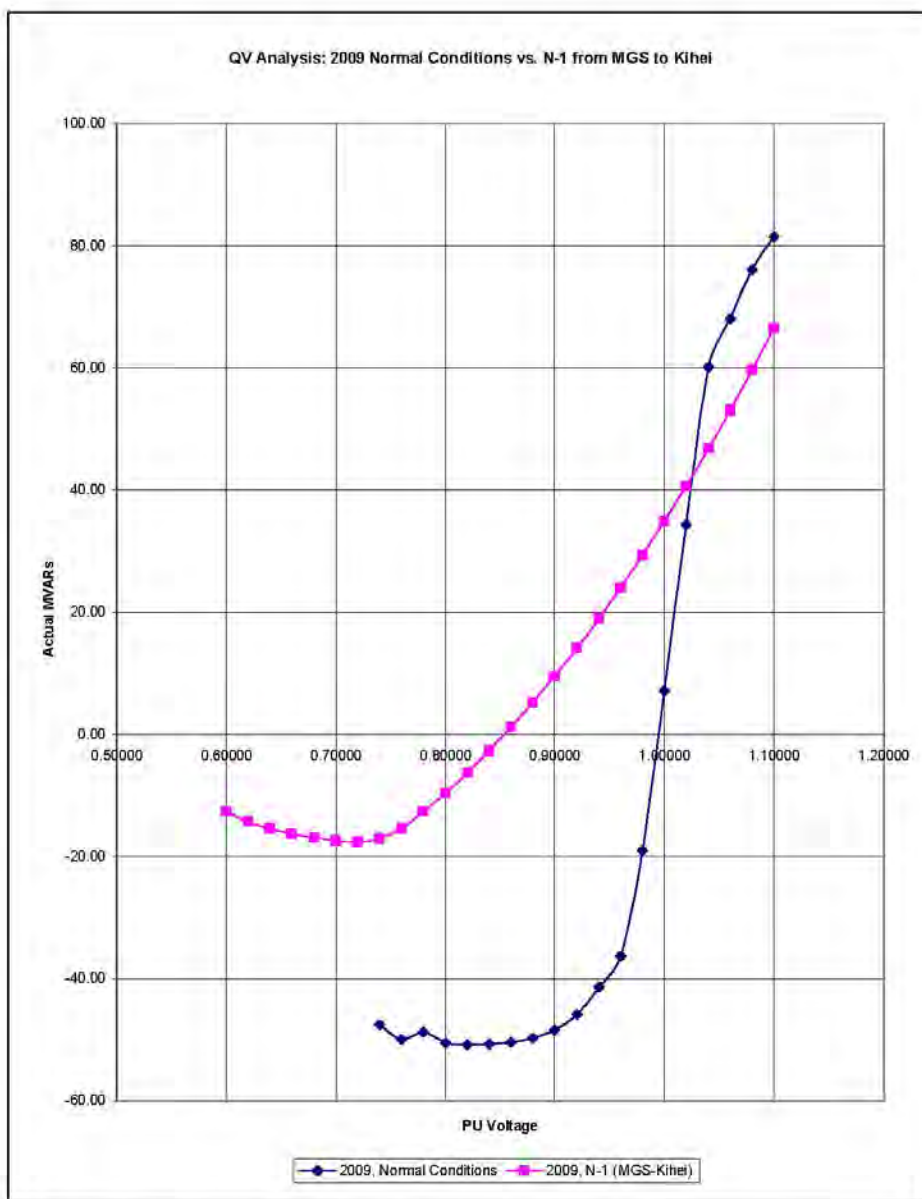


Figure 1: 2009, Normal vs. N-1 (MGS-Kihei) Voltage Collapse Analysis

## Maalaea-Kamalii Transmission Line Alternatives

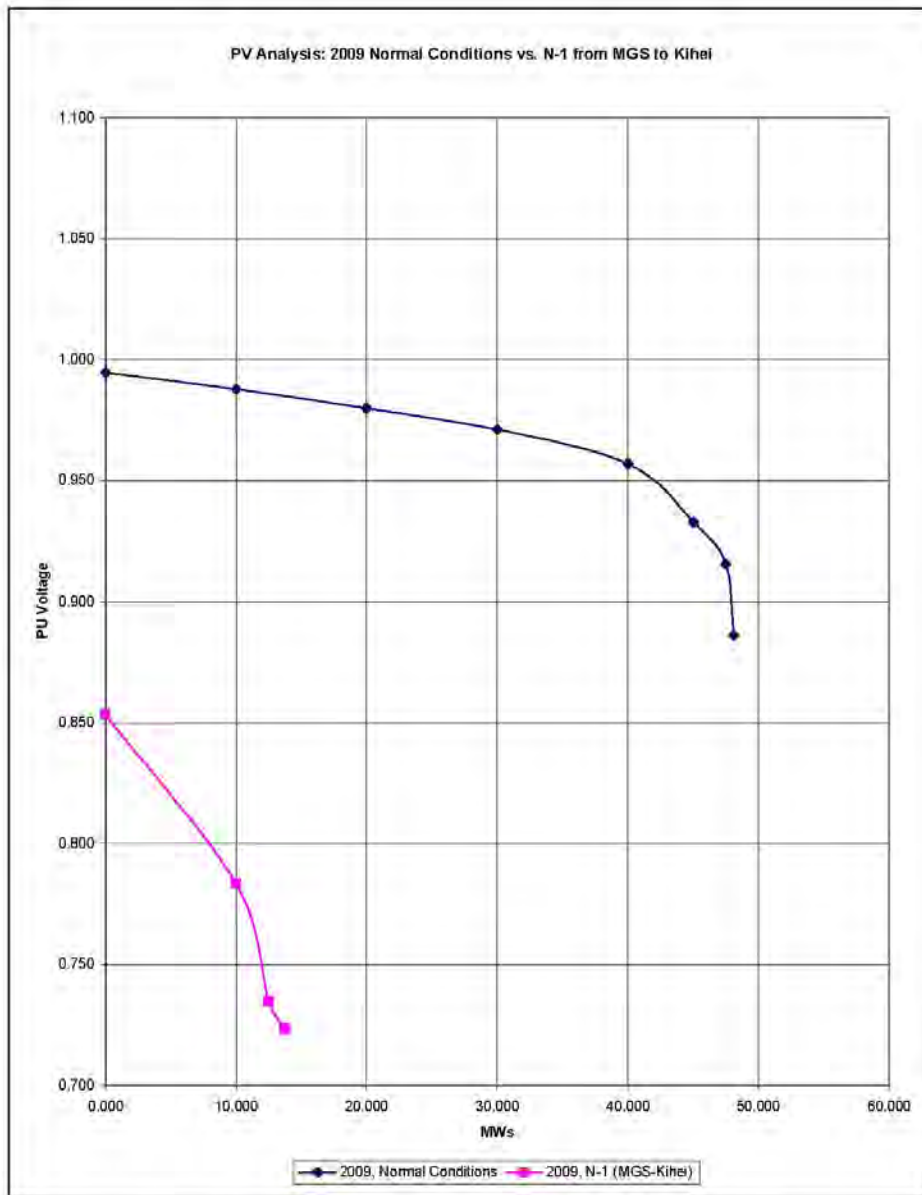


Figure 2: PV Analysis, 2009 Normal Conditions vs. N-1 (MGS-Kihei)

disturbance such as the loss of the MGS (39) to Kealahou (83) line. Also notice that with the N-1 case, at 0 MVAR, meaning at current conditions with no additional loading or compensation, the voltage is already as low as 0.85 p.u.

Figure 2 shows the PV analysis comparing normal conditions to the case where we lose the line between MGS (39) and Kihei (35). Normal conditions show that the system can handle an additional 40 MW of bus load with dropping voltage to only 0.96 p.u. However, the N-1 condition (with current bus loading conditions) already starts at 0.85 p.u. voltage and cannot handle more than 10 MWs before the voltage starts to collapse.

#### Alternatives:

Three alternatives considered are a) re-conductoring lines, b) adding capacitor banks to help boost low voltages, and c) add another line from MGS (39) to a new substation at Kamalii (96).

##### a. Re-conductoring:

The first alternative considered was to re-conductor the existing 336 AAC line with 556 AAC for the South Maui line, between MGS-Kihei-Wailea-Kealahou line (shown as the bolded sections of line in the diagram below). This study found that re-conductoring provides little improvement to the low voltage problems. With the new conductors, during the N-1 condition for the loss of the MGS (39) to Kihei (35) line, the voltages at Kihei (35) and Wailea (25) are raised by approximately 0.02 p.u. For the N-1 case in 2009, re-conductoring boosts Wailea (25) to 0.8883 p.u. and Kihei (35) to 0.8769 p.u. which is still not within the acceptable range. The re-conductoring also provides little improvement to the voltage collapse possibility. As seen in Figure 4, the 556 AAC conductor case follows closely to the curve of the 336 AAC conductor case. With the loss of the MGS (39) to Kihei (35) line, the new conductors only add approximately 4 MVAR at the most before the possibility of a voltage collapse situation.

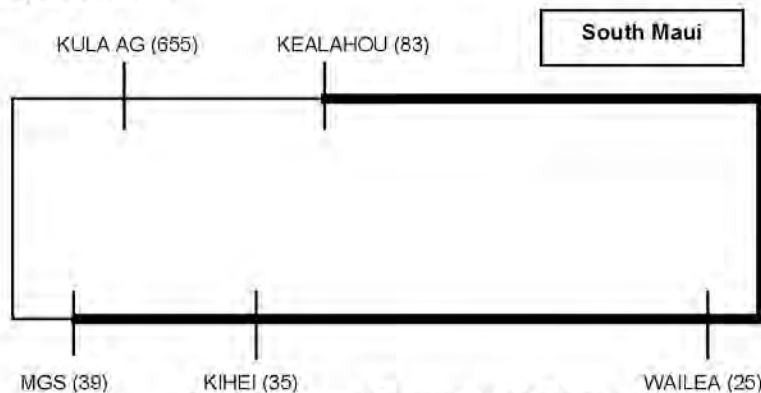
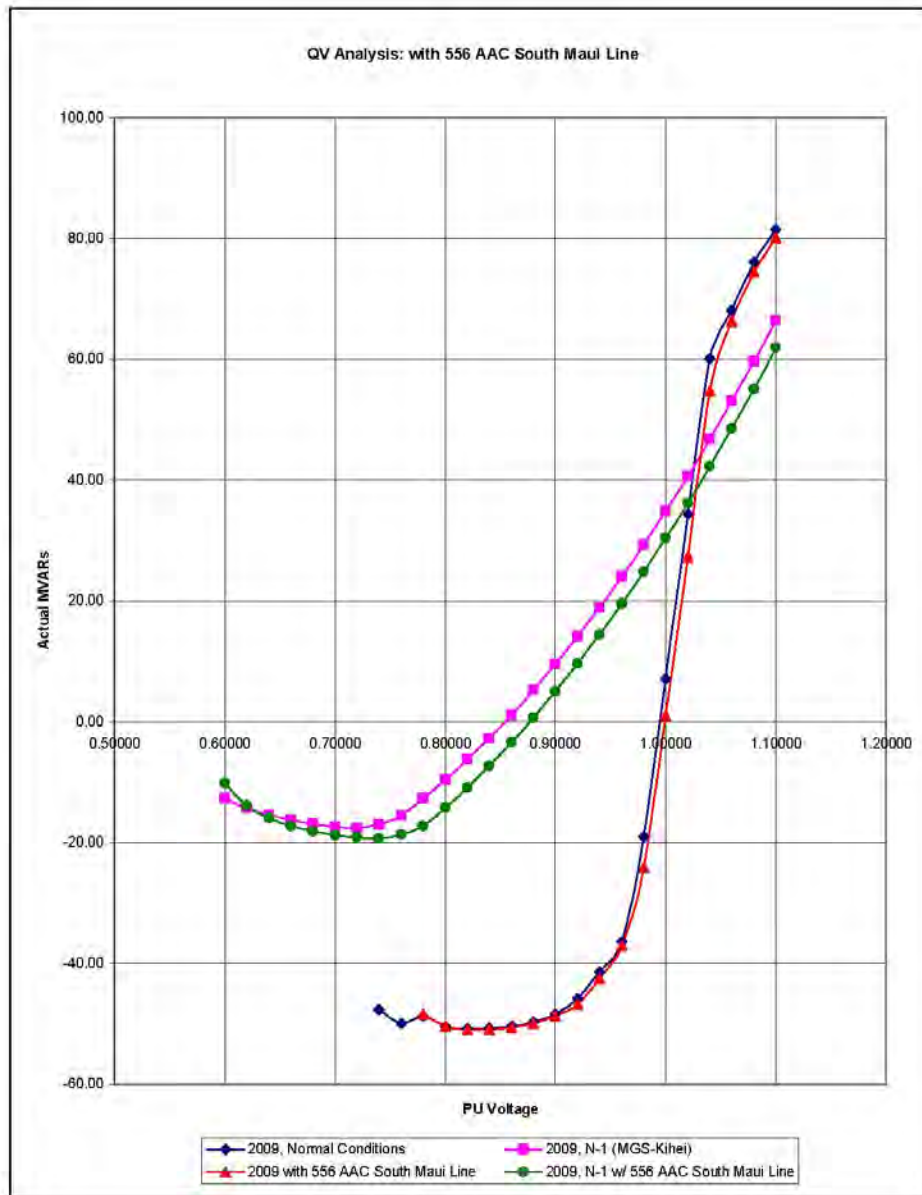


Figure 3: Proposed Re-conducted Section

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 4: With 556 AAC South Maui Line**



## b. Capacitor Banks:

Assuming that the 3.6 MVAR capacitor bank at Kihei A (35-1) is on during peak conditions, it would take turning on the existing 3.6 MVAR capacitor bank at Kihei B (35-2) and the installation of another 3.6 MVAR capacitor bank at Kihei C (35-3) to boost voltage levels at Kihei (35) and Wailea (25) above 0.90 p.u. This solution will only keep voltages slightly above an acceptable level shown below in Table 2.

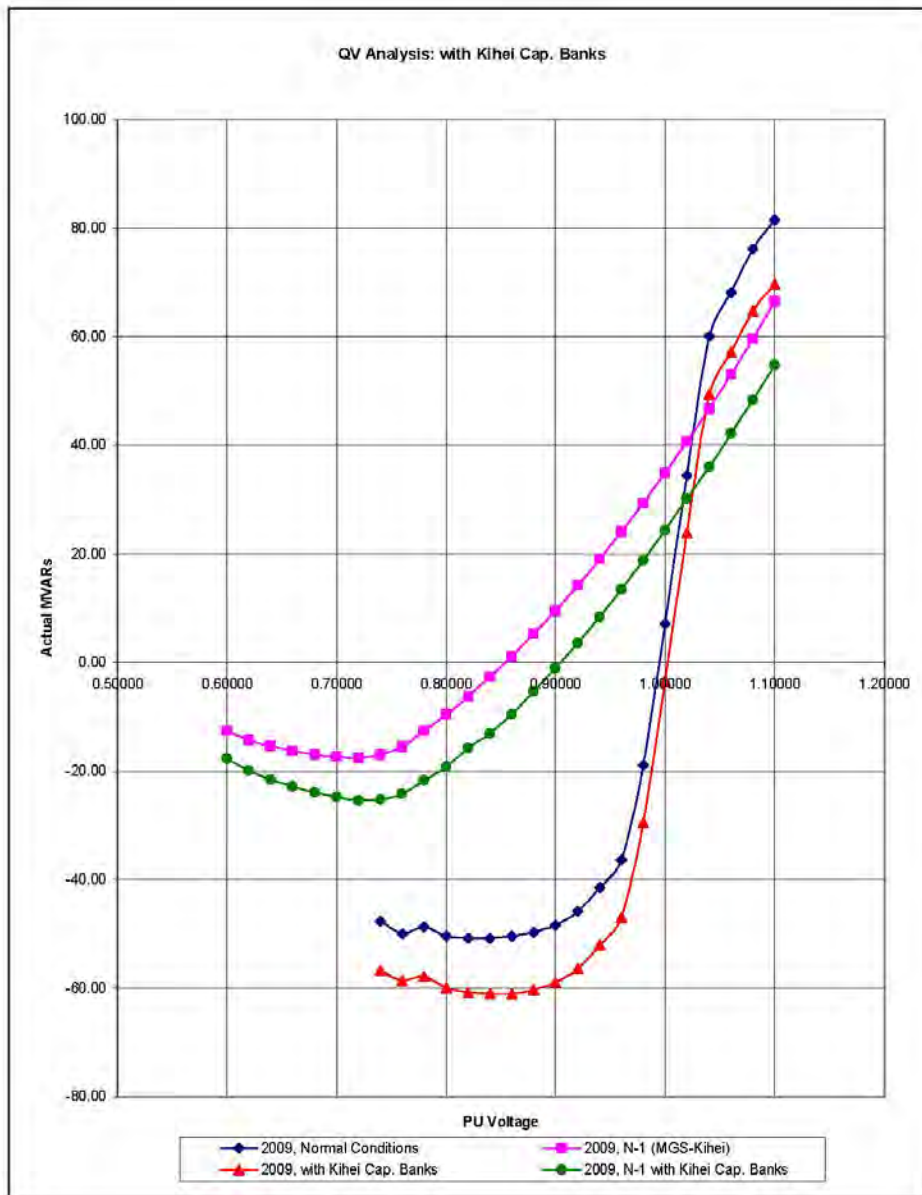
| Year | Kihei (35) Voltage (p.u.)   |                                 | Wailea (25) Voltage (p.u.)  |                                 |
|------|-----------------------------|---------------------------------|-----------------------------|---------------------------------|
|      | N-1, MGS-Kihei<br>69kV line | N-1, MGS-Kihei<br>w/ Cap. Banks | N-1, MGS-Kihei<br>69kV line | N-1, MGS-Kihei<br>w/ Cap. Banks |
| 2009 | 0.8543                      | 0.9055                          | 0.8709                      | 0.9122                          |
| 2010 | 0.8757                      | 0.9242                          | 0.8903                      | 0.9293                          |
| 2011 | 0.8742                      | 0.9227                          | 0.8890                      | 0.9280                          |
| 2012 | 0.8732                      | 0.9216                          | 0.8880                      | 0.9270                          |
| 2013 | 0.8717                      | 0.9209                          | 0.8867                      | 0.9262                          |
| 2014 | 0.8700                      | 0.9192                          | 0.8851                      | 0.9247                          |
| 2015 | 0.8674                      | 0.9169                          | 0.8828                      | 0.9226                          |
| 2016 | 0.8645                      | 0.9146                          | 0.8801                      | 0.9205                          |

Table 2: Kihei (35) and Wailea (25) Voltages for N-1 (MGS-Kihei) w/ Capacitor Banks

The addition of the capacitor bank at Kihei will increase the amount of MVAR left before a voltage collapse situation by approximately 10 MVAR, shown below in Figure 5. However, with a capacitor,  $Q=V^2Y$ , so as the voltage decreases, the amount of VARs that it can provide will decrease at a quadratic rate. Therefore, the capacitors will provide less and less compensation during a voltage collapse situation, making the situation progressively worse.

Assuming that the 3.60 MVAR capacitor bank at Kihei A (35-1) is on, modeling a synchronous condenser at Kihei C (35-3) shows that in order to maintain a voltage of 0.90 p.u. at Kihei (35) for the N-1 condition (MGS-Kihei) in 2009, would require an additional 6.0552 MVAR from capacitor banks. The system would require 20.5297 MVAR of capacitor banks at Kihei C (35-3) to maintain a voltage of 0.95 p.u. at Kihei (35) and 39.5483 MVAR to maintain a voltage of 1.0 p.u.

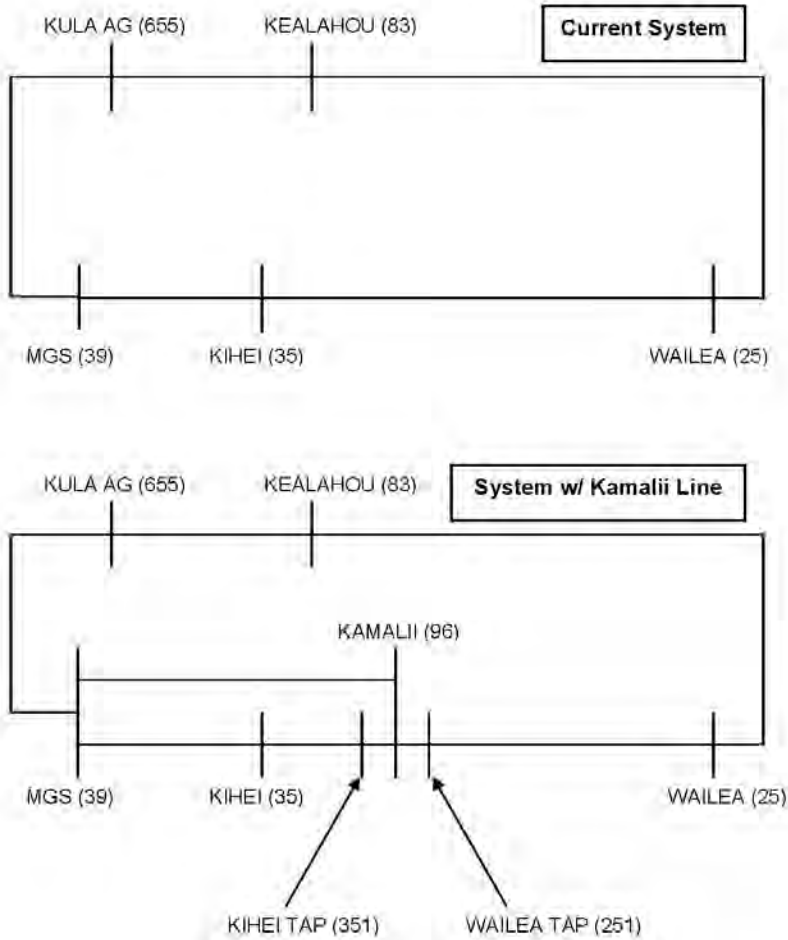
## Maalaea-Kamalii Transmission Line Alternatives



**Figure 5: 2009, with Additional Cap. Banks at Kihei**

- c. Install a new transmission line from MGS to the new Kamalii Substation:

The addition of a new line from MGS (39) to the Kihei (35) and Wailea (25) area would include the addition of the Kamalii (96) Substation as shown below in Figure 6:



**Figure 6: Current System vs. System w/ Kamalii Substation**

## Maalaea-Kamalii Transmission Line Alternatives

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By adding the second line to Kamalii (96), the voltage levels at Kihei (35) and Wailea (25) will remain significantly above 0.90 p.u. through the year 2016.

Table 3 shows the voltage levels at Kihei (35) and Wailea (25) with a second line during an N-1 condition from MGS (39) to Kihei (35).

| Year | Kihei (35) Voltage (p.u.)   |                                   | Wailea (25) Voltage (p.u.)  |                                   |
|------|-----------------------------|-----------------------------------|-----------------------------|-----------------------------------|
|      | N-1, MGS-Kihei<br>69kV line | N-1, MGS-Kihei<br>w/ Kamalii Sub. | N-1, MGS-Kihei<br>69kV line | N-1, MGS-Kihei<br>w/ Kamalii Sub. |
| 2009 | 0.8543                      | 0.9893                            | 0.8709                      | 0.9878                            |
| 2010 | 0.8757                      | 0.9929                            | 0.8903                      | 0.9916                            |
| 2011 | 0.8742                      | 0.9926                            | 0.8890                      | 0.9914                            |
| 2012 | 0.8732                      | 0.9924                            | 0.8880                      | 0.9911                            |
| 2013 | 0.8717                      | 0.9922                            | 0.8867                      | 0.9909                            |
| 2014 | 0.8700                      | 0.9919                            | 0.8851                      | 0.9906                            |
| 2015 | 0.8674                      | 0.9915                            | 0.8828                      | 0.9901                            |
| 2016 | 0.8645                      | 0.9910                            | 0.8801                      | 0.9896                            |

**Table 3: Kihei (35) and Wailea (25) Voltages for N-1 (MGS-Kihei) w/ Kamalii Substation**

The additional line will also reduce the possibility of a voltage collapse situation by increasing the amount of MVARs that are left before the start of a collapse as shown in Figure 7. Figure 7 shows that with the second line to the Kamalii (96) Substation, even with an N-1 condition from MGS (39) to Kihei (35), there is only a small decrease of MVARs. This still leaves approximately 33 MVARs before a voltage collapse situation.

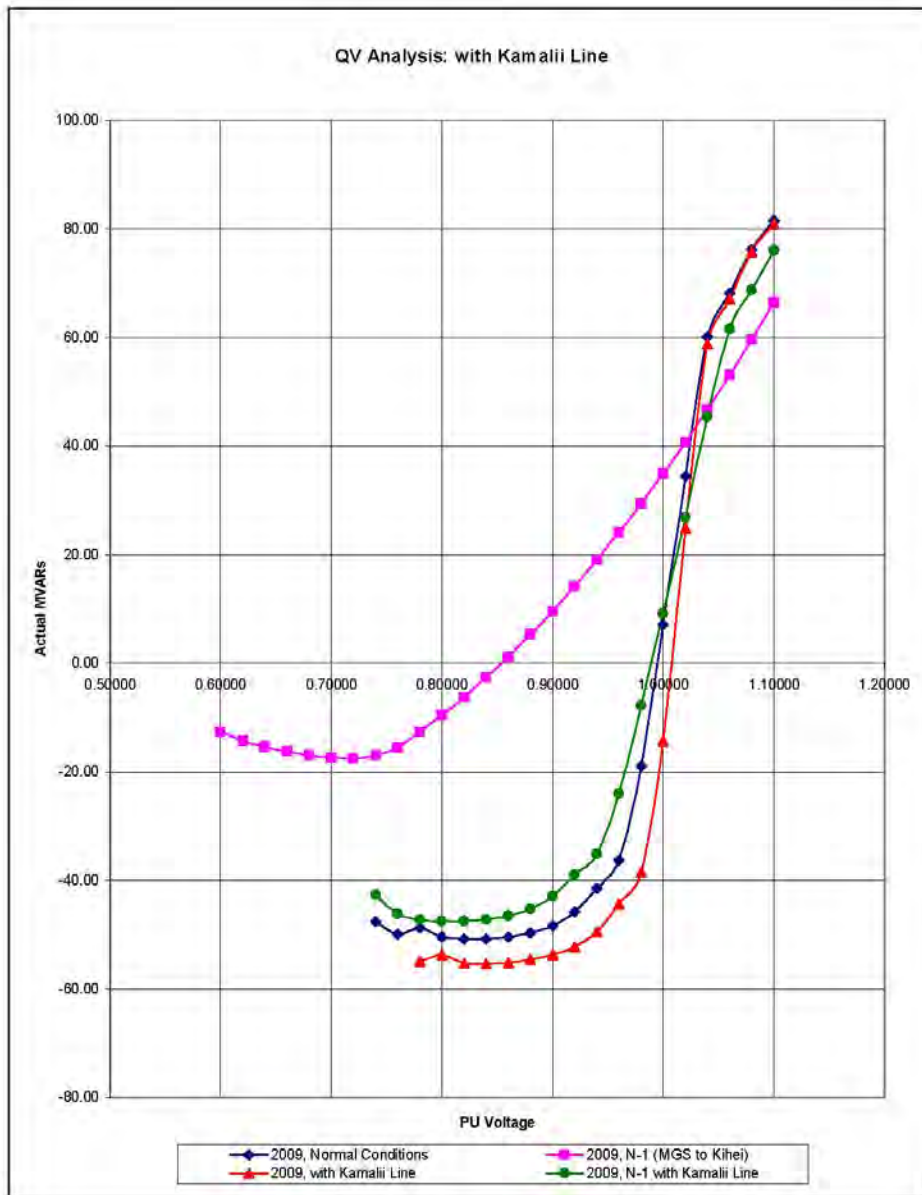


Figure 7: 2009, with Kamalii Line

## Maalaea-Kamalii Transmission Line Alternatives

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### Alternative Comparison:

With an N-1 contingency from MGS (39) to Kihei (35), and a total of 10.8 MVAR compensation by capacitor banks at Kihei, the voltage levels at Kihei and Wailea are maintained only slightly above 0.90 p.u. A second line through Kamalii (96) will maintain voltage levels at Kihei (35) and Wailea (25) above 0.985 p.u. at least through the end of this study period, 2016. The Kamalii (96) line will also aid in maintaining voltages at Kihei (35) and Wailea (25) during N-1 contingencies from MGS (39) to Kealahou (83) and from MGS (39) to Puunene (402). These results are listed in Appendix A. Building a second line is essentially avoiding the currently possible N-1 condition.

When comparing the voltage collapse analysis, the line to Kamalii (96) almost doubles the amount of MVAR that is left before the system would go into a voltage collapse situation shown in Figures 8, 10, and 12 for 2009, 2012, and 2016 respectively. As time goes on, the Kamalii line is the only alternative that can maintain the voltage considerably above 0.90 p.u. and handle more MVAR loading.

The comparison of the PV analysis shown in Figures 9, 11, and 13 for 2009, 2012, and 2016, respectively, also shows that the Kamalii line provides the best solution since it can handle significantly more MW loading while staying well above 0.90 p.u. voltage levels.

As discussed previously, to re-conductor the South Maui line is not a viable alternative because it provides no significant improvements to the low voltage problems, nor does it help with the possible voltage collapse situations.

Therefore, the proposed solution would be a second line from MGS (39) to the Kihei - Wailea service area via a new substation in Kamalii (96). Figures 8-13, illustrate the value of the line through Kamalii (96) versus the rest of the alternatives using PV and QV analysis.

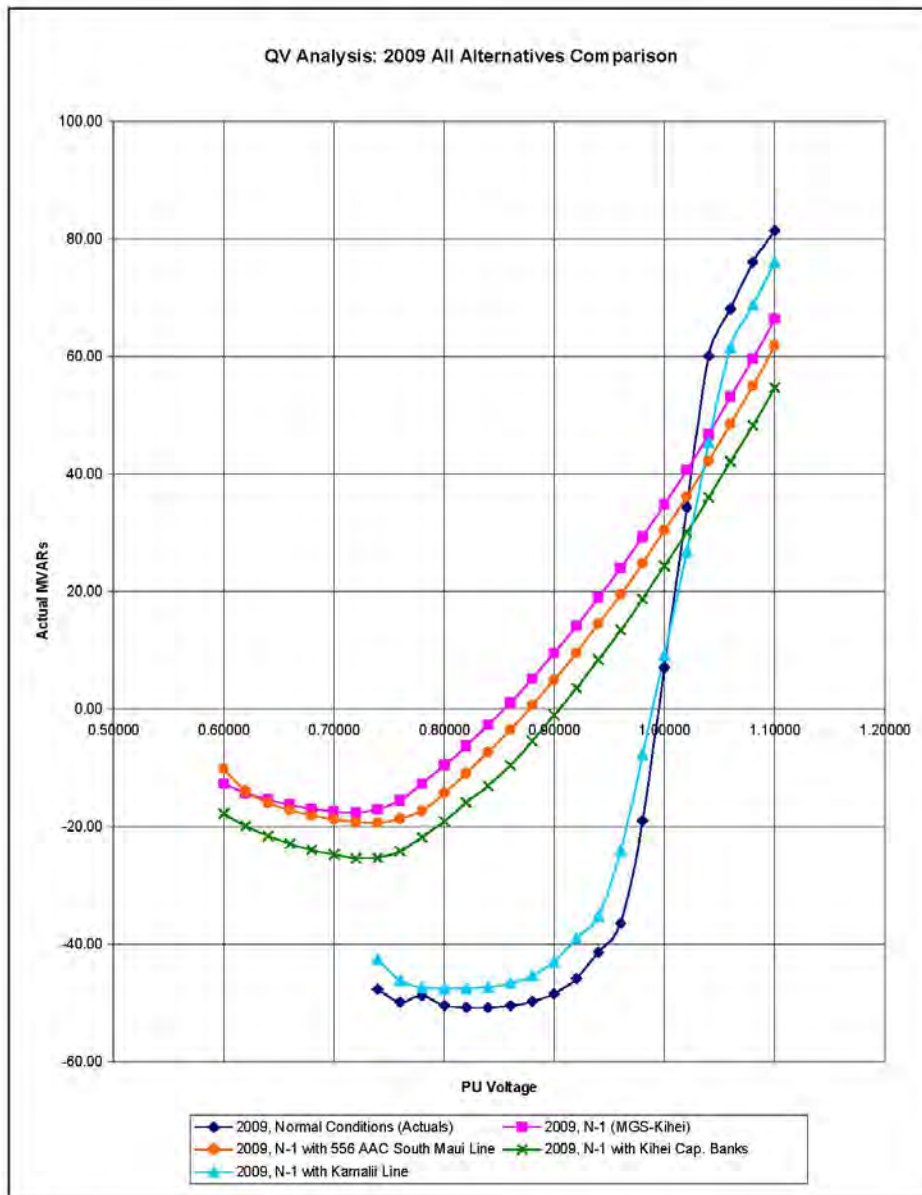
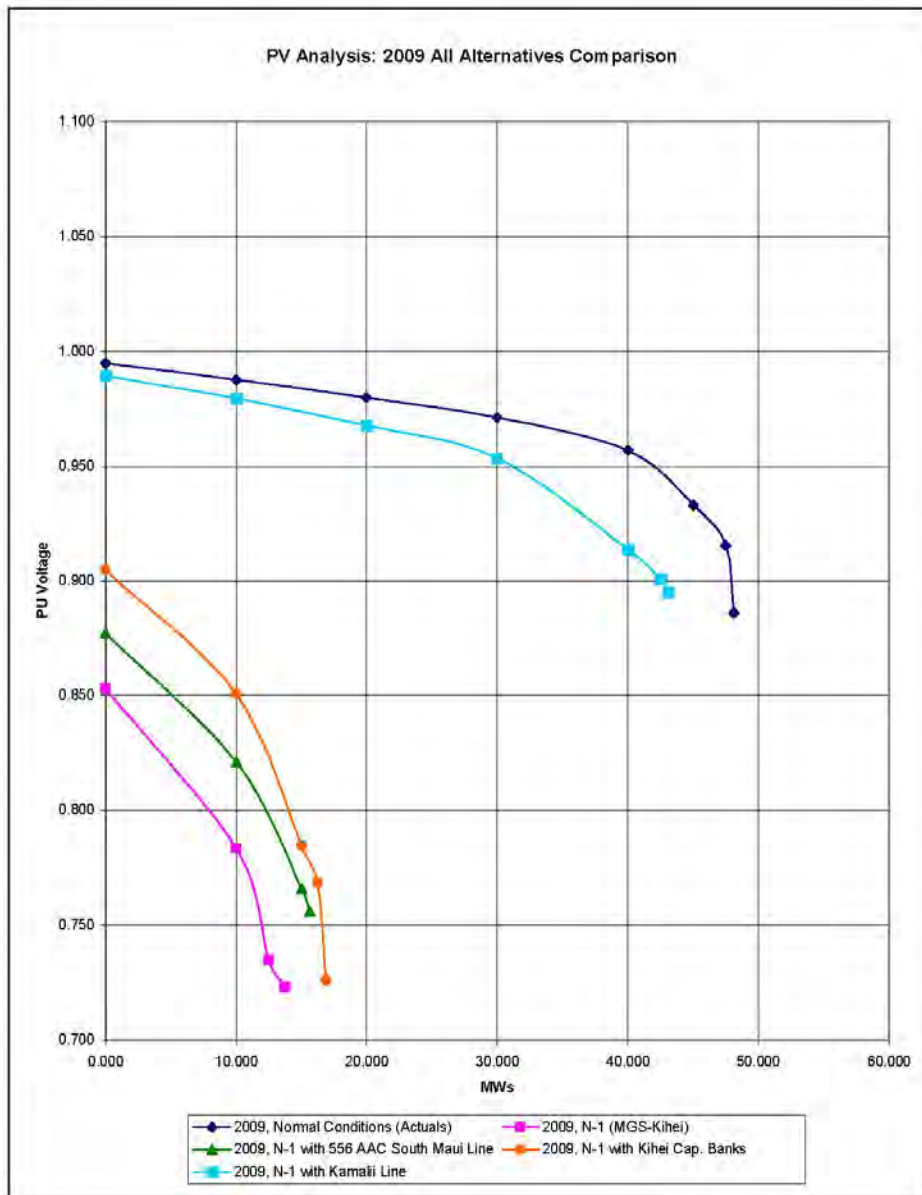


Figure 8: 2009 QV Analysis, All Alternatives Comparison

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 9: 2009 PV Analysis, All Alternatives Comparison**



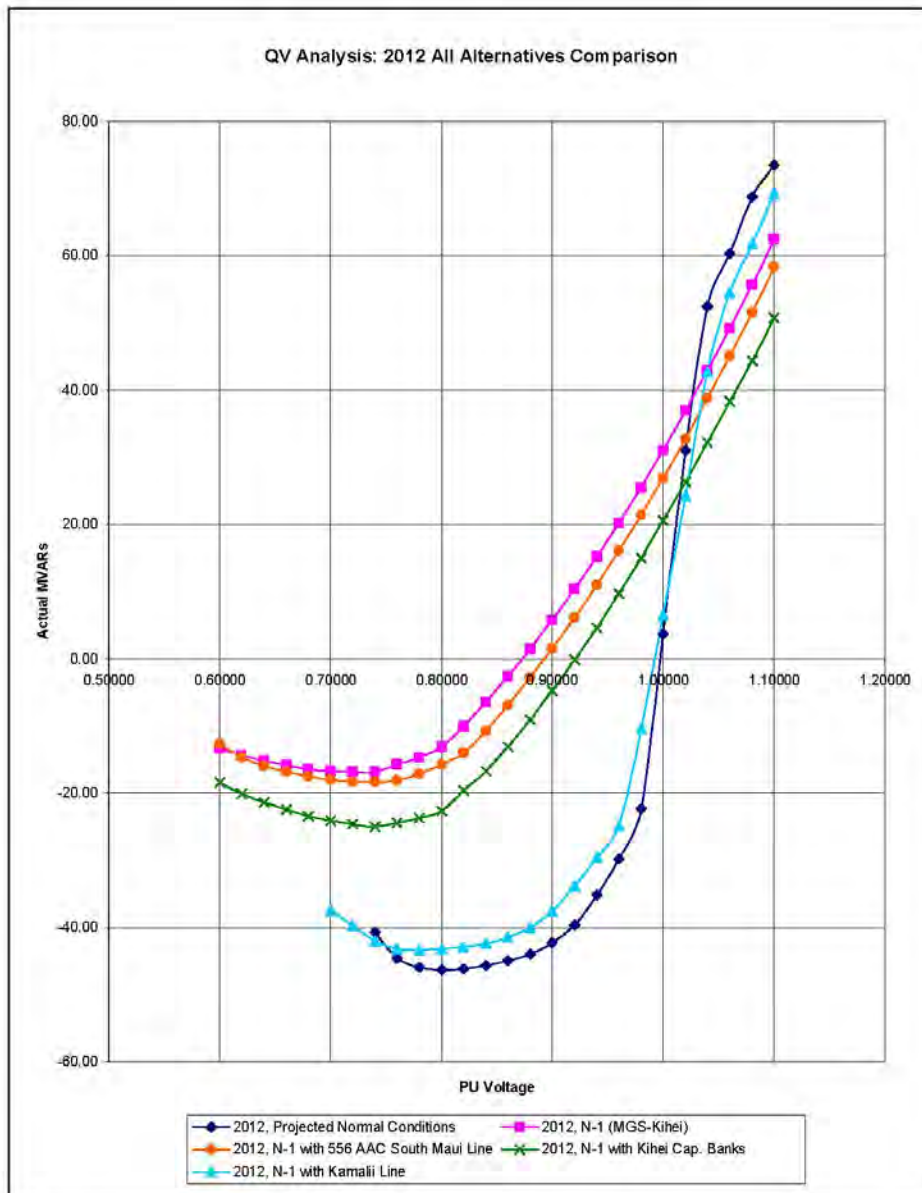
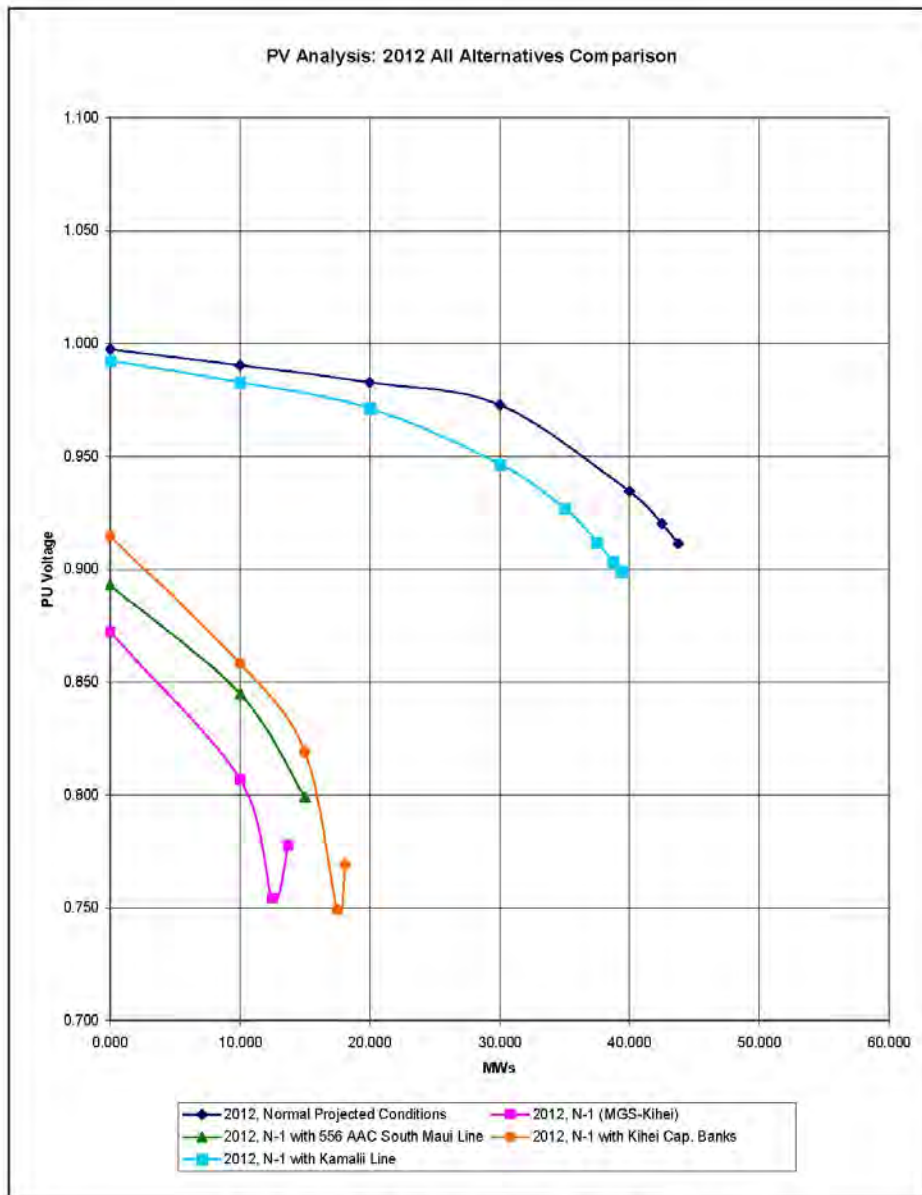


Figure 8: 2012 QV Analysis, All Alternatives Comparison

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 9: 2012 PV Analysis, All Alternatives Comparison**

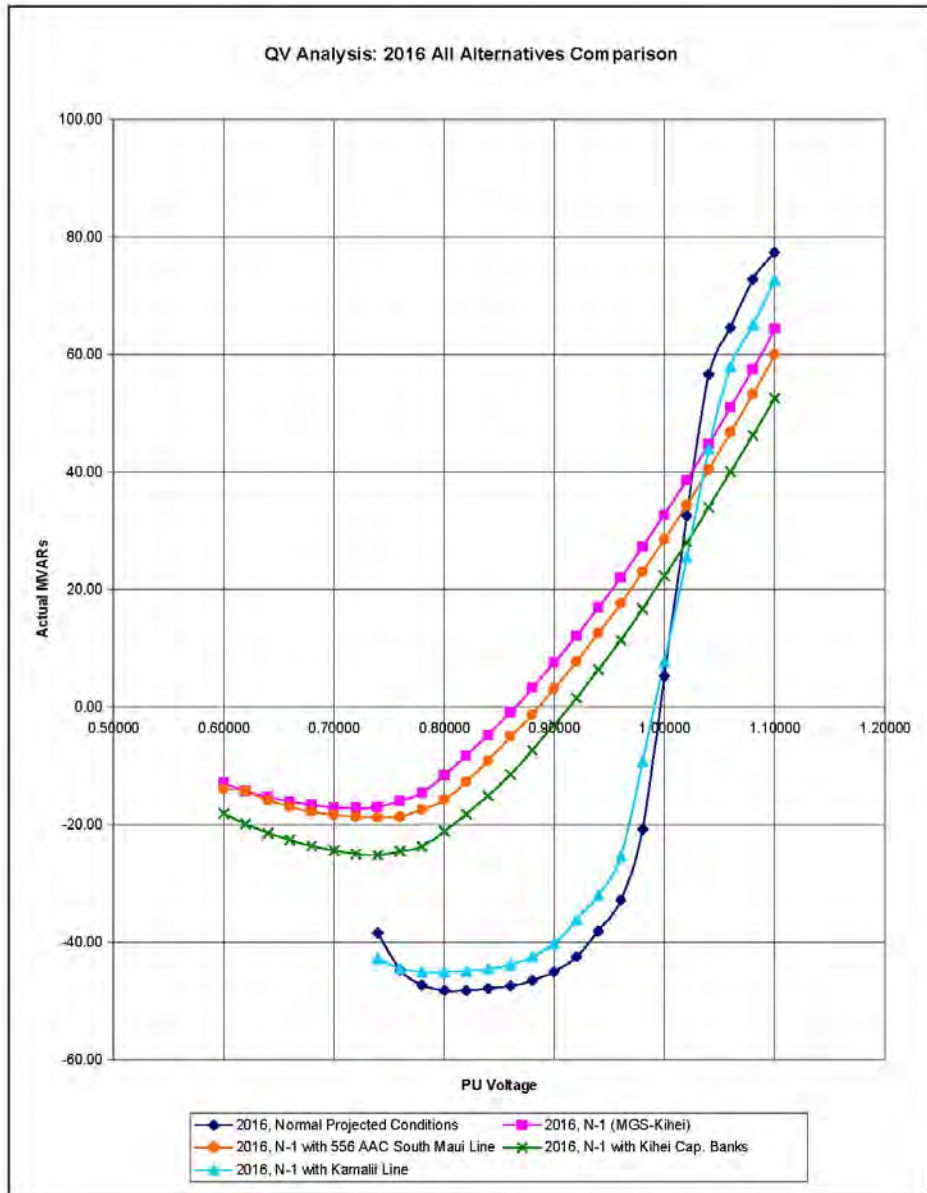
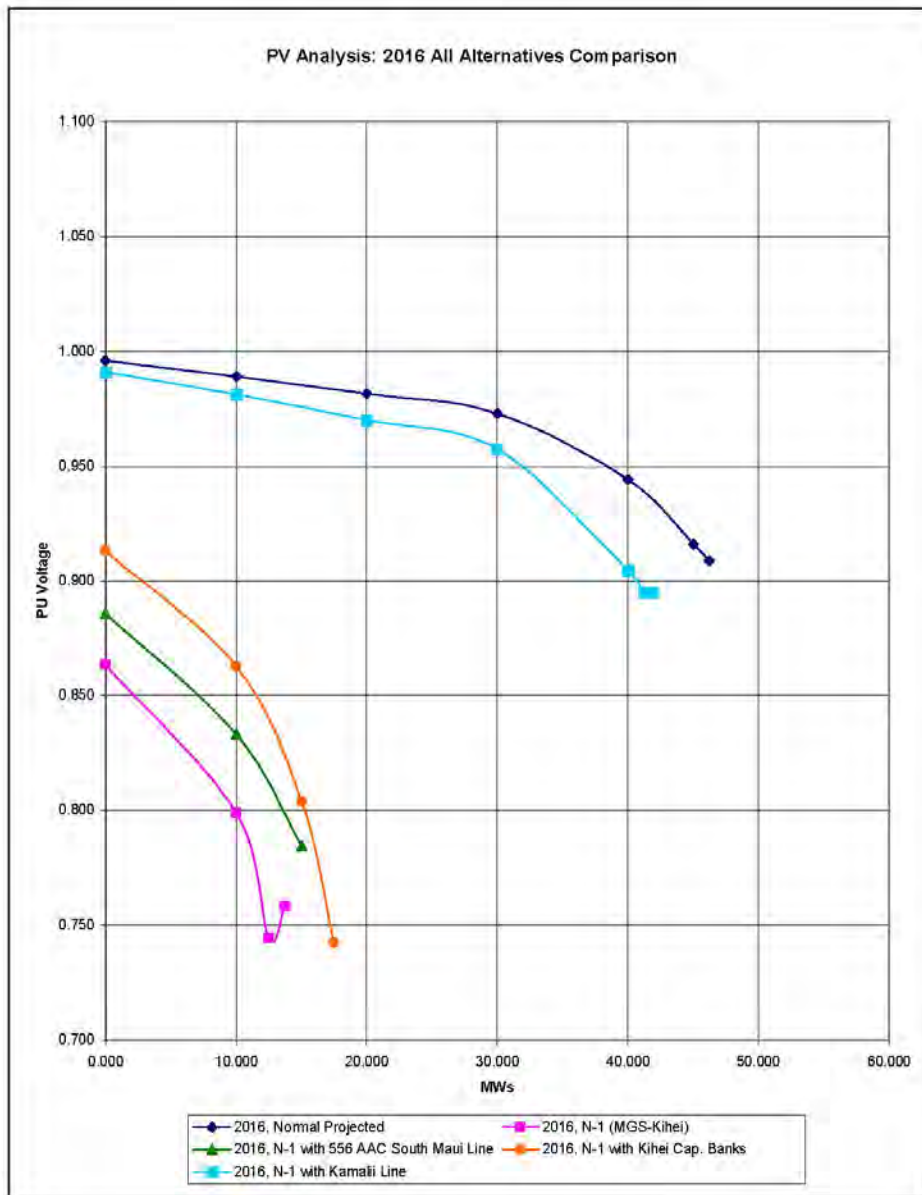


Figure 10: 2016 QV Analysis, All Alternatives Comparison

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 11: 2016 PV Analysis, All Alternatives Comparison**

### Conclusions & Recommendations:

This study discussed the problem of low voltage situations and its consequence of a possible voltage collapse situation. Several alternatives studied included replacing the existing 336 AAC South Maui lines with 556 AAC, adding more capacitor banks at Kihei (35), and building a second line from MGS (39) to the Kihei-Wailea service area via a new substation at Kamalii (96).

The recommended solution is to build the second line to Kamalii from Maalaea because the second line is the only alternative that mitigates the low voltages at Kihei (35) and Wailea (25) during N-1 contingencies as well as reduce the possibility of a voltage collapse situation. Also, the second line is able to mitigate these issues throughout the term of the study period.

It is also recommended that this solution be implemented as soon as possible due to the fact that current system conditions can create the low voltage conditions discussed throughout this report. Until the new line is built, it is recommended that an undervoltage load shedding scheme is followed to avoid a system voltage collapse. The typical heavily-loaded months for the MECO system are September, October, November, and December. During these months, the Undervoltage Load Shedding (UVLS) scheme should be implemented at the Kihei (SUB 35) and Wailea (SUB 25) substations as an interim solution until the MPP-Kamalii line construction is completed. The implementation of this interim solution is contingent upon the results of a detailed UVLS study and installation of the necessary UVLS relays. The UVLS study will evaluate the system peak load conditions as well as other high risk cases such as the outage of the following lines while also losing the MPP-Kihei line:

- MPP to Kealahou (69kV)
- MPP to Puunene (69kV)
- Puunene to Kanaha (69kV)

## Maalaea-Kamalii Transmission Line Alternatives

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### APPENDIX A

Bus Voltages at Kihei (35) and Wailea (25):

| Case                                       | Bus | Voltage (p.u.) |        |        |        |        |        |        |        |
|--|-----|----------------|--------|--------|--------|--------|--------|--------|--------|
|  |     | 2009           | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   |
| Normal                                     | 35  | 0.9947         | 0.9976 | 0.9974 | 0.9973 | 0.9971 | 0.9968 | 0.9965 | 0.9960 |
|  | 25  | 0.9853         | 0.9893 | 0.9890 | 0.9888 | 0.9885 | 0.9882 | 0.9877 | 0.9871 |
| Normal w/ Kamalii Line<br>(no contingency) | 35  | 1.0075         | 1.0091 | 1.0090 | 1.0089 | 1.0088 | 1.0086 | 1.0084 | 1.0082 |
|  | 25  | 0.9991         | 1.0017 | 1.0015 | 1.0013 | 1.0012 | 1.0010 | 1.0007 | 1.0003 |
| N-1, MGS to Kihei                          | 35  | 0.8543         | 0.8757 | 0.8742 | 0.8732 | 0.8717 | 0.8700 | 0.8674 | 0.8645 |
|  | 25  | 0.8709         | 0.8903 | 0.8890 | 0.8880 | 0.8867 | 0.8851 | 0.8828 | 0.8801 |
| N-1, MGS to Kihei w/<br>Kamalii Line       | 35  | 0.9893         | 0.9929 | 0.9926 | 0.9924 | 0.9922 | 0.9919 | 0.9915 | 0.9910 |
|  | 25  | 0.9878         | 0.9916 | 0.9914 | 0.9911 | 0.9909 | 0.9906 | 0.9901 | 0.9896 |
| N-1, MGS to Kealahou                       | 35  | 0.9834         | 0.9878 | 0.9875 | 0.9873 | 0.9870 | 0.9866 | 0.9861 | 0.9855 |
|  | 25  | 0.9657         | 0.9721 | 0.9717 | 0.9714 | 0.9710 | 0.9704 | 0.9697 | 0.9688 |
| N-1, MGS to Kealahou<br>w/ Kamalii Line    | 35  | 1.0032         | 1.0054 | 1.0053 | 1.0051 | 1.0050 | 1.0048 | 1.0046 | 1.0042 |
|  | 25  | 0.9890         | 0.9928 | 0.9925 | 0.9923 | 0.9920 | 0.9917 | 0.9913 | 0.9907 |
| N-1, MGS to Puunene                        | 35  | 0.9911         | 0.9946 | 0.9944 | 0.9942 | 0.9940 | 0.9937 | 0.9933 | 0.9928 |
|  | 25  | 0.9792         | 0.9847 | 0.9838 | 0.9835 | 0.9832 | 0.9828 | 0.9822 | 0.9815 |
| N-1, MGS to Puunene<br>w/ Kamalii Line     | 35  | 1.0058         | 1.0077 | 1.0076 | 1.0074 | 1.0073 | 1.0072 | 1.0070 | 1.0067 |
|  | 25  | 0.9951         | 0.9982 | 0.9980 | 0.9978 | 0.9977 | 0.9974 | 0.9970 | 0.9966 |

**APPENDIX B**

***Undervoltage Load Shed Study (UVLS): Interim Solution for South Maui Line***

## Maalaea-Kamalii Transmission Line Alternatives

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ENG 20-4/YT

### INTEROFFICE CORRESPONDENCE

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Hawaiian Electric Co., Inc.

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January 28, 2011

To: Chris Reynolds  
From: Dean Arakawa *DKA*  
Subject: MECO Undervoltage Load Shed Study (UVLS): Interim Solution for South Maui Line

Please find attached a copy of the Undervoltage Load Shed Study (UVLS): Interim Solution for South Maui Line. The report specifies requirements for the UVLS scheme necessary to mitigate potential violations to MECO's transmission planning criteria as a result of the deferral of the South Maui 69 kV line project (reference the MECO 8 Year Transmission Study, 2009-2016, South/UP-country Maui report). If you have any questions, please contact Tammy Okubo at ext. 7286 or Gemini Yau at ext. 7888.

TO  
Attachment

cc : D. Park  
F. Oshiro  
R. Jung  
M. Ribao  
S. Sano  
R. Uemura  
Engineering Library  
TPD File





Maui Electric Company (MECO)

**Undervoltage Load Shed Study (UVLS):  
Interim Solution for South Maui Line**

Prepared by  
System Integration Department  
Transmission Planning Division  
Hawaiian Electric Company, Inc.

December 2010

## Maalaea-Kamalii Transmission Line Alternatives

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APPENDIX A- ASSUMED GENERATOR SETTINGS

APPENDIX B- DYNAMIC SIMULATION RESULTS

**EXECUTIVE SUMMARY:**

The purpose of this study is to develop the requirements for an undervoltage load-shedding (UVLS) scheme as an interim solution for the delayed installation of the additional South Maui 69 kV line as recommended in the MECO 8 Year Transmission Study, 2009-2016, South/Up-country Maui report. The undervoltage load-shedding scheme should be considered a "remedial measure", and does not negate the need for the additional transmission line to the South Maui area. The shedding of load is used to prevent voltage instability and collapse.

This study recommends that the UVLS scheme be armed for any system loads greater than 150 MW. The speed at which this scheme is implemented should be long enough to allow system faults to clear as well as allow enough time for the generators to attempt to mitigate the voltage problem.

The load that will be shed is as follows:

- 1<sup>st</sup> Load Shed: Kihei Substation, Unit 3
- 2<sup>nd</sup> Load Shed: Kihei Substation, Unit 4
- 3<sup>rd</sup> Load Shed: Kihei Substation, Units 1 and 2
- 4<sup>th</sup> Load Shed: Wailea Substation, Unit 4

The voltage for this scheme will be sampled at the 69kV level to provide a more accurate reading of how the system is behaving. Sampling on the distribution level may lead to a false impression of the system behavior due to the load tap changers (LTC's) on the distribution transformers.

Keep in mind that this scheme should be sufficient for most contingencies. However, for the N-2 contingency, outage of both the MPP to Kihei and MPP to Kealahou 69 kV lines, the scheme may not be able to fully mitigate a collapse in this situation since this extreme situation cuts off two of the main feeders that feed the Kihei and Wailea loads. With these two lines out, the power must flow through a much longer path to reach the load. The scheme may not solve all the undervoltage problems associated with this double contingency, but it will provide a considerable amount of relief.

Again, the UVLS scheme should be considered a "remedial" measure and is not intended to replace other system improvements. Additionally, the scheme should be reviewed following any major system changes or upgrades.

## Maalaea-Kamalii Transmission Line Alternatives

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### **INTRODUCTION:**

#### **Purpose:**

The purpose of this study is to develop the requirements for an undervoltage load-shedding scheme as an interim solution for the delayed installation of the additional South Maui line as recommended in the MECO 8 Year Transmission Study, 2009-2016, South/Up-country Maui report. The undervoltage load-shedding scheme should be considered a "remedial measure", and does not negate the need for the additional transmission line to the South Maui area. The use of the undervoltage load-shedding scheme is to stabilize system voltages and to prevent a possible system wide voltage collapse.

Kihei and Wailea are susceptible to low voltage conditions during the N-1 contingency (loss of the 69 kV line) from the Maalaea Power Plant (MPP) to the Kihei Substation. With the loss of that line, the power must travel much farther, through the MPP to Kealahou line, to reach the heavy South Maui load. These voltage issues are in violation of the MECO Transmission Planning Criteria and could also create a system wide voltage collapse if the system cannot supply the necessary reactive power to sustain acceptable voltages.

This study will outline the undervoltage load-shedding requirements including:

- System load threshold for "arming" the UVLS scheme
- Amount of load to shed
- Required speed of shedding
- UVLS relay settings

#### **Assumptions:**

The following are the assumptions used for this study:

- The peak and min base cases are based off of 2009 actuals
- 100 MW and 125 MW cases are scaled up from the min base case
- 150 MW and 175 MW cases are scaled down from the peak base case
- Generators dispatched as found in Appendix A
- Minimum of 6 MW spinning reserve or half of KWP | online power, whichever greatest
- Minimum of 6 MW down reserve

- Unless curtailed for down reserve requirements or specified otherwise, KWPI is assumed to be at 80% or 24 MW of output
- Kihei and Wailea Capacitor banks assumed offline to show most pessimistic voltage result

#### **DISCUSSION:**

##### **System Load Threshold:**

Figures 1 and 2 are PV plots and Figures 3 and 4 are QV plots that compare the curves for different system load scenarios. As stated in the assumptions listed above, the 100 MW and 125 MW cases were scaled up from the Min Base case, which has the South Maui load at approximately 28 % of the total system load. The 150 MW, 175 MW, and the Peak Base cases have a South Maui load equivalent to approximately 23% of the system load. Therefore the plots of the 125 MW case and the 150 MW case behave similarly.

Figures 1 and 3 show that during normal conditions, all system load scenarios can sufficiently support loads in the South Maui area. However, Figures 2 and 4 show that for the N-1 condition from MPP to Kihei, certain system load levels may operate close to possible voltage collapse conditions. These figures show that around 150 MW to 175 MW is a relatively safe margin to use as a system load threshold for arming the UVLS scheme.

Since these cases are snapshots in time, more PV and QV analysis was done to test the sensitivities of the percentage of South Maui area load in comparison with the total system load. The next set of PV and QV curves, Figures 5-8, compare between the South Maui load at 23% and 28% for the 150 MW and 175 MW system load cases. Figures 5-8 show that the difference in load corresponds to a roughly 8-10 MW and MVAR difference for the PV and QV curves, respectively. Therefore, a system load threshold of 150 MW would provide better reliability due to the possibility of South Maui locally peaking at a different time than the rest of the system without having to arm the scheme unnecessarily. Note that the threshold is only the minimum system load that the scheme must be armed, the scheme can also be armed at all times.

# Maalaea-Kamalii Transmission Line Alternatives

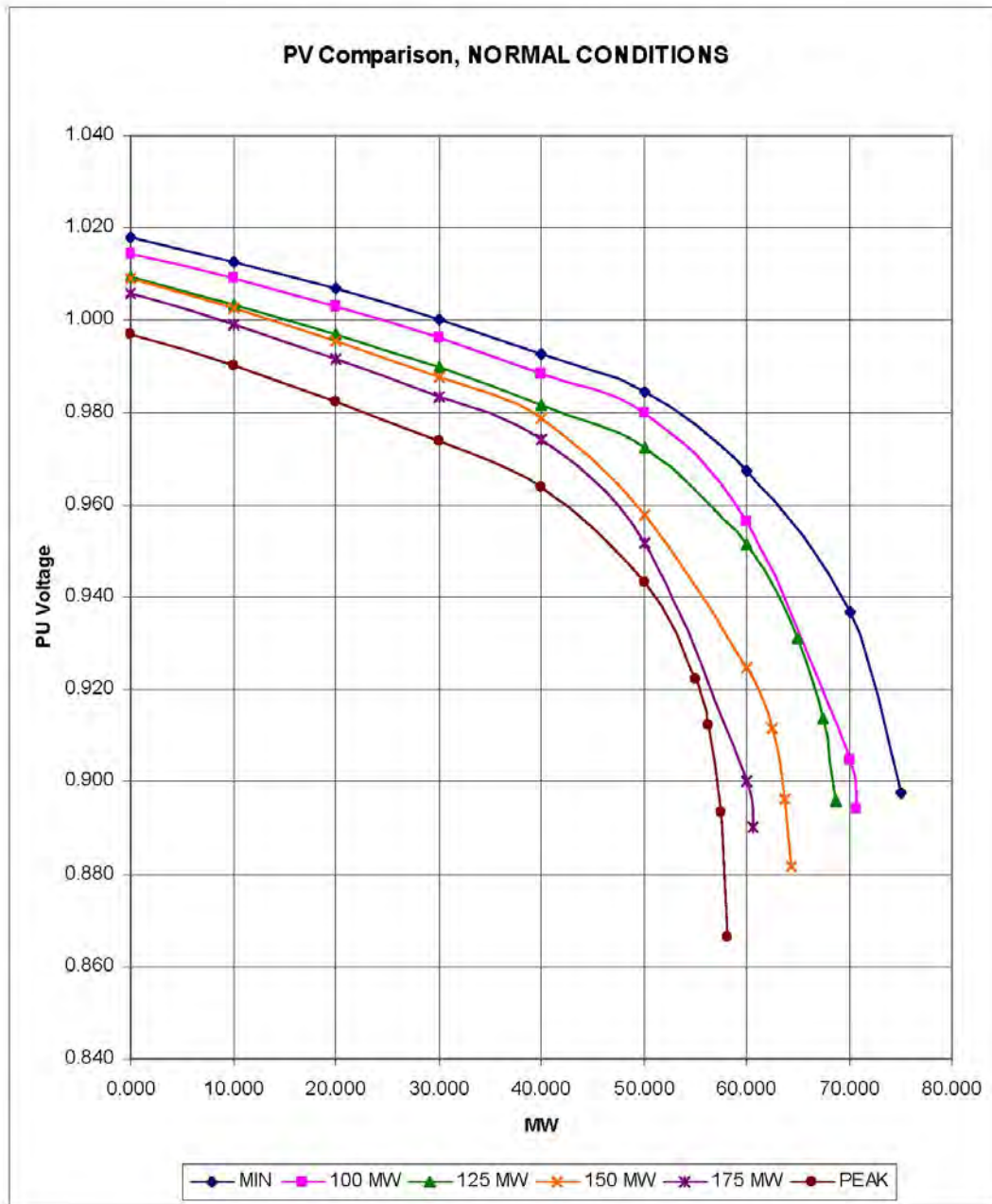


Figure 1: PV Comparison, Normal Conditions

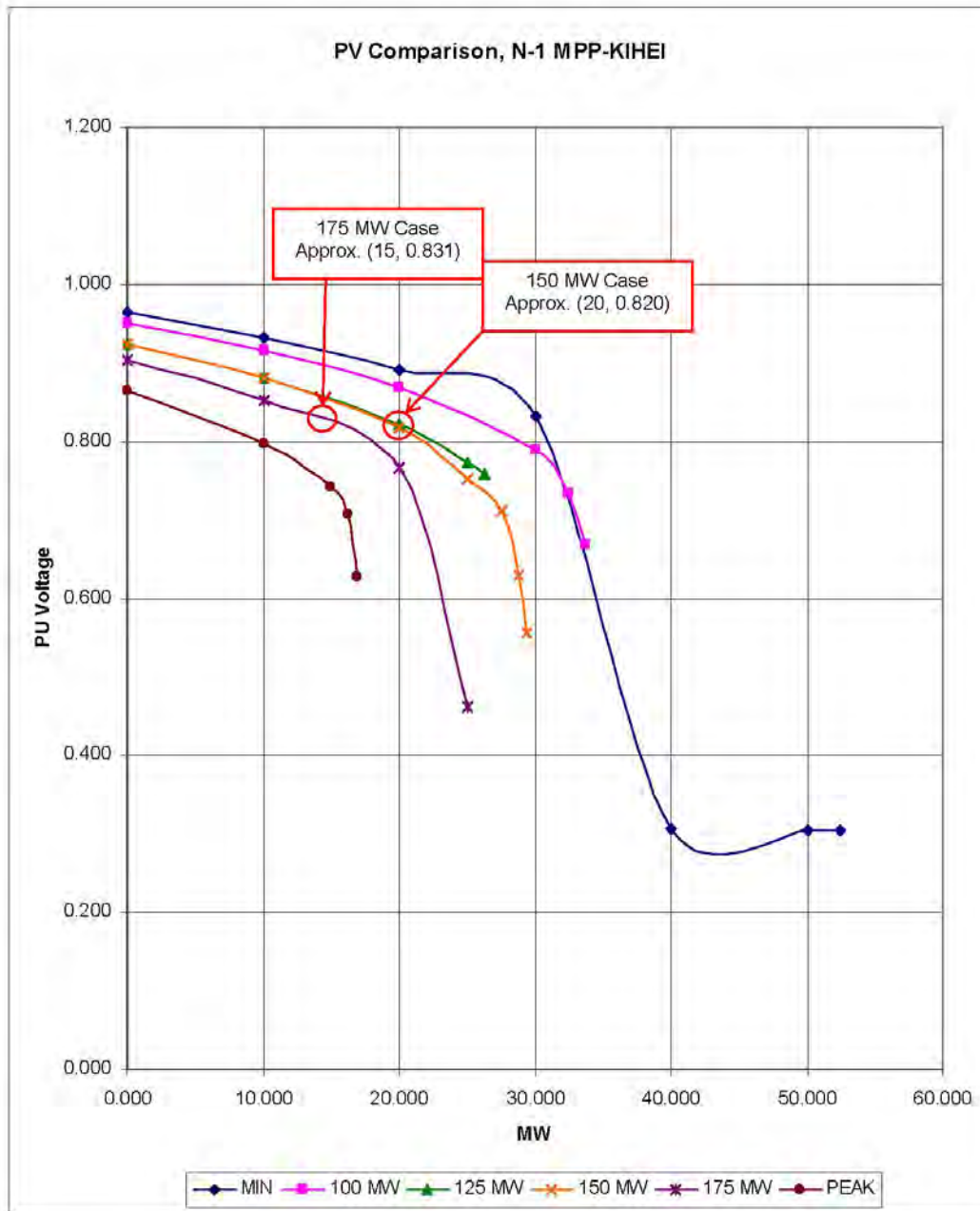


Figure 2: PV Comparison, N-1 MPP to Kihei

# Maalaea-Kamalii Transmission Line Alternatives

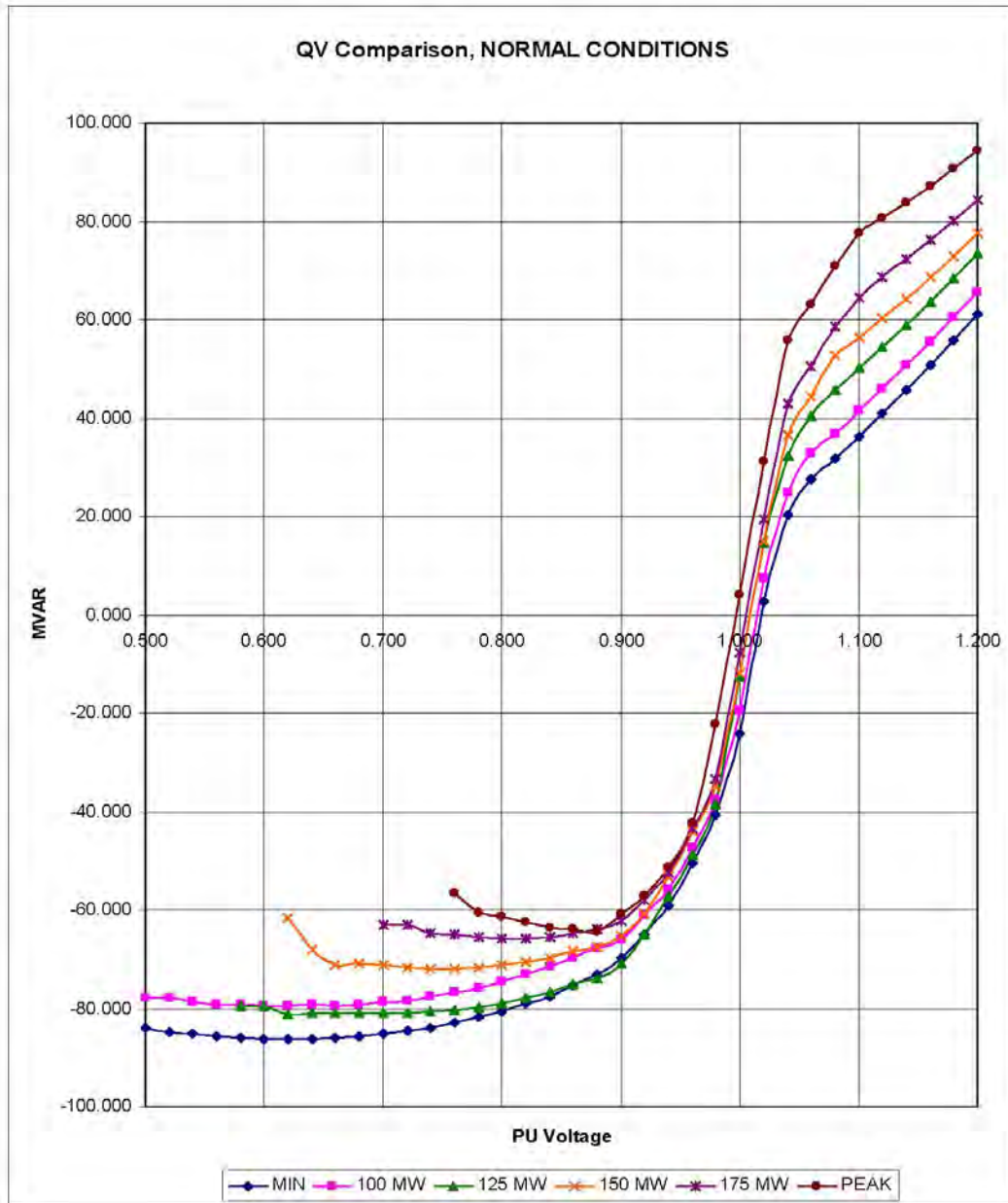


Figure 3: QV Comparison, Normal Conditions



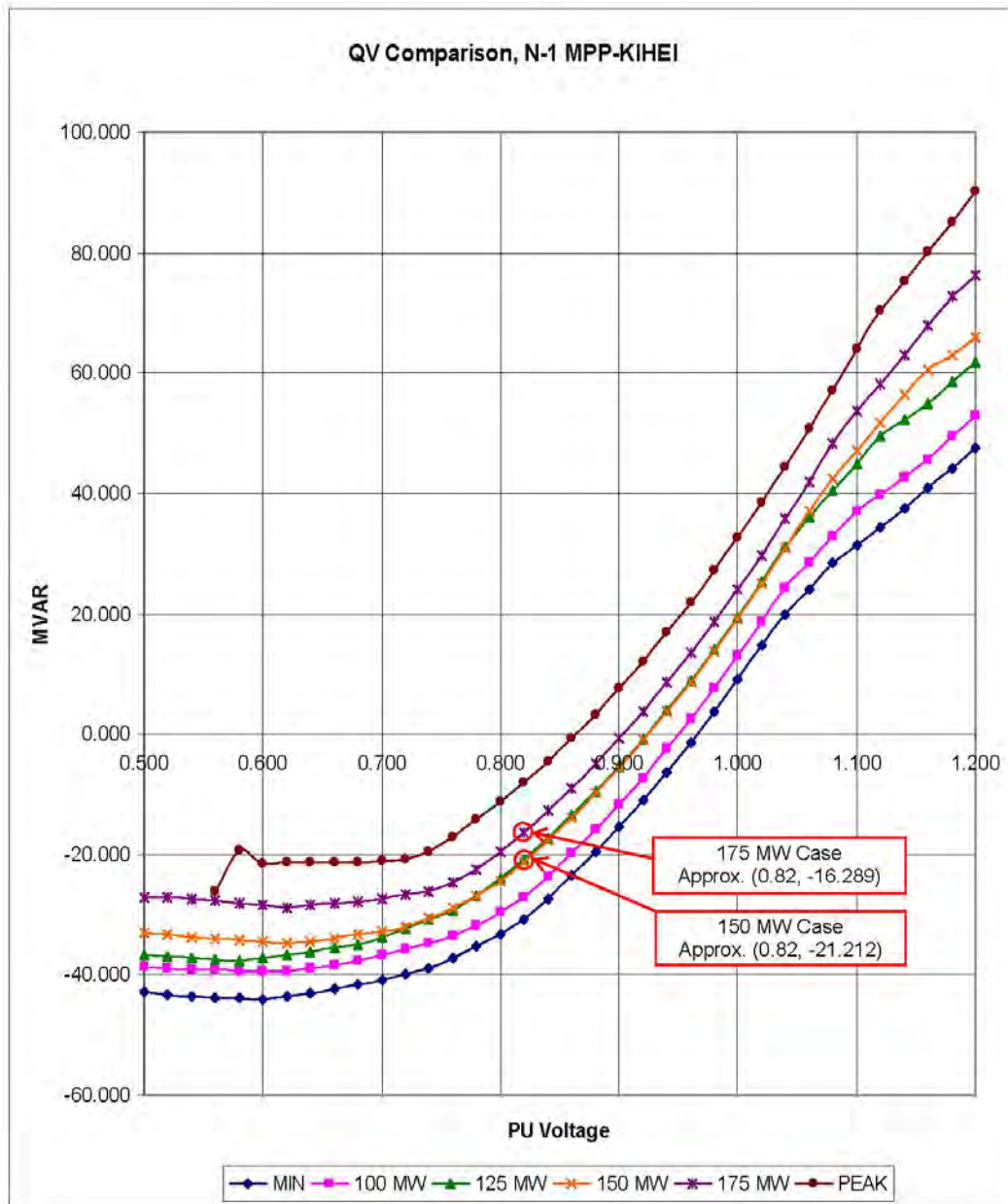
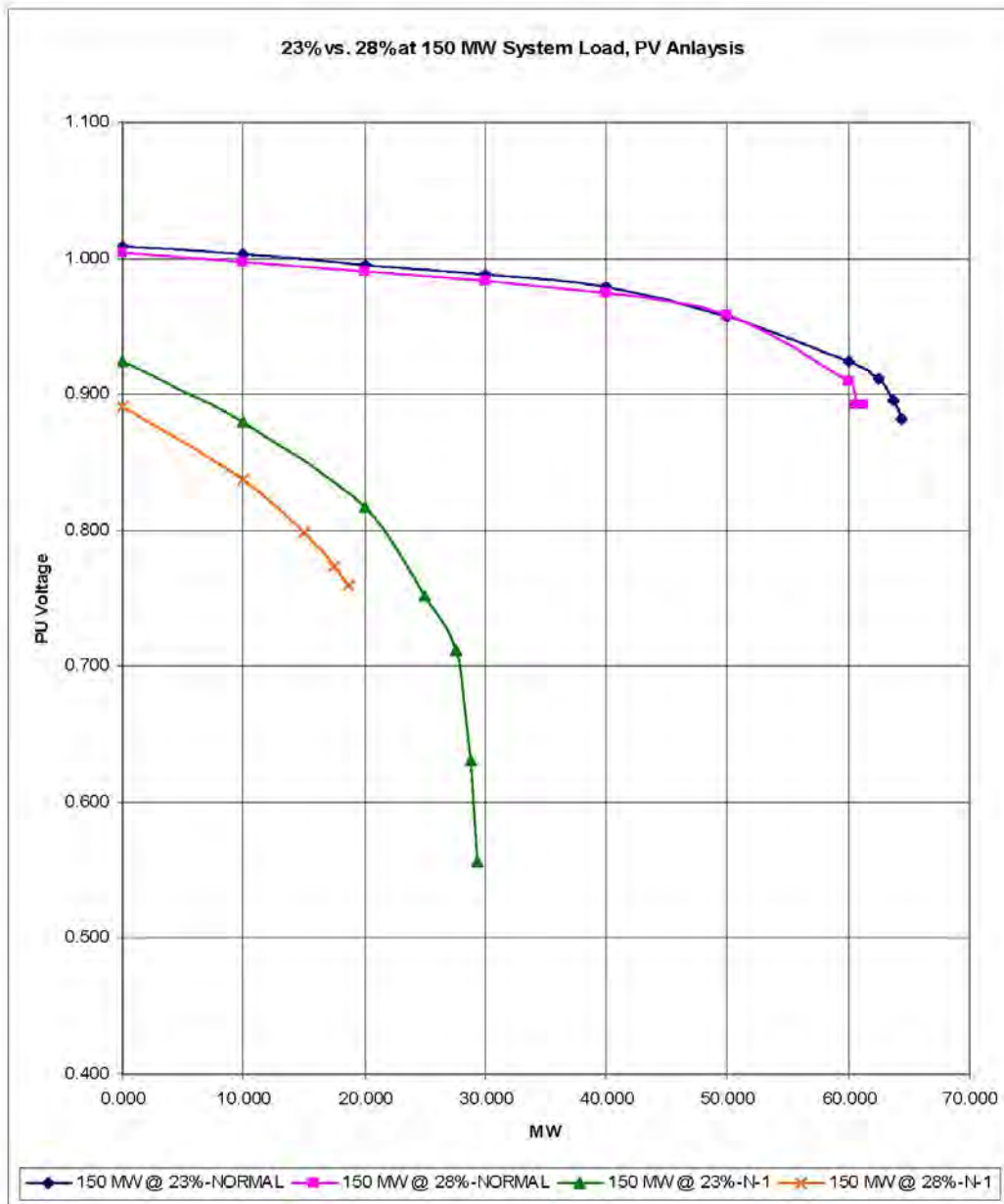


Figure 4: QV Comparison, N-1 MPP to Kihei

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 5: 23% vs. 28% of 150 MW System Load, PV Analysis**

NOTE: N-1 condition in figure above is with the line from MPP to Kihei out.

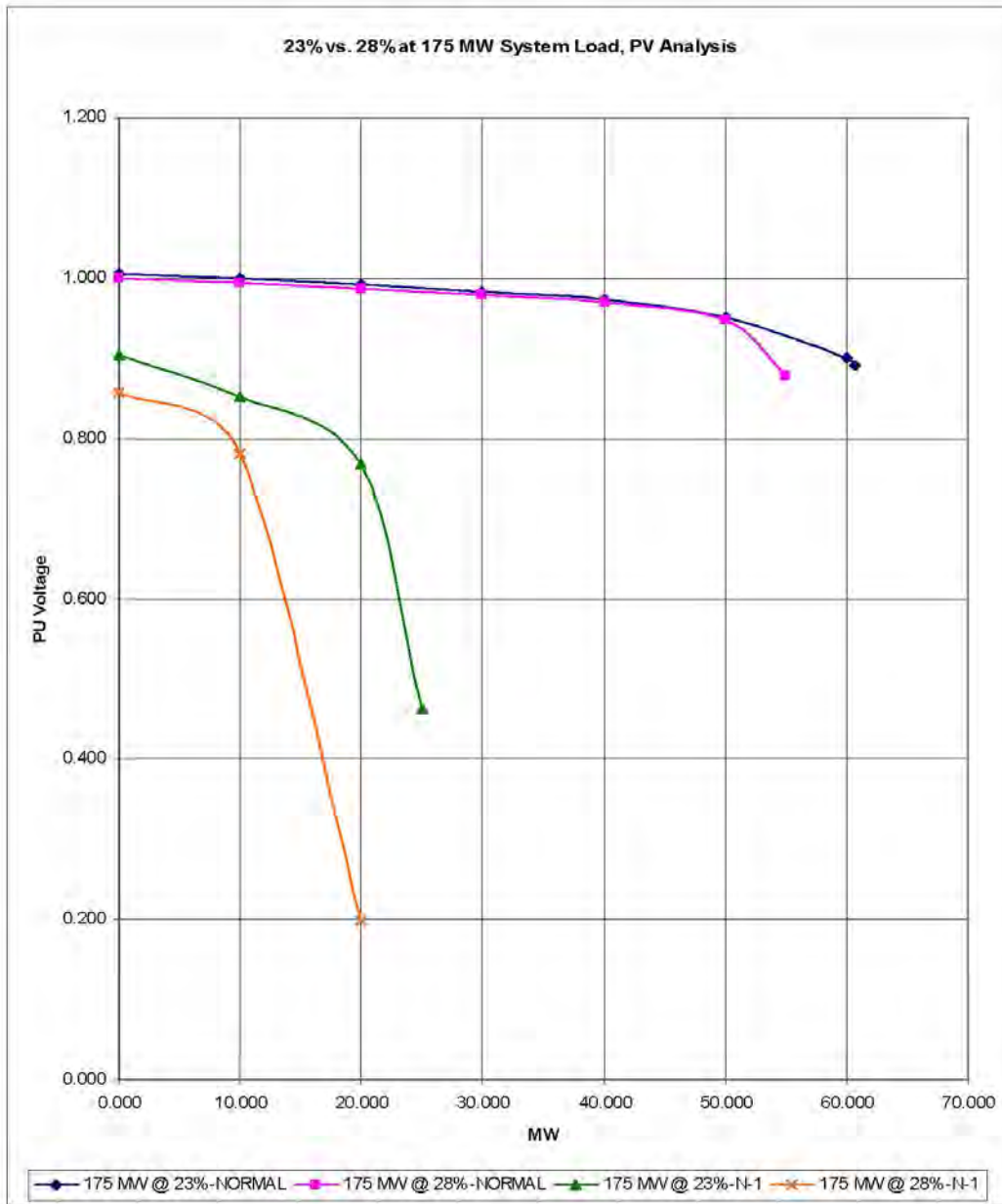
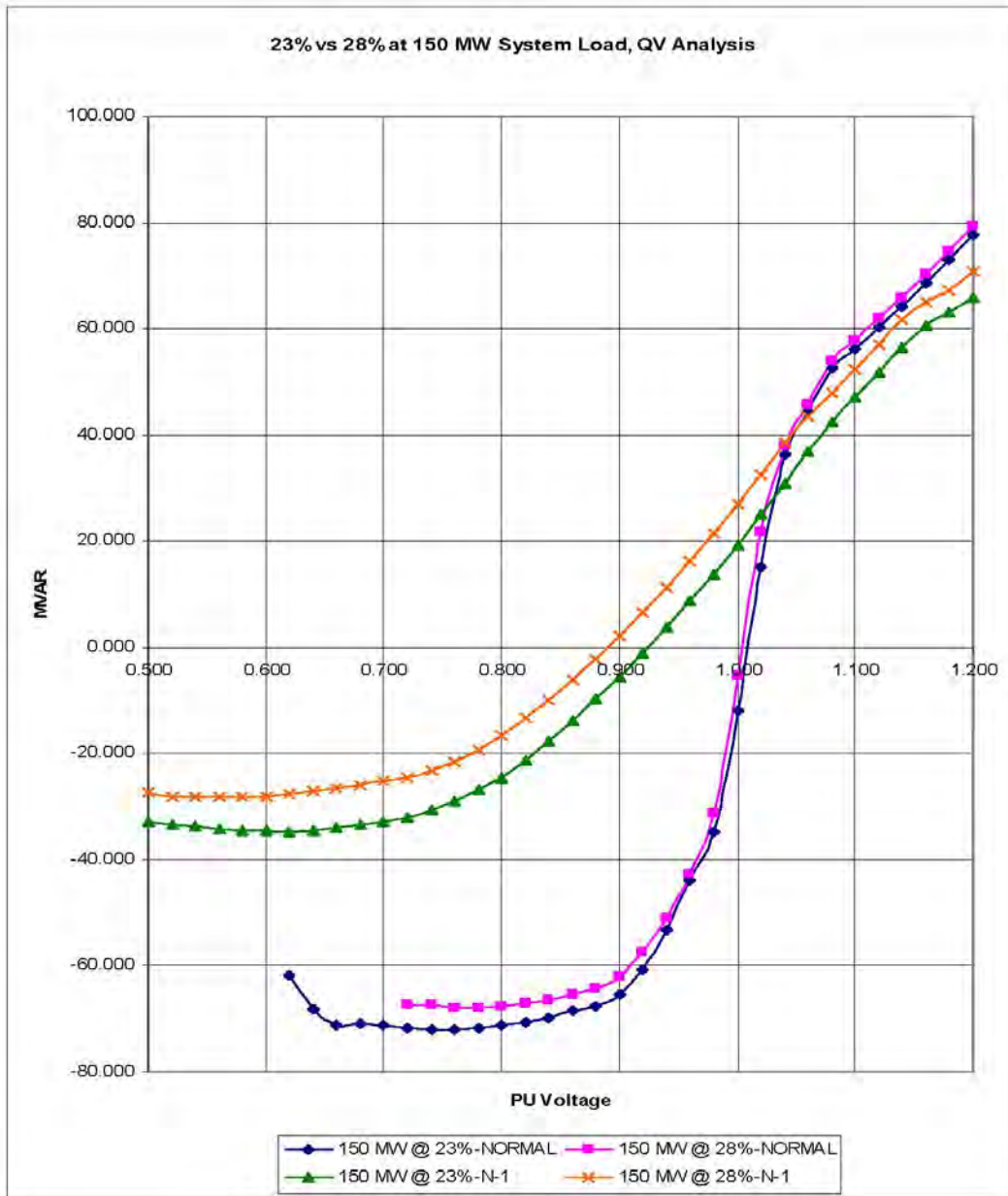


Figure 6: 23% vs. 28% of 175 MW System Load, PV Analysis

NOTE: N-1 condition in figure above is with the line from MPP to Kihei out.

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 7: 23% vs. 28% of 150 MW System Load, QV Analysis**

NOTE: N-1 condition in figure above is with the line from MPP to Kihei out.

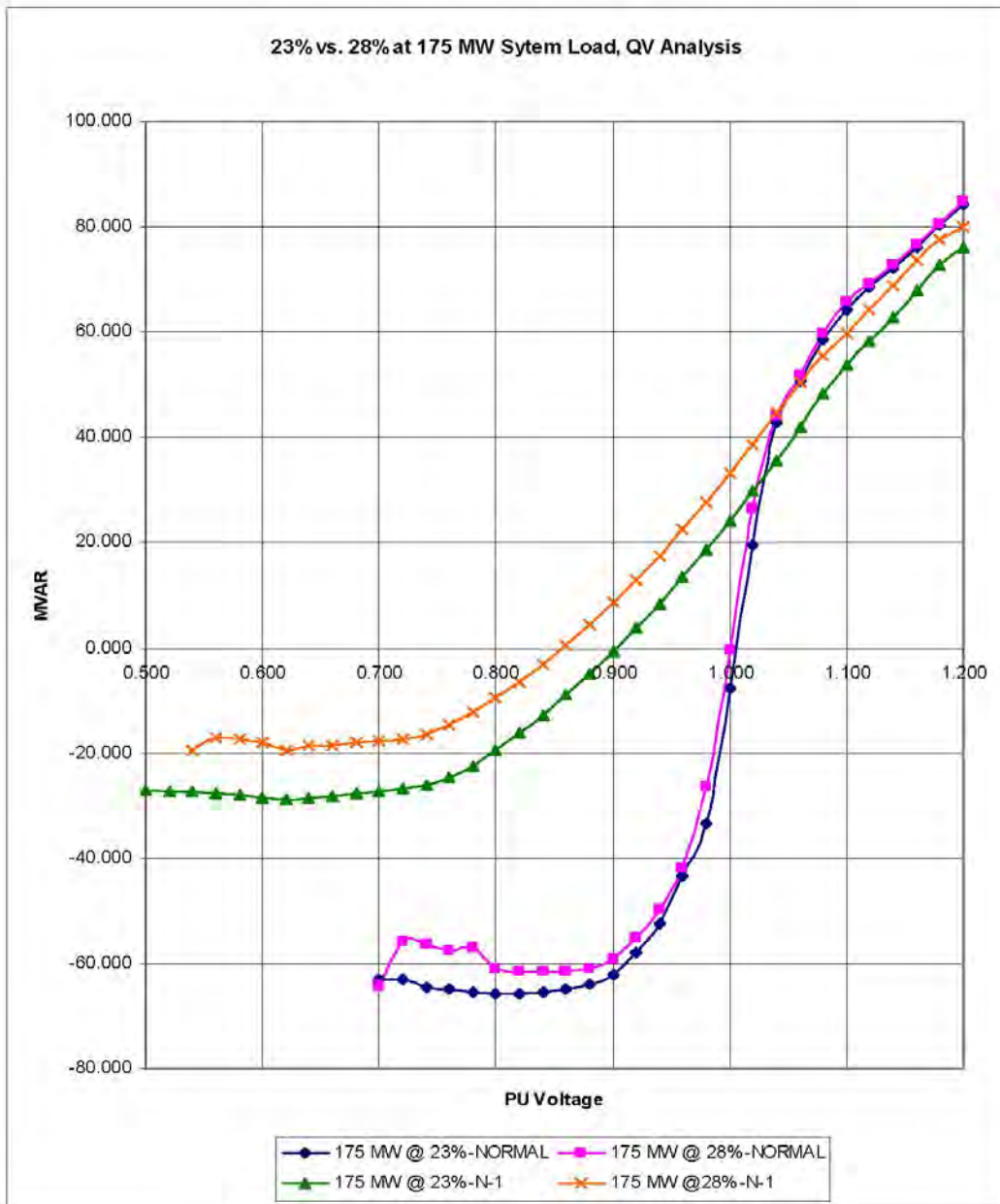


Figure 8: 23% vs. 28% of 175 MW System Load, QV Analysis

NOTE: N-1 condition in figure above is with the line from MPP to Kihei out.

## Maalaea-Kamalii Transmission Line Alternatives

**Amount of Load to Shed:**

Below in Table 1 are the voltages at Kihei and Wailea during certain N-1 contingencies. Notice the undervoltage conditions for the loss of the MPP to Kihei line during the system peak. Table 2, also highlights the worst N-2 conditions that can be very detrimental to the MECO system.

| CASE          | BUS    | PU VOLTAGE NORMAL | PU VOLTAGE N-1 MPP-Kihei | PU VOLTAGE N-1 Puunene-Kanaha | PU VOLTAGE N-1 MPP-Puunene | PU VOLTAGE N-1 MPP-Kealahou |                        |
|---------------|--------|-------------------|--------------------------|-------------------------------|----------------------------|-----------------------------|------------------------|
| PEAK BASECASE | KIHEI  | 0.9970            | 0.8637                   | 0.9916                        | 0.9944                     | 0.9870                      | SOUTH MAUI 23% OF LOAD |
|               | WAILEA | 0.9887            | 0.8807                   | 0.9794                        | 0.9843                     | 0.9713                      |                        |
| 175 MW        | KIHEI  | 1.0057            | 0.9034                   | 1.0019                        | 1.0040                     | 0.9979                      |                        |
|               | WAILEA | 0.9991            | 0.9163                   | 0.9925                        | 0.9962                     | 0.9855                      |                        |
| 150 MW        | KIHEI  | 1.0090            | 0.9246                   | 1.0060                        | 1.0075                     | 1.0022                      | SOUTH MAUI 28% OF LOAD |
|               | WAILEA | 1.0031            | 0.9351                   | 0.9978                        | 1.0005                     | 0.9911                      |                        |
| 125 MW        | KIHEI  | 1.0093            | 0.9236                   | 1.0065                        | 1.0082                     | 1.0034                      |                        |
|               | WAILEA | 1.0046            | 0.9358                   | 0.9997                        | 1.0027                     | 0.9941                      |                        |
| 100 MW        | KIHEI  | 1.0145            | 0.9504                   | 1.0123                        | 1.0135                     | 1.0096                      |                        |
|               | WAILEA | 1.0106            | 0.9594                   | 1.0066                        | 1.0088                     | 1.0019                      |                        |
| MIN BASECASE  | KIHEI  | 1.0180            | 0.9654                   | 1.0161                        | 1.0171                     | 1.0139                      |                        |
|               | WAILEA | 1.0147            | 0.9728                   | 1.0133                        | 1.0130                     | 1.0073                      |                        |

**Table 1: Load Flow Voltages for Kihei and Wailea, N-1 Contingencies**

| CASE          | BUS    | PU VOLTAGE N-2, Puunene-Kanaha, MPP-Kihei | PU VOLTAGE N-2, MPP-Puunene, MPP-Kihei | PU VOLTAGE N-2, MPP-Kealahou, MPP-Kihei |
|---------------|--------|---|--|---|
| PEAK BASECASE | KIHEI  | 0.7886                                    | 0.8349                                 | *0.3899                                 |
|               | WAILEA | 0.8071                                    | 0.8520                                 | *0.4089                                 |
| 175 MW        | KIHEI  | 0.8672                                    | 0.8825                                 | 0.4295                                  |
|               | WAILEA | 0.8808                                    | 0.8958                                 | 0.4511                                  |
| 150 MW        | KIHEI  | 0.9008                                    | 0.9149                                 | 0.9248                                  |
|               | WAILEA | 0.9117                                    | 0.9256                                 | 0.6414                                  |
| 125 MW        | KIHEI  | 0.9002                                    | 0.9133                                 | 0.6481                                  |
|               | WAILEA | 0.9128                                    | 0.9256                                 | 0.6649                                  |
| 100 MW        | KIHEI  | 0.9338                                    | 0.9427                                 | 0.7999                                  |
|               | WAILEA | 0.9430                                    | 0.9519                                 | 0.8111                                  |
| MIN BASECASE  | KIHEI  | 0.9522                                    | 0.9596                                 | 0.8567                                  |
|               | WAILEA | 0.9597                                    | 0.9671                                 | 0.8652                                  |

**Table 2: Load Flow Voltages for Kihei and Wailea, N-2 Contingencies**

\*NOTE: Large mismatch in the solution for this specific case; therefore the accuracy is uncertain.

By using dynamic studies to shed loads in the South Maui area, the amount of load needed to be shed per 1% increase in voltage can be calculated and averaged to approximately 3.3MVA. The following plots and tables show this for the Peak Basecase and the 150 MW case.

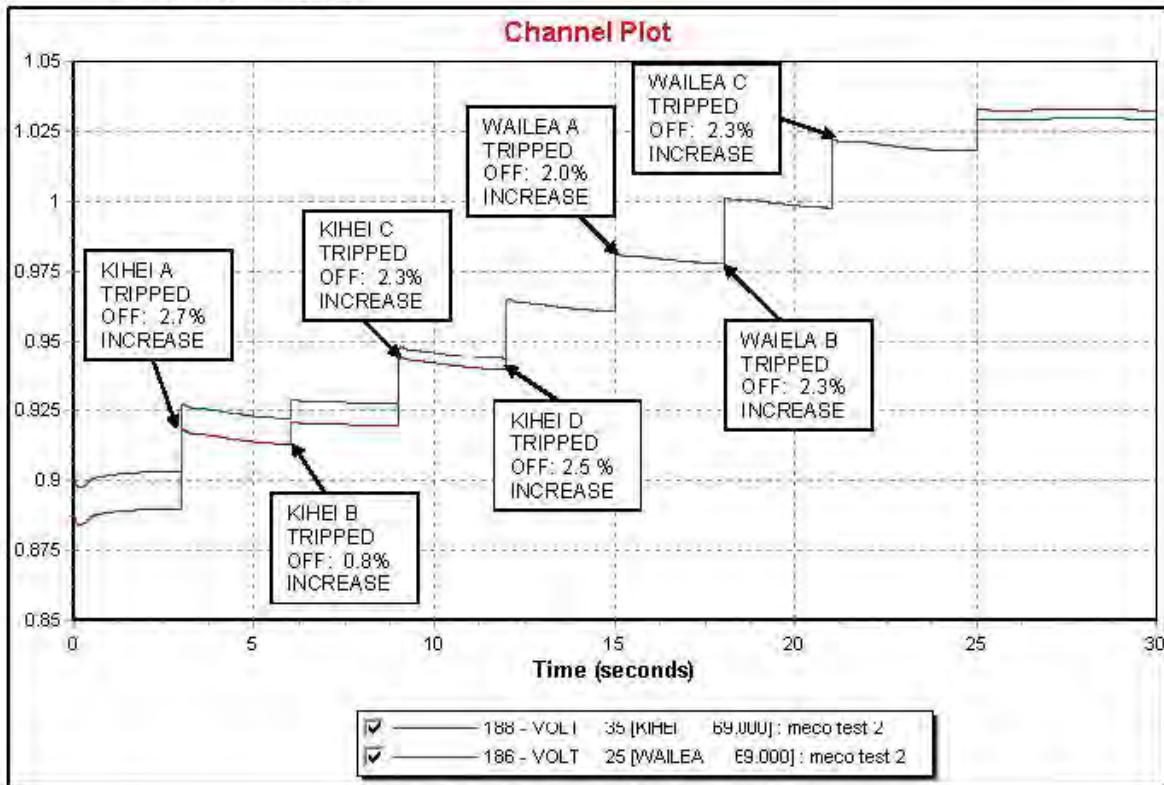
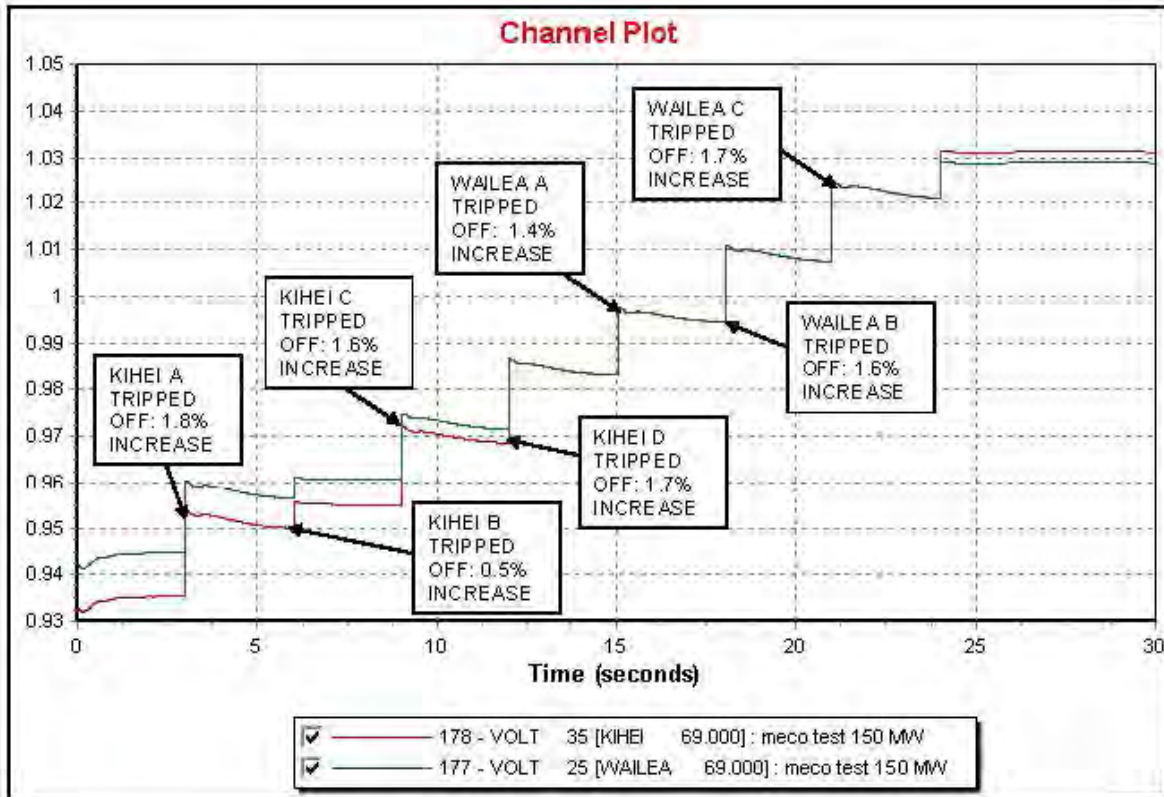


Figure 9: Peak Basecase Manually Shed Load

| PEAK CASE       |        |        |        |                       |                          |
|-----------------|--------|--------|--------|-----------------------|--------------------------|
| LOAD TSF        | MW     | MVAR   | MVA    | % INCREASE IN VOLTAGE | MVA SHED PER 1% INCREASE |
| KIHEI A         | 9.1820 | 0.8410 | 9.2204 | 2.7                   | 3.4150                   |
| KIHEI B         | 2.1563 | 0.7591 | 2.2860 | 0.8                   | 2.8575                   |
| KIHEI C         | 6.1963 | 2.1812 | 6.5690 | 2.3                   | 2.8561                   |
| KIHEI D         | 6.5327 | 2.3726 | 6.9502 | 2.5                   | 2.7801                   |
| WAILEA A        | 6.7263 | 2.1026 | 7.0473 | 2.0                   | 3.5236                   |
| WAILEA B        | 7.6871 | 2.4030 | 8.0539 | 2.3                   | 3.5017                   |
| WAILEA C        | 8.0990 | 2.5317 | 8.4855 | 2.3                   | 3.6893                   |
| <b>AVERAGE:</b> |        |        |        |                       | 3.2319                   |

Table 3: Peak Basecase, % Voltage Increase vs. Load Shed

## Maalaea-Kamalii Transmission Line Alternatives



**Figure 10: 150 MW Case Manually Shed Load**

| 150 MW CASE     |        |        |        |                       |                          |
|-----------------|--------|--------|--------|-----------------------|--------------------------|
| LOAD TSF        | MW     | MVAR   | MVA    | % INCREASE IN VOLTAGE | MVA SHED PER 1% INCREASE |
| KIHEI A         | 6.7219 | 0.6157 | 6.7500 | 1.8                   | 3.7500                   |
| KIHEI B         | 1.5786 | 0.5557 | 1.6736 | 0.5                   | 3.3471                   |
| KIHEI C         | 4.5362 | 1.5968 | 4.8090 | 1.6                   | 3.0057                   |
| KIHEI D         | 4.7824 | 1.7369 | 5.0880 | 1.7                   | 2.9930                   |
| WAILEA A        | 4.9241 | 1.5393 | 5.1591 | 1.4                   | 3.6851                   |
| WAILEA B        | 5.6276 | 1.7592 | 5.8962 | 1.6                   | 3.6851                   |
| WAILEA C        | 5.9291 | 1.8534 | 6.2120 | 1.7                   | 3.6541                   |
| <b>AVERAGE:</b> |        |        |        |                       | <b>3.4457</b>            |

**Table 4: 150 MW Case, % Voltage Increase vs. Load Shed**



As an example, to increase the Kihei bus voltage from 0.8637 pu to 0.9 pu during peak load conditions with the loss of the Maalaea-Kihei 69 kV line, as indicated in Table 1, a total of approximately 12 MVA load would have to be shed. To restore the bus to a more stable voltage range, from 0.92 pu to 0.95 pu, about 18 MVA to 28 MVA would have to be shed, respectively.

**Speed of Load Shed:**

When designing the speed of load shed there are several factors to consider including:

- False tripping due to faults
- Load Tap Changers
- Generator Response

High-impedance faults on the system can result in momentary low voltage conditions until the fault can be cleared. In some cases, it may take several seconds for a fault to clear. The UVLS scheme should provide a long enough delay to avoid nuisance tripping of loads.

The automatic load tap changers (LTC's) on the distribution transformers at the Kihei and Wailea substations regulate the low side of these transformers, and they run on a 30 second time delay. Typically, it is recommended to shed loads before the operation of the LTC's to prevent an increased demand of reactive power to support voltage. However, the results of a load flow analysis (Table 5 below) show that after the loss of the MPP to Kihei line, the system as a whole would require an approximate increase of 4 MW and 15.7 MVAR. But, the increase in load in the South Maui area is small, 0.68 MVAR to Kihei and 0.36 MVAR to Wailea. In fact, for the third case, which allows the taps to move, the amount of power needed for the whole system actually decreases a little. Therefore, for this case, shedding before the LTC movement is not critical.

| CASES                                  | KIHEI     |                 | WAILEA    |                 | TOTAL SYSTEM |                 |
|--|-----------|-----------------|-----------|-----------------|--------------|-----------------|
|  | REAL (MW) | REACTIVE (MVAR) | REAL (MW) | REACTIVE (MVAR) | REAL (MW)    | REACTIVE (MVAR) |
| 1 PEAK NORMAL                          | 24.0673   | 8.1098          | 22.5124   | 8.3729          | 204.1643     | 77.6800         |
| 2 "INSTANTANEOUS" N-1 WITH LOCKED TAPS | 24.0672   | 8.7897          | 22.5123   | 8.7330          | 208.1694     | 93.4093         |
| 3 N-1 WITH STEPPING TAPS               | 24.0680   | 8.7831          | 22.5126   | 8.7292          | 208.0686     | 92.2274         |

Table 5: LTC Impact on Load

Lastly, the generators do not respond instantaneously to the low voltage problems. There is a time delay from the sensing of the change in voltage and the generator's response. Since shedding customer load is never ideal, ample time must be given for the generators to attempt to mitigate this problem, before shedding. Therefore, the UVLS relays will delay for at least 60 seconds before load shedding commences. This delay also gives more than enough time to avoid the nuisance tripping for high-impedance faults.

## Maalaea-Kamalii Transmission Line Alternatives

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### RESULTS AND RECOMMENDATIONS:

#### Undervoltage Load Shed Scheme:

With the existing equipment at Kihei Substation, feeder 1473 of Unit 3 and feeder 1515 of Unit 4 have the ability to trip offline for undervoltage problems. However, in order to trip Unit 1 and Unit 2, an existing transmission line relay would have to be upgraded. It is recommended for uniformity and to avoid unnecessary confusion that this upgraded relay is used for the shedding of all four units. The voltage will be sampled from the existing coupling capacitors, which measures the 69 kV level. Since the UVLS scheme has a long time delay, the response time delay of the coupling capacitors will not be an issue. As seen previously in this study, Units 3 and 4 (transformers C and D, respectively) of Kihei sum up to about 10 MVA to 13.5 MVA, depending on the total system load. By shedding this load, the voltage in South Maui can improve by about 3% to 4.5%. Units 1 and 2 (transformers A and B, respectively), sum up to about 8.4 MVA to 11.5 MVA. Shedding Units 1 and 2 can improve voltage in the South Maui area by approximately 2.4% to 3.4%.

The future Wailea Unit 4 will also have the capability of undervoltage load shedding. For this study, the existing load at Wailea is assumed to be redistributed equally amongst all four units, which will load Unit 4 at approximately 5.9 MVA at the system peak load condition. Shedding Unit 4 at Wailea, if loaded at around 5.9 MVA, will provide slightly less than 2% increase in the South Maui Voltage.

Table 6 shows the settings used for the relay models.

| SUB/UNIT      | TIME DELAY  | VOLTAGE PICK-UP | LOAD SHED (PEAK CASE) |
|---------------|-------------|-----------------|-----------------------|
| Kihei/Unit 3  | 60 seconds  | 0.91 pu         | 6.6 MVA               |
| Kihei/Unit 4  | 90 seconds  | 0.91 pu         | 7.0 MVA               |
| Kihei/Unit 1  | 120 seconds | 0.91 pu         | 9.2 MVA               |
| Kihei/Unit 2  | 120 seconds | 0.91 pu         | 2.3 MVA               |
| Wailea/Unit 4 | 150 seconds | 0.91 pu         | 5.9 MVA               |

Table 6: UVLS Relay Trip Settings



**Plots:**

The first two plots, Figures 11 and 12, shown below are dynamic plots of the peak system case where the line from MPP to Kihei is tripped at 2 seconds. As shown, the UVLS scheme picks up 60 seconds later by tripping Kihei Unit 3 because the voltage at Kihei settled below 0.91 pu. In this case, the shedding Kihei Unit 3 was enough to raise the Kihei bus voltage above the set point. Keep in mind that these cases do not have any capacitor banks online in Kihei and Wailea to show the most pessimistic cases for this study. Therefore, even though the voltage at Kihei is only slightly above 0.90 pu, typically there will be more VAR support from local capacitor banks to boost the voltage into a more ideal range.

The second set of plots, Figures 13 and 14, show a case where Kihei has an extra heavy reactive load which is modeled as an additional 15 MVAR load at the Kihei bus. Again, the line from MPP to Kihei trips off at the 2 second mark. The plots show that the additional load drags the voltage down lower and triggers the UVLS scheme. The load at Kihei Unit 3 trips off at 62 seconds, followed by Kihei Unit 4 load at 92 seconds, and lastly Kihei Units 1 and 2 at 122 seconds.

## Maalaea-Kamalii Transmission Line Alternatives

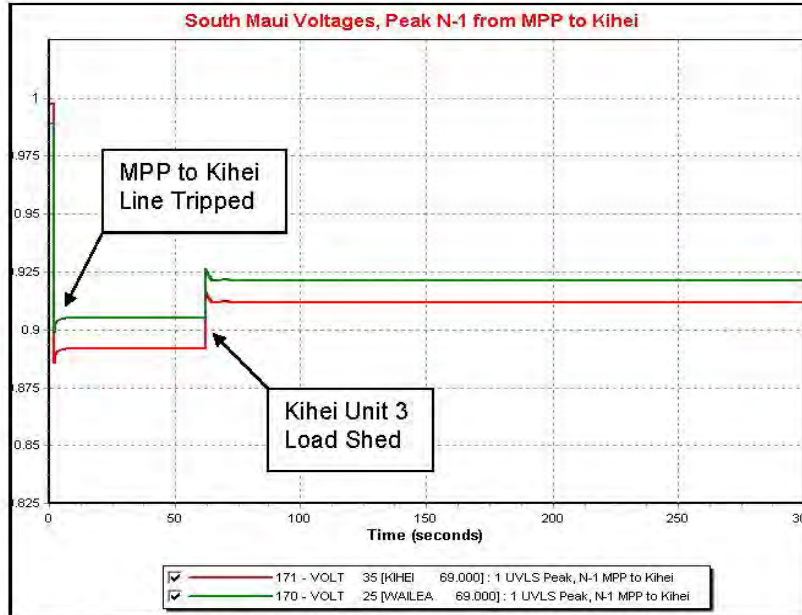


Figure 11: South Maui Voltages, Peak with N-1 from MPP to Kihei

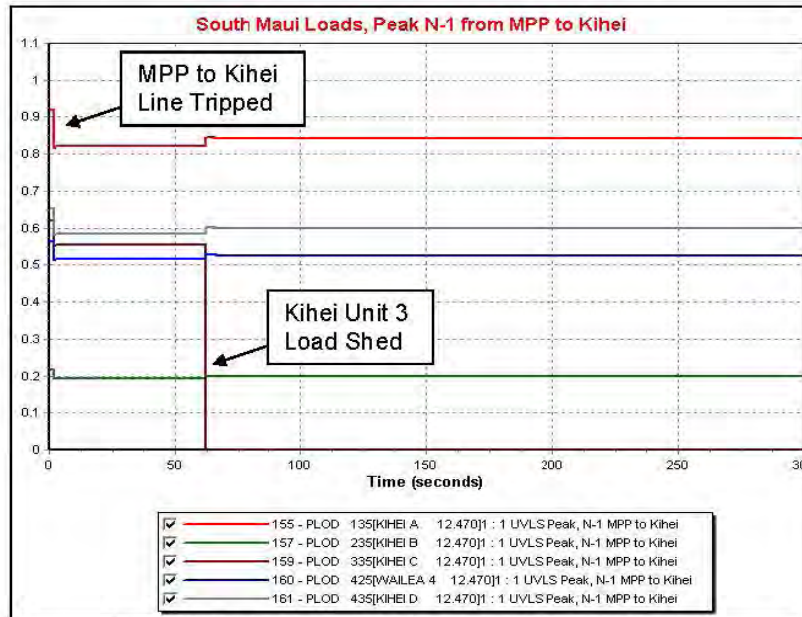


Figure 12: South Maui Loads, Peak with N-1 from MPP to Kihei

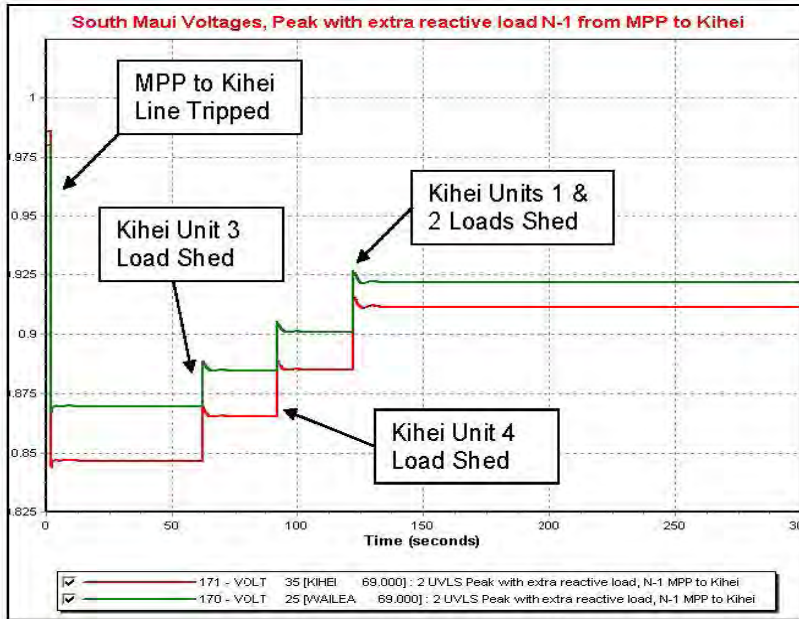


Figure 13: South Maui Voltages, Peak with Extra Kihei Load, N-1 MPP to Kihei

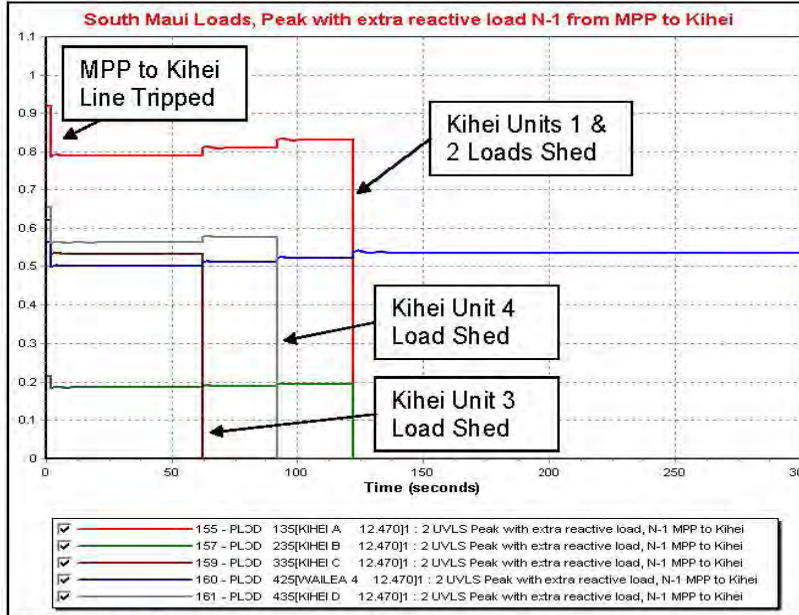


Figure 14: South Maui Loads, Peak with Extra Kihei Load, N-1 MPP to Kihei

## Maalaea-Kamalii Transmission Line Alternatives

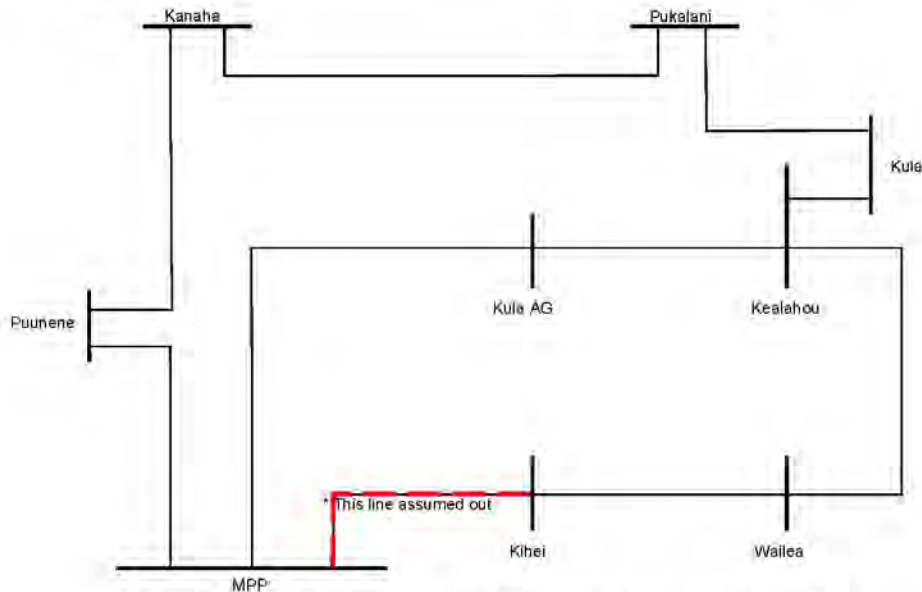
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**Worst-case Scenarios:**

Even though the MECO planning criteria does not require to plan for N-2 conditions, it is important that operators are aware of the following scenarios that can cause severe voltage problems as well as the high risk of voltage collapse. As identified earlier, the N-1 case from MPP to Kihei creates low voltage conditions in the South Maui area, as well as puts the MECO system at risk for a possible voltage collapse. When the MPP to Kihei line-out condition is paired with several of the other line-out conditions the system is at great risk for collapse.

Assuming the line from MPP to Kihei is out, if any of the 69 kV lines **from MPP to Puunene, or Puunene to Kanaha, or Kanaha to Pukalani** is out at the same time, it is possible that the system will be either at the point of collapse or very close to it. This is illustrated by the QV plot on the following page. However, the UVLS scheme should be able to mitigate these cases. The dynamic plots for the UVLS scheme implemented for these worst case scenarios can be found in Appendix B.

In addition, if the line from **MPP to Kealahou** is out while the MPP to Kihei line is also out, then the system will be the most susceptible to a collapse because the power that is usually fed by the two lines that are out must now travel all the way from MPP through Puunene, Kanaha, Pukalani, and Kula to serve the South Maui load. Due to the severe nature of this contingency, the UVLS scheme may not be able to mitigate a collapse for this specific case, however the load shedding will make a considerable difference in the resulting voltage.



**Figure 15: 69 kV Transmission Lines Feeding South/Up-country Maui Area**

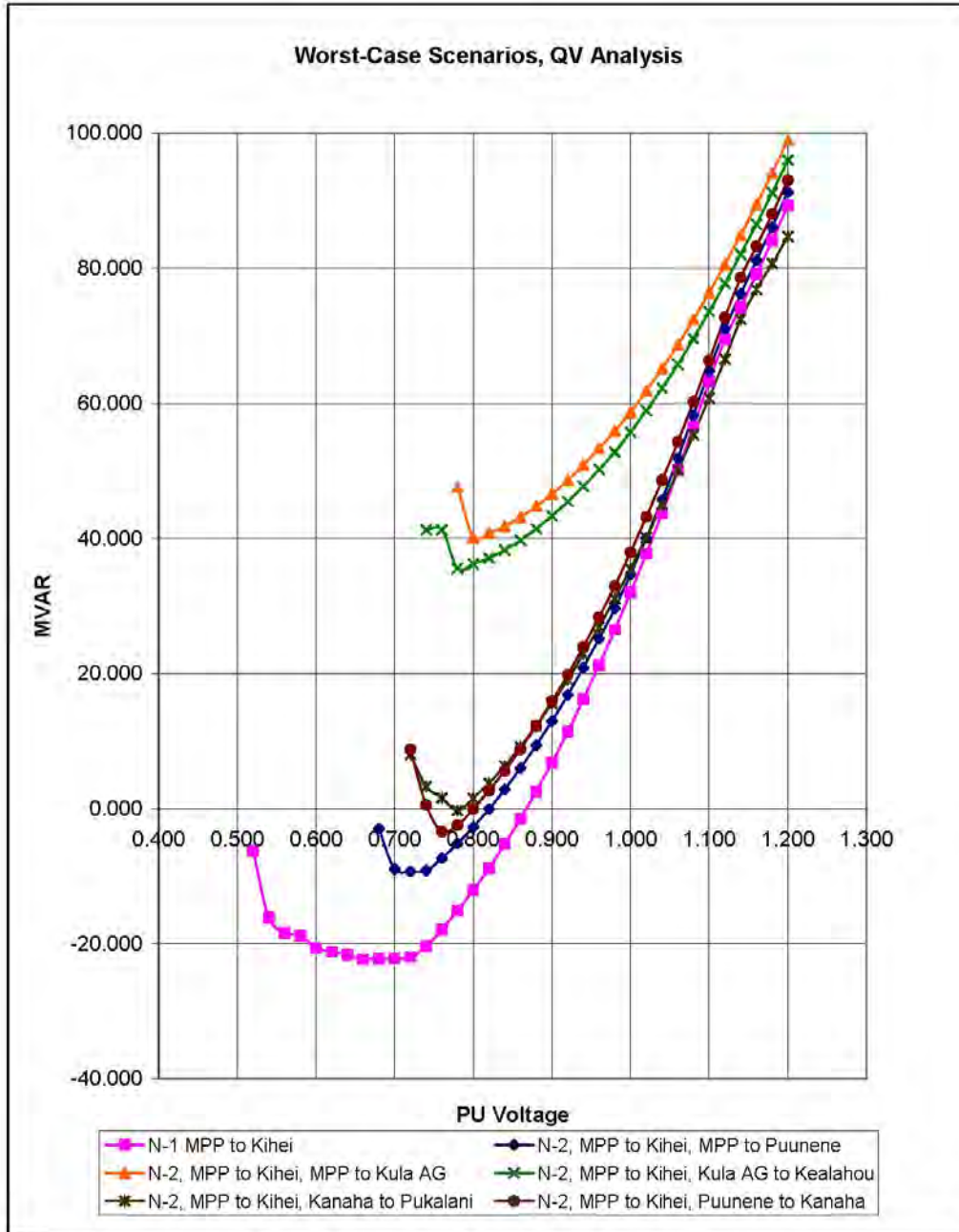


Figure 16: Worst-case Scenario, QV Analysis

## Maalaea-Kamalii Transmission Line Alternatives

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### **CONCLUSION:**

The UVLS scheme is an interim solution for the delayed installation of the second transmission line to the South Maui area. This scheme will help correct undervoltage violations and will help mitigate a system wide voltage collapse.

The UVLS scheme utilizes a relatively long time delay to avoid nuisance tripping, to allow faults to clear, and to allow the generators time to respond. This scheme will shed load in four blocks starting with Kihei Unit 3, then Kihei Unit 4, followed by both Kihei Unit 1 and Unit 2, and lastly Wailea Unit 4. In total, the scheme can shed up to approximately 15 % of the total system load.

Again, the UVLS scheme should be considered a "remedial" measure and is not intended to replace other system improvements. Additionally, the scheme should be reviewed following any major system changes or upgrades.



APPENDIX A

# Maalaea-Kamalii Transmission Line Alternatives

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR       | Minimum Load | Min load violation?     | DR |        |          |  |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|----------|--------------|-------------------------|----|--------|----------|--|
| 101        | KGS-1    | 11 500 | 1    | -2          | 1.022             | 200        | 0         | 4.76      | 5         | 0           | 2.9276      | 3           | 0           | 6.25     | 0            | 2.5                     | 0  | 0      |          |  |
| 102        | KGS-2    | 11 500 | 2    | -2          | 1.022             | 200        | 0         | 4.8       | 5         | 0           | 2.0015      | 3           | 0           | 6.25     | 0            | 2.5                     | 0  | 0      |          |  |
| 103        | KGS-3    | 11 500 | 3    | 2           | 1.022             | 200        | 1         | 7.5       | 11.5      | 0           | 2.9569      | 7.1         | 0           | 13.53    | 4            | 7.5                     | 1  | 0      |          |  |
| 104        | KGS-4    | 11 500 | 4    | 2           | 1.022             | 200        | 1         | 7.5       | 12.5      | 0           | 2.9569      | 9.375       | 0           | 15.63    | 5            | 7.5                     | 1  | 0      |          |  |
| 105        | MGS-123  | 4 1600 | 1    | -2          | 1.031             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0      |          |  |
| 105        | MGS-123  | 4 1600 | 2    | -2          | 1.031             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0      |          |  |
| 105        | MGS-123  | 4 1600 | 3    | -2          | 1.031             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0      |          |  |
| 106        | MGS-458  | 4 1600 | 4    | -2          | 1.031             | 39         | 0         | 3.43      | 5.6       | 0           | 1.4013      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 106        | MGS-458  | 4 1600 | 5    | -2          | 1.031             | 39         | 0         | 4.41      | 5.6       | 0           | 1.8016      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 106        | MGS-458  | 4 1600 | 6    | -2          | 1.031             | 39         | 0         | 0         | 5.6       | 0           | 1.491       | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 107        | MGS-679  | 4 1600 | 6    | -2          | 1.031             | 39         | 0         | 3.39      | 5.6       | 0           | 1.3938      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 107        | MGS-679  | 4 1600 | 7    | -2          | 1.031             | 39         | 0         | 4.4       | 5.6       | 0           | 1.8091      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 107        | MGS-679  | 4 1600 | 8    | -2          | 1.031             | 39         | 0         | 0         | 5.6       | 0           | 2.1169      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0      |          |  |
| 108        | MGS-1011 | 6 9000 | 0    | -2          | 1.031             | 39         | 0         | 10.86     | 12.5      | 0           | 5.3381      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0      |          |  |
| 108        | MGS-1011 | 6 9000 | 1    | -2          | 1.031             | 39         | 0         | 5.43      | 12.5      | 0           | 3.6141      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0      |          |  |
| 109        | MGS-1213 | 6 9000 | 2    | -2          | 1.031             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0      |          |  |
| 109        | MGS-1213 | 6 9000 | 3    | -2          | 1.031             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0      |          |  |
| 110        | MGS-X1X2 | 4 1600 | 1    | -2          | 1.031             | 39         | 0         | 0         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0      |          |  |
| 110        | MGS-X1X2 | 4 1600 | 2    | -2          | 1.031             | 39         | 0         | 2         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0      |          |  |
| 301        | CT-1 M14 | 13 800 | 1    | 3           | 1.005             | 0          | 1         | 15.8429   | 21.5      | 0           | 5.886       | 15          | 0           | 26.81    | 5.8571       | 12.5                    | 1  | 3.1429 |          |  |
| 302        | CT-2 M16 | 13 800 | 2    | 2           | 1.029             | 39         | 1         | 15.5      | 21.5      | 0           | 5.6596      | 15          | 0           | 26.81    | 6            | 12.5                    | 1  | 3      |          |  |
| 303        | ST-1 M15 | 13 800 | 3    | 2           | 1.031             | 39         | 1         | 11        | 15        | 0           | 4.009       | 12          | 0           | 18.5     | 4            | 11                      | 1  | 0      |          |  |
| 304        | CT-3 M17 | 13 800 | 4    | 2           | 1.031             | 39         | 1         | 14        | 21.5      | 0           | 4.9051      | 15          | 0           | 26.81    | 7.5          | 14                      | 1  | 0      |          |  |
| 305        | CT-4 M19 | 13 800 | 5    | -2          | 1.031             | 39         | 0         | 16        | 21.5      | 0           | 5.3867      | 15          | 0           | 26.81    | 0            | 14                      | 0  | 0      |          |  |
| 306        | ST-2 M18 | 13 800 | 6    | 2           | 1.029             | 39         | 1         | 3         | 15        | 0           | 1.2407      | 12          | 0           | 18.5     | 12           | 3                       | 1  | 0      |          |  |
| 804        | HC&S TG4 | 13 800 | 4    | 2           | 0.9501            | 0          | 1         | 8         | 19.6      | 0           | 0.2678      | 5.1         | 0           | 24.5     | 8            | 8                       | 1  | 0      |          |  |
| 90971      | KWPI_1   | 0.5750 | 1    | -2          | 1                 | 0          | 1         | 3         | 30        | 0           | 0           | 14.5        | 0           | 33.34    | 0            | 8                       | 1  | 0      |          |  |
| 9          |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR | 35.3571      |                         | 9  | 6.1429 | Total DR |  |
|            |          |        |      |             |                   |            |           |           |           |             |             |             |             | SR Flag  | 0            | Min Load Violation Flag | 0  | 0      | DR Flag  |  |

MACHINE SUMMARY:

| Bus#             | X-       | NAME   | --K | BASKV   | ID     | KW      | KVAR | QMAX   | QMIN    | ETERM  | CURRENT | PF | KVBASE | X    | T | R | A | N | GENTAP | ZONE | AREA | SWING |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|------------------|----------|--------|-----|---------|--------|---------|------|--------|---------|--------|---------|----|--------|------|---|---|---|---|--------|------|------|-------|---------|---------|-----------|-----|--|--|----------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| 103              | KGS-3    | 11.500 | 3   | 7500.0  | 2956.9 | 7100.0  | 0.0  | 0.9663 | 8174.0  | 0.9303 | 13529.0 | 19 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 104              | KGS-4    | 11.500 | 4   | 7500.0  | 2956.9 | 9375.0  | 0.0  | 1.0074 | 8002.5  | 0.9303 | 13625.0 | 19 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 301              | CT-1 M14 | 13.800 | 1   | 15642.9 | 5886.0 | 15000.0 | 0.0  | 1.0050 | 16630.5 | 0.9359 | 26813.0 | 20 | 2      | SYST |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 302              | CT-2 M16 | 13.800 | 2   | 15500.0 | 5659.8 | 15000.0 | 0.0  | 1.0042 | 16431.4 | 0.9393 | 26813.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 303              | ST-1 M15 | 13.800 | 3   | 11000.0 | 4009.0 | 12000.0 | 0.0  | 0.9989 | 11720.2 | 0.9395 | 18500.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 304              | CT-3 M17 | 13.800 | 4   | 14000.0 | 4905.1 | 15000.0 | 0.0  | 0.9789 | 15154.9 | 0.9438 | 26813.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 306              | ST-2 M18 | 13.800 | 6   | 3000.0  | 1226.3 | 12000.0 | 0.0  | 0.9659 | 3355.3  | 0.9257 | 18500.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 804              | HC&S TG4 | 13.800 | 4   | 8000.0  | 297.6  | 5100.0  | 0.0  | 0.9501 | 8426.0  | 0.9993 | 24500.0 | 9  | 1      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 90971            | KWPI_1   | 0.5750 | 1   | 3000.0  | 0.0    | 14500.0 | 0.0  | 1.0048 | 2985.6  | 1.0000 | 33340.0 | 11 | 1      |      |   |   |   |   |        |      |      |       |         |         |           |     |  |  |          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| SUBSYSTEM TOTALS |          |        |     |         |        |         |      |        |         |        |         |    |        |      |   |   |   |   |        |      |      |       | 85142.9 | 27897.8 | 8105075.0 | 0.0 |  |  | 204433.0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

MIN BASECASE

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR       | Minimum Load | Min load violation?     | DR |       |          |  |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|----------|--------------|-------------------------|----|-------|----------|--|
| 101        | KGS-1    | 11 500 | 1    | -2          | 1.022             | 200        | 0         | 4.76      | 5         | 0           | 2.9276      | 3           | 0           | 6.25     | 0            | 2.5                     | 0  | 0     |          |  |
| 102        | KGS-2    | 11 500 | 2    | -2          | 1.022             | 200        | 0         | 4.8       | 5         | 0           | 2.0015      | 3           | 0           | 6.25     | 0            | 2.5                     | 0  | 0     |          |  |
| 103        | KGS-3    | 11 500 | 3    | 2           | 1.022             | 200        | 1         | 7.5       | 11.5      | 0           | 3.596       | 7.1         | 0           | 13.53    | 4            | 7.5                     | 1  | 0     |          |  |
| 104        | KGS-4    | 11 500 | 4    | 2           | 1.022             | 200        | 1         | 7.5       | 12.5      | 0           | 3.596       | 9.375       | 0           | 15.63    | 5            | 7.5                     | 1  | 0     |          |  |
| 105        | MGS-123  | 4 1600 | 1    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0     |          |  |
| 105        | MGS-123  | 4 1600 | 2    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0     |          |  |
| 105        | MGS-123  | 4 1600 | 3    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0     |          |  |
| 106        | MGS-458  | 4 1600 | 4    | -2          | 1.029             | 39         | 0         | 3.43      | 5.6       | 0           | 1.4013      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 106        | MGS-458  | 4 1600 | 5    | -2          | 1.029             | 39         | 0         | 4.41      | 5.6       | 0           | 1.8016      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 106        | MGS-458  | 4 1600 | 6    | -2          | 1.029             | 39         | 0         | 0         | 5.6       | 0           | 1.491       | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 107        | MGS-679  | 4 1600 | 6    | -2          | 1.029             | 39         | 0         | 3.39      | 5.6       | 0           | 1.3938      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 107        | MGS-679  | 4 1600 | 7    | -2          | 1.029             | 39         | 0         | 4.4       | 5.6       | 0           | 1.8091      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 107        | MGS-679  | 4 1600 | 8    | -2          | 1.029             | 39         | 0         | 0         | 5.6       | 0           | 2.1169      | 4.2         | 0           | 7        | 0            | 2                       | 0  | 0     |          |  |
| 108        | MGS-1011 | 6 9000 | 0    | -2          | 1.029             | 39         | 0         | 10.86     | 12.5      | 0           | 5.3381      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0     |          |  |
| 108        | MGS-1011 | 6 9000 | 1    | -2          | 1.029             | 39         | 0         | 5.43      | 12.5      | 0           | 3.6141      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0     |          |  |
| 109        | MGS-1213 | 6 9000 | 2    | -2          | 1.029             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0     |          |  |
| 109        | MGS-1213 | 6 9000 | 3    | -2          | 1.029             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63    | 0            | 6                       | 0  | 0     |          |  |
| 110        | MGS-X1X2 | 4 1600 | 1    | -2          | 1.029             | 39         | 0         | 0         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0     |          |  |
| 110        | MGS-X1X2 | 4 1600 | 2    | -2          | 1.029             | 39         | 0         | 2         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44     | 0            | 2.5                     | 0  | 0     |          |  |
| 301        | CT-1 M14 | 13 800 | 1    | 3           | 1.0003            | 0          | 1         | 14.808    | 21.5      | 0           | 5.039       | 15          | 0           | 26.81    | 6.692        | 12.5                    | 1  | 2.308 |          |  |
| 302        | CT-2 M16 | 13 800 | 2    | 2           | 1.029             | 39         | 1         | 15        | 21.5      | 0           | 4.7938      | 15          | 0           | 26.81    | 6.5          | 12.5                    | 1  | 2.5   |          |  |
| 303        | ST-1 M15 | 13 800 | 3    | 2           | 1.029             | 39         | 1         | 11        | 15        | 0           | 4.5118      | 12          | 0           | 18.5     | 4            | 11                      | 1  | 0     |          |  |
| 304        | CT-3 M17 | 13 800 | 4    | 2           | 1.029             | 39         | 1         | 16        | 21.5      | 0           | 5.6397      | 15          | 0           | 26.81    | 5.5          | 14                      | 1  | 2     |          |  |
| 305        | CT-4 M19 | 13 800 | 5    | -2          | 1.029             | 39         | 0         | 16        | 21.5      | 0           | 5.3867      | 15          | 0           | 26.81    | 0            | 14                      | 0  | 0     |          |  |
| 306        | ST-2 M18 | 13 800 | 6    | 2           | 1.029             | 39         | 1         | 3         | 15        | 0           | 1.2407      | 12          | 0           | 18.5     | 12           | 3                       | 1  | 0     |          |  |
| 804        | HC&S TG4 | 13 800 | 4    | 2           | 0.9501            | 0          | 1         | 8         | 19.6      | 0           | 0.8417      | 5.1         | 0           | 24.5     | 8            | 8                       | 1  | 0     |          |  |
| 90971      | KWPI_1   | 0.5750 | 1    | 2           | 1.01              | 0          | 1         | 17        | 30        | 0           | 0.8604      | 14.5        | 0           | 33.34    | 0            | 8                       | 1  | 0     |          |  |
| 9          |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR | 34.692       |                         | 8  | 6.608 | Total DR |  |
|            |          |        |      |             |                   |            |           |           |           |             |             |             |             | SR Flag  | 0            | Min Load Violation Flag | 0  | 0     | DR Flag  |  |

MACHINE SUMMARY:

| Bus# | X-       | NAME   | --K | BASKV   | ID     | KW      | KVAR | QMAX   | QMIN    | ETERM  | CURRENT | PF | KVBASE | X    | T | R | A | N | GENTAP | ZONE | AREA | SWING |
|------|----------|--------|-----|---------|--------|---------|------|--------|---------|--------|---------|----|--------|------|---|---|---|---|--------|------|------|-------|
| 103  | KGS-3    | 11.500 | 3   | 7500.0  | 3543.3 | 7100.0  | 0.0  | 0.9685 | 8391.6  | 0.9042 | 13529.0 | 19 | 2      |      |   |   |   |   |        |      |      |       |
| 104  | KGS-4    | 11.500 | 4   | 7500.0  | 3543.3 | 9375.0  | 0.0  | 1.0085 | 8224.7  | 0.9042 | 13625.0 | 19 | 2      |      |   |   |   |   |        |      |      |       |
| 301  | CT-1 M14 | 13.800 | 1   | 14825.4 | 6111.2 | 15000.0 | 0.0  | 1.0050 | 15955.8 | 0.9245 | 26813.0 | 20 | 2      | SYST |   |   |   |   |        |      |      |       |
| 302  | CT-2 M16 | 13.800 | 2   | 15000.0 | 6281.5 | 15000.0 | 0.0  | 1.0056 | 16112.2 | 0.9224 | 26813.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |
| 303  | ST-1 M15 | 13.800 | 3   | 11000.0 | 5025.2 | 12000.0 | 0.0  | 1.0016 | 12074.6 | 0.9096 | 18500.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |
| 304  | CT-3 M17 | 13.800 | 4   | 16000.0 | 6281.5 | 15000.0 | 0.0  | 0.9827 | 17492.0 | 0.9308 | 26813.0 | 20 | 2      |      |   |   |   |   |        |      |      |       |
| 306  | ST-2 M18 | 13.800 | 6   | 3000.0  | 1381.9 | 12000.0 | 0.0  | 0.9656 | 3420.6  | 0.9083 | 18500.0 | 20 |        |      |   |   |   |   |        |      |      |       |

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR        | Minimum Load | Min load violation?     | DR |         |           |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|--------------|-------------------------|----|---------|-----------|
| 101        | KGS-1    | 11.500 | 1    | 2           | 1.022             | 200        | 1         | 4.8       | 5         | 0           | 1.7623      | 3           | 0           | 6.25      | 0.2          | 2.5                     | 1  | 2.3     |           |
| 102        | KGS-2    | 11.500 | 2    | 2           | 1.022             | 200        | 1         | 4.8       | 5         | 0           | 1.7623      | 3           | 0           | 6.25      | 0.2          | 2.5                     | 1  | 2.3     |           |
| 103        | KGS-3    | 11.500 | 3    | 2           | 1.022             | 200        | 1         | 7.5       | 11.5      | 0           | 2.6434      | 7.1         | 0           | 13.53     | 4            | 7.5                     | 1  | 0       |           |
| 104        | KGS-4    | 11.500 | 4    | 2           | 1.022             | 200        | 1         | 7.5       | 12.5      | 0           | 2.6434      | 9.375       | 0           | 15.63     | 5            | 7.5                     | 1  | 0       |           |
| 105        | MGS-123  | 4.1600 | 1    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 105        | MGS-123  | 4.1600 | 2    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 105        | MGS-123  | 4.1600 | 3    | -2          | 1.029             | 39         | 0         | 1.75      | 2.5       | 0           | 0.7117      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 4    | -2          | 1.029             | 39         | 0         | 3.43      | 5.6       | 0           | 1.4013      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 5    | -2          | 1.029             | 39         | 0         | 4.41      | 5.6       | 0           | 1.8016      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 8    | -2          | 1.029             | 39         | 0         | 0         | 5.6       | 0           | 1.491       | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 6    | -2          | 1.029             | 39         | 0         | 3.39      | 5.6       | 0           | 1.3938      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 7    | -2          | 1.029             | 39         | 0         | 4.4       | 5.6       | 0           | 1.8091      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 9    | -2          | 1.029             | 39         | 0         | 0         | 5.6       | 0           | 2.1169      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 108        | MGS-1011 | 6.9000 | 0    | -2          | 1.029             | 39         | 0         | 10.86     | 12.5      | 0           | 5.3381      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 108        | MGS-1011 | 6.9000 | 1    | -2          | 1.029             | 39         | 0         | 5.43      | 12.5      | 0           | 3.6141      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 109        | MGS-1213 | 6.9000 | 2    | -2          | 1.029             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 109        | MGS-1213 | 6.9000 | 3    | -2          | 1.029             | 39         | 0         | 7         | 12.5      | 0           | 3.5871      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 110        | MGS-X1X2 | 4.1600 | 1    | -2          | 1.029             | 39         | 0         | 0         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 110        | MGS-X1X2 | 4.1600 | 2    | -2          | 1.029             | 39         | 0         | 2         | 2.5       | 0           | 1.875       | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 301        | CT-1 M14 | 13.800 | 1    | 3           | 1.003             | 0          | 1         | 14.8234   | 21.5      | 0           | 5.8084      | 15          | 0           | 26.81     | 6.6766       | 12.5                    | 1  | 2.3234  |           |
| 302        | CT-2 M16 | 13.800 | 2    | 2           | 1.029             | 39         | 1         | 14.5      | 21.5      | 0           | 5.3892      | 15          | 0           | 26.81     | 7            | 12.5                    | 1  | 2       |           |
| 303        | ST-1 M15 | 13.800 | 3    | 2           | 1.029             | 39         | 1         | 11        | 15        | 0           | 4.7504      | 12          | 0           | 18.5      | 4            | 11                      | 1  | 0       |           |
| 304        | CT-3 M17 | 13.800 | 4    | 2           | 1.029             | 39         | 1         | 14        | 21.5      | 0           | 5.988       | 15          | 0           | 26.81     | 7.5          | 14                      | 1  | 0       |           |
| 305        | CT-4 M19 | 13.800 | 5    | 2           | 1.029             | 39         | 1         | 14        | 21.5      | 0           | 5.988       | 15          | 0           | 26.81     | 7.5          | 14                      | 1  | 0       |           |
| 306        | ST-2 M18 | 13.800 | 6    | 2           | 1.029             | 39         | 1         | 8         | 15        | 0           | 3.6928      | 12          | 0           | 18.5      | 7            | 3                       | 1  | 5       |           |
| 804        | HC&S TG4 | 13.800 | 2    | 0.9501      | 0                 | 1          | 12        | 19.6      | 0         | 1.2940      | 5.1         | 0           | 24.5        | 8         | 8            | 1                       | 1  |         |           |
| 90971      | KWPI_1   | 0.6750 | 1    | 2           | 1.01              | 0          | 1         | 12        | 30        | 0           | 1.3811      | 14.5        | 0           | 33.34     | 0            | 0                       | 1  | 1       |           |
| 12         |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR= | 39.6766      |                         | 12 | 9.3234  | =Total DR |
|            |          |        |      |             |                   |            |           |           |           |             |             |             |             | SR Flag   | 0            | Min Load Violation Flag | 0  | DR Flag | 0         |

MACHINE SUMMARY:

| BUS#                                 | X-- NAME | --X    | BASKV | ID      | KW     | KVAR    | QMAX | QMIN   | ETERM   | CURRENT | PF      | KVBASE | X T R A N | GENTAP | ZONE | AREA | SWING |
|--------------------------------------|----------|--------|-------|---------|--------|---------|------|--------|---------|---------|---------|--------|-----------|--------|------|------|-------|
| 101                                  | KGS-1    | 11.500 | 1     | 4800.0  | 1762.3 | 3000.0  | 0.0  | 1.0214 | 5066.1  | 0.9387  | 6250.0  | 19     | 2         |        |      |      |       |
| 102                                  | KGS-2    | 11.500 | 2     | 4800.0  | 1762.3 | 3000.0  | 0.0  | 0.9947 | 5140.4  | 0.9387  | 6250.0  | 19     | 2         |        |      |      |       |
| 103                                  | KGS-3    | 11.500 | 3     | 7500.0  | 2643.4 | 7100.0  | 0.0  | 0.9846 | 8076.7  | 0.9431  | 13529.0 | 19     | 2         |        |      |      |       |
| 104                                  | KGS-4    | 11.500 | 4     | 7500.0  | 2643.4 | 9375.0  | 0.0  | 1.0063 | 7902.4  | 0.9431  | 15625.0 | 19     | 2         |        |      |      |       |
| 301                                  | CT-1 M14 | 13.800 | 1     | 14823.4 | 5808.4 | 15000.0 | 0.0  | 1.0030 | 15873.1 | 0.9311  | 26813.0 | 20     | 2         | SYST   |      |      |       |
| 302                                  | CT-2 M16 | 13.800 | 2     | 14500.0 | 5389.2 | 15000.0 | 0.0  | 1.0016 | 15444.6 | 0.9374  | 26813.0 | 20     | 2         |        |      |      |       |
| 303                                  | ST-1 M15 | 13.800 | 3     | 11000.0 | 4790.4 | 12000.0 | 0.0  | 0.9998 | 12000.2 | 0.9168  | 18500.0 | 20     | 2         |        |      |      |       |
| 304                                  | CT-3 M17 | 13.800 | 4     | 14000.0 | 5988.0 | 15000.0 | 0.0  | 0.9811 | 15520.2 | 0.9194  | 26813.0 | 20     | 2         |        |      |      |       |
| 305                                  | CT-4 M19 | 13.800 | 5     | 14000.0 | 5988.0 | 15000.0 | 0.0  | 0.9811 | 15520.2 | 0.9194  | 26813.0 | 20     | 2         |        |      |      |       |
| 306                                  | ST-2 M18 | 13.800 | 6     | 8000.0  | 3502.8 | 12000.0 | 0.0  | 0.9728 | 9015.4  | 0.9122  | 18500.0 | 20     | 2         |        |      |      |       |
| 804                                  | HC&S TG4 | 13.800 | 4     | 12000.0 | 1294.9 | 5100.0  | 0.0  | 0.9501 | 12703.6 | 0.9942  | 24500.0 | 9      | 1         |        |      |      |       |
| 90971                                | KWPI_1   | 0.6750 | 1     | 12000.0 | 1381.1 | 14500.0 | 0.0  | 1.0100 | 11959.6 | 0.9934  | 33340.0 | 11     | 1         |        |      |      |       |
| SUBSYSTEM TOTALS                     |          |        |       |         |        |         |      |        |         |         |         |        |           |        |      |      |       |
| 124923.4 43044.5126075.0 0.0 24374.6 |          |        |       |         |        |         |      |        |         |         |         |        |           |        |      |      |       |

125 MW CASE

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR        | Minimum Load | Min load violation?     | DR |         |           |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|--------------|-------------------------|----|---------|-----------|
| 101        | KGS-1    | 11.500 | 1    | 2           | 1.0255            | 200        | 1         | 4.8       | 5         | 0           | 1.8503      | 3           | 0           | 6.25      | 0.2          | 2.5                     | 1  | 2.3     |           |
| 102        | KGS-2    | 11.500 | 2    | 2           | 1.0255            | 200        | 1         | 4.8       | 5         | 0           | 1.8503      | 3           | 0           | 6.25      | 0.2          | 2.5                     | 1  | 2.3     |           |
| 103        | KGS-3    | 11.500 | 3    | 2           | 1.0255            | 200        | 1         | 11        | 11.5      | 0           | 3.7006      | 7.1         | 0           | 13.53     | 0.5          | 7.5                     | 1  | 3.5     |           |
| 104        | KGS-4    | 11.500 | 4    | 2           | 1.0255            | 200        | 1         | 12        | 12.5      | 0           | 3.7006      | 9.375       | 0           | 15.63     | 0.5          | 7.5                     | 1  | 4.5     |           |
| 105        | MGS-123  | 4.1600 | 1    | -2          | 1.0285            | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 105        | MGS-123  | 4.1600 | 2    | -2          | 1.0285            | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 105        | MGS-123  | 4.1600 | 3    | -2          | 1.0285            | 39         | 0         | 2.42      | 2.5       | 0           | 0.7826      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 4    | -2          | 1.0285            | 39         | 0         | 4.3056    | 5.6       | 0           | 1.8749      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 5    | -2          | 1.0285            | 39         | 0         | 4.3707    | 5.6       | 0           | 1.1779      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 106        | MGS-458  | 4.1600 | 8    | -2          | 1.0285            | 39         | 0         | 4.0472    | 5.6       | 0           | 1.7624      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 6    | -2          | 1.0285            | 39         | 0         | 3.93      | 5.6       | 0           | 3.6373      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 7    | -2          | 1.0285            | 39         | 0         | 4.3841    | 5.6       | 0           | 1.3854      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 107        | MGS-679  | 4.1600 | 9    | -2          | 1.0285            | 39         | 0         | 2.5374    | 5.6       | 0           | 1.4260      | 4.2         | 0           | 7         | 0            | 2                       | 0  | 0       |           |
| 108        | MGS-1011 | 6.9000 | 0    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 8.0104      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 108        | MGS-1011 | 6.9000 | 1    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 4.1743      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 109        | MGS-1213 | 6.9000 | 2    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 4.2889      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 109        | MGS-1213 | 6.9000 | 3    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 4.2889      | 9.375       | 0           | 15.63     | 0            | 6                       | 0  | 0       |           |
| 110        | MGS-X1X2 | 4.1600 | 1    | -2          | 1.0285            | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1241      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 110        | MGS-X1X2 | 4.1600 | 2    | -2          | 1.0285            | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1257      | 1.875       | 0           | 3.44      | 0            | 2.5                     | 0  | 0       |           |
| 301        | CT-1 M14 | 13.800 | 1    | 3           | 1.009             | 0          | 1         | 16.2463   | 21.5      | 0           | 7.7444      | 15          | 0           | 26.81     | 5.2537       | 12.5                    | 1  | 3.7463  |           |
| 302        | CT-2 M16 | 13.800 | 2    | 2           | 1.0285            | 39         | 1         | 16        | 21.5      | 0           | 7.4179      | 15          | 0           | 26.81     | 5.5          | 12.5                    | 1  | 3.5     |           |
| 303        | ST-1 M15 | 13.800 | 3    | 2           | 1.0285            | 39         | 1         | 15        | 15        | 0           | 6.8473      | 12          | 0           | 18.5      | 0            | 11                      | 1  | 4       |           |
| 304        | CT-3 M17 | 13.800 | 4    | 2           | 1.0285            | 39         | 1         | 16        | 21.5      | 0           | 7.1897      | 15          | 0           | 26.81     | 5.5          | 14                      | 1  | 2       |           |
| 305        | CT-4 M19 | 13.800 | 5    | 2           | 1.0285            | 39         | 1         | 16        | 21.5      | 0           | 7.4179      | 15          | 0           | 26.81     | 5.5          | 14                      | 1  | 2       |           |
| 306        | ST-2 M18 | 13.800 | 6    | 2           | 1.0285            | 39         | 1         | 8         | 15        | 0           | 3.8231      | 12          | 0           | 18.5      | 7            | 3                       | 1  | 5       |           |
| 804        | HC&S TG4 | 13.800 | 4    | 2           | 0.937             | 0          | 1         | 12        | 13        | 0           | 0           | 5.1         | 0           | 24.5      | 8            | 1                       | 1  | 1       |           |
| 90971      | KWPI_1   | 0.6750 | 1    | 2           | 1.008             | 0          | 1         | 18        | 30        | 0           | 0.9746      | 14.5        | -0.2374     | 33.34     | 0            | 0                       | 1  | 1       |           |
| 12         |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR= | 28.7537      |                         | 12 | 20.2463 | =Total DR |
|            |          |        |      |             |                   |            |           |           |           |             |             |             |             | SR Flag   | 0            | Min Load Violation Flag | 0  | DR Flag | 0         |

MACHINE SUMMARY:

| BUS# | X-- NAME | --X    | BASKV | ID      | KW     | KVAR    | QMAX | QMIN   | ETERM   | CURRENT | PF      | KVBASE | X T R A N | GENTAP | ZONE | AREA | SWING |
|------|----------|--------|-------|---------|--------|---------|------|--------|---------|---------|---------|--------|-----------|--------|------|------|-------|
| 101  | KGS-1    | 11.500 | 1     | 4800.0  | 1850.3 | 3000.0  | 0.0  | 1.0217 | 5035.1  | 0.9331  | 6250.0  | 19     | 2         |        |      |      |       |
| 102  | KGS-2    | 11.500 | 2     | 4800.0  | 1850.3 | 3000.0  | 0.0  | 0.9941 | 5174.7  | 0.9331  | 6250.0  | 19     | 2         |        |      |      |       |
| 103  | KGS-3    | 11.500 | 3     | 11000.0 | 3700.6 | 7100.0  | 0.0  | 0.9927 | 11691.0 | 0.9478  | 13529.0 | 19     | 2         |        |      |      |       |
| 104  | KGS-4    | 11.500 | 4     | 12000.0 | 3700.6 | 9375.0  | 0.0  | 1.0130 | 12396.9 | 0.9556  | 15625.0 | 19     | 2         |        |      |      |       |
| 301  | CT-1 M14 | 13.800 | 1     | 16246.3 | 7744.4 | 15000.0 | 0.0  | 1.0090 | 17837.2 | 0.9027  | 26813.0 | 20     | 2         | SYST   |      |      |       |
| 302  | CT-2 M16 | 13.800 | 2     | 16000.0 | 7417.9 | 15000.0 | 0.0  | 1.0079 | 17497.4 | 0.9072  | 26813.0 | 20     | 2         |        |      |      |       |
| 303  | ST-1 M15 | 13.800 | 3     | 15000.0 | 6847.3 | 12000.  |      |        |         |         |         |        |           |        |      |      |       |

# Maalaea-Kamalii Transmission Line Alternatives

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR        | Minimum Load            | Min load violation? | DR |         |          |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|-------------------------|---------------------|----|---------|----------|
| 101        | KGS-1    | 11.500 | 1    | 2           | 1.025             | 200        | 1         | 4.8       | 5         | 0           | 1.2099      | 3           | 0           | 6.25      | 0.2                     | 2.5                 | 1  | 2.3     |          |
| 102        | KGS-2    | 11.500 | 2    | 1           | 1.025             | 200        | 1         | 4.8       | 5         | 0           | 1.2099      | 3           | 0           | 6.25      | 0.2                     | 2.5                 | 1  | 2.3     |          |
| 103        | KGS-3    | 11.500 | 3    | 2           | 1.025             | 200        | 1         | 11        | 11.5      | 0           | 2.6332      | 7.1         | 0           | 13.53     | 0.5                     | 7.5                 | 1  | 3.5     |          |
| 104        | KGS-4    | 11.500 | 4    | 2           | 1.025             | 200        | 1         | 12        | 12.5      | 0           | 2.8704      | 9.375       | 0           | 15.63     | 0.5                     | 7.6                 | 1  | 4.5     |          |
| 105        | MGS-123  | 4.1600 | 1    | -2          | 1.0285            | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 105        | MGS-123  | 4.1600 | 2    | -2          | 1.0285            | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 105        | MGS-123  | 4.1600 | 3    | -2          | 1.0285            | 39         | 0         | 2.42      | 2.5       | 0           | 0.7826      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 4    | -2          | 1.0285            | 39         | 0         | 4.3056    | 5.6       | 0           | 1.8749      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 5    | -2          | 1.0285            | 39         | 0         | 4.3707    | 5.6       | 0           | 1.1779      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 6    | -2          | 1.0285            | 39         | 0         | 4.0472    | 5.6       | 0           | 1.7624      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 6    | -2          | 1.0285            | 39         | 0         | 3.93      | 5.6       | 0           | 3.6373      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 7    | -2          | 1.0285            | 39         | 0         | 4.3841    | 5.6       | 0           | 3.854       | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 8    | -2          | 1.0285            | 39         | 0         | 2.5374    | 5.6       | 0           | 1.4266      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 108        | MGS-1011 | 6.9000 | 0    | -2          | 1.0285            | 39         | 1         | 11        | 12.5      | 0           | 9.375       | 9.375       | 0           | 15.63     | 1.5                     | 6                   | 1  | 5       |          |
| 108        | MGS-1011 | 6.9000 | 1    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 5.3956      | 9.375       | 0           | 15.63     | 0                       | 6                   | 0  | 0       |          |
| 109        | MGS-1213 | 6.9000 | 2    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 4.2889      | 9.375       | 0           | 15.63     | 0                       | 6                   | 0  | 0       |          |
| 109        | MGS-1213 | 6.9000 | 3    | -2          | 1.0285            | 39         | 0         | 11        | 12.5      | 0           | 4.2889      | 9.375       | 0           | 15.63     | 0                       | 6                   | 0  | 0       |          |
| 110        | MGS-X1X2 | 4.1600 | 1    | -2          | 1.0285            | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1241      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 110        | MGS-X1X2 | 4.1600 | 2    | -2          | 1.0285            | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1267      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 301        | CT-1 M14 | 13.800 | 1    | 3           | 1.011             | 0          | 1         | 17.8795   | 21.5      | 0           | 8.4218      | 15          | 0           | 26.81     | 3.6205                  | 12.5                | 1  | 5.3795  |          |
| 302        | CT-2 M16 | 13.800 | 2    | 2           | 1.0285            | 39         | 1         | 17.5      | 21.5      | 0           | 8.609       | 15          | 0           | 26.81     | 4                       | 12.5                | 1  | 5       |          |
| 303        | ST-1 M15 | 13.800 | 3    | 2           | 1.0285            | 39         | 1         | 11        | 15        | 0           | 5.2979      | 12          | 0           | 18.5      | 4                       | 11                  | 1  | 5       |          |
| 304        | CT-3 M17 | 13.800 | 4    | 2           | 1.0285            | 39         | 1         | 19        | 21.5      | 0           | 7.9468      | 15          | 0           | 26.81     | 2.5                     | 14                  | 1  | 5       |          |
| 305        | CT-4 M19 | 13.800 | 5    | 2           | 1.0285            | 39         | 1         | 19        | 21.5      | 0           | 7.2845      | 15          | 0           | 26.81     | 2.5                     | 14                  | 1  | 5       |          |
| 306        | ST-2 M18 | 13.800 | 6    | 2           | 1.0285            | 39         | 1         | 11        | 15        | 0           | 3.9734      | 12          | 0           | 18.5      | 4                       | 3                   | 1  | 8       |          |
| 804        | HC&S TG4 | 13.800 | 4    | 2           | 0.937             | 0          | 1         | 12        | 13        | 0           | 5.1         | 0           | 0           | 24.5      | 8                       | 1                   | 1  | 8       |          |
| 90971      | KWPI_1   | 0.5750 | 1    | 2           | 1.0065            | 0          | 1         | 24        | 30        | 0           | 0.749       | 14.5        | -0.2374     | 33.34     |                         |                     |    | 1       |          |
| 13         |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR= | 22.1205                 |                     | 13 | 33.3795 | Total DR |
| SR Flag    |          |        |      |             |                   |            |           |           |           |             |             |             |             | 0         | Min Load Violation Flag | 0                   | 0  | DR Flag |          |

MACHINE SUMMARY:

| BUS#             | X        | NAME   | --K | BASKV   | ID     | KW      | KVAR   | QMAX   | QMIN    | ETERM  | CURRENT | PF | KVBASE | X | T | R | A | N | GENTAP | ZONE | AREA | SWING    |         |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
|------------------|----------|--------|-----|---------|--------|---------|--------|--------|---------|--------|---------|----|--------|---|---|---|---|---|--------|------|------|----------|---------|----------|--------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|----------|
| 101              | KGS-1    | 11.500 | 1   | 4800.0  | 2143.5 | 3000.0  | 0.0    | 1.0242 | 5132.8  | 0.9131 | 6250.0  |    |        |   |   |   |   |   |        |      |      | 19       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 102              | KGS-2    | 11.500 | 2   | 4800.0  | 2143.5 | 3000.0  | 0.0    | 0.9872 | 5271.7  | 0.9131 | 6250.0  |    |        |   |   |   |   |   |        |      |      | 19       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 103              | KGS-3    | 11.500 | 3   | 11000.0 | 4665.3 | 7100.0  | 0.0    | 0.9978 | 11974.5 | 0.9206 | 13529.0 |    |        |   |   |   |   |   |        |      |      | 19       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 104              | KGS-4    | 11.500 | 4   | 12000.0 | 5085.6 | 9375.0  | 0.0    | 1.0178 | 12804.8 | 0.9207 | 15625.0 |    |        |   |   |   |   |   |        |      |      | 19       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 108              | MGS-1011 | 6.9000 | 0   | 11000.0 | 4958.0 | 9375.0  | 0.0    | 0.9935 | 12144.8 | 0.9117 | 15625.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 301              | CT-1 M14 | 13.800 | 1   | 17899.2 | 8423.0 | 15000.0 | 0.0    | 1.0110 | 19566.8 | 0.9048 | 26813.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 302              | CT-2 M16 | 13.800 | 2   | 17500.0 | 8056.8 | 15000.0 | 0.0    | 1.0098 | 19078.2 | 0.9084 | 26813.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 303              | ST-1 M15 | 13.800 | 3   | 11000.0 | 4958.0 | 12000.0 | 0.0    | 0.9999 | 12066.7 | 0.9117 | 18500.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 304              | CT-3 M17 | 13.800 | 4   | 19000.0 | 8676.5 | 15000.0 | 0.0    | 0.9895 | 21110.0 | 0.9096 | 26813.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 305              | CT-4 M19 | 13.800 | 5   | 19000.0 | 8676.5 | 15000.0 | 0.0    | 0.9895 | 21110.0 | 0.9096 | 26813.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 306              | ST-2 M18 | 13.800 | 6   | 11000.0 | 4958.0 | 12000.0 | 0.0    | 0.9773 | 12349.1 | 0.9117 | 18500.0 |    |        |   |   |   |   |   |        |      |      | 20       | 2       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 804              | HC&S TG4 | 13.800 | 4   | 12000.0 | 0.0    | 5100.0  | 0.0    | 0.9397 | 12770.3 | 1.0000 | 24500.0 |    |        |   |   |   |   |   |        |      |      | 9        | 1       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| 90971            | KWPI_1   | 0.5750 | 1   | 24000.0 | 749.0  | 14500.0 | -237.4 | 1.0065 | 23856.6 | 0.9999 | 33340.0 |    |        |   |   |   |   |   |        |      |      | 11       | 1       |          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |          |
| SUBSYSTEM TOTALS |          |        |     |         |        |         |        |        |         |        |         |    |        |   |   |   |   |   |        |      |      | 174999.2 | 63493.0 | 133450.0 | -237.4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 259371.0 |

175 MW CASE

| Bus Number | Bus Name | Id     | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Ogen (Mvar) | Omax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR        | Minimum Load            | Min load violation? | DR |         |          |
|------------|----------|--------|------|-------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|-------------------------|---------------------|----|---------|----------|
| 101        | KGS-1    | 11.500 | 1    | 2           | 1.0217            | 200        | 1         | 4.8       | 5         | 0           | 1.7943      | 3           | 0           | 6.25      | 0.2                     | 2.5                 | 1  | 2.3     |          |
| 102        | KGS-2    | 11.500 | 2    | 1           | 1.0217            | 200        | 1         | 4.8       | 5         | 0           | 1.7943      | 3           | 0           | 6.25      | 0.2                     | 2.5                 | 1  | 2.3     |          |
| 103        | KGS-3    | 11.500 | 3    | 2           | 1.0217            | 200        | 1         | 11        | 11.5      | 0           | 3.9053      | 7.1         | 0           | 13.53     | 0.5                     | 7.5                 | 1  | 3.5     |          |
| 104        | KGS-4    | 11.500 | 4    | 2           | 1.0217            | 200        | 1         | 12        | 12.5      | 0           | 4.2571      | 9.375       | 0           | 15.63     | 0.5                     | 7.5                 | 1  | 4.5     |          |
| 105        | MGS-123  | 4.1600 | 1    | -2          | 1.025             | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 105        | MGS-123  | 4.1600 | 2    | -2          | 1.025             | 39         | 0         | 2.4       | 2.5       | 0           | 0.7762      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 105        | MGS-123  | 4.1600 | 3    | -2          | 1.025             | 39         | 0         | 2.42      | 2.5       | 0           | 0.7826      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 4    | -2          | 1.025             | 39         | 0         | 4.3056    | 5.6       | 0           | 1.8749      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 5    | -2          | 1.025             | 39         | 0         | 4.3707    | 5.6       | 0           | 1.1779      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 106        | MGS-458  | 4.1600 | 6    | -2          | 1.025             | 39         | 0         | 4.0472    | 5.6       | 0           | 1.7624      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 6    | -2          | 1.025             | 39         | 0         | 3.93      | 5.6       | 0           | 3.6373      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 7    | -2          | 1.025             | 39         | 0         | 4.3841    | 5.6       | 0           | 3.854       | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 107        | MGS-679  | 4.1600 | 8    | -2          | 1.025             | 39         | 0         | 2.5374    | 5.6       | 0           | 1.4266      | 4.2         | 0           | 7         | 0                       | 2                   | 0  | 0       |          |
| 108        | MGS-1011 | 6.9000 | 0    | -2          | 1.025             | 39         | 1         | 11        | 12.5      | 0           | 5.5177      | 9.375       | 0           | 15.63     | 1.5                     | 6                   | 1  | 5       |          |
| 108        | MGS-1011 | 6.9000 | 1    | -2          | 1.025             | 39         | 0         | 11        | 12.5      | 0           | 5.5177      | 9.375       | 0           | 15.63     | 0                       | 6                   | 0  | 0       |          |
| 109        | MGS-1213 | 6.9000 | 2    | -2          | 1.025             | 39         | 1         | 11        | 12.5      | 0           | 9.375       | 9.375       | 0           | 15.63     | 1.5                     | 6                   | 1  | 5       |          |
| 109        | MGS-1213 | 6.9000 | 3    | -2          | 1.025             | 39         | 0         | 11        | 12.5      | 0           | 5.3557      | 9.375       | 0           | 15.63     | 0                       | 6                   | 0  | 0       |          |
| 110        | MGS-X1X2 | 4.1600 | 1    | -2          | 1.025             | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1241      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 110        | MGS-X1X2 | 4.1600 | 2    | -2          | 1.025             | 39         | 0         | 2.4659    | 2.5       | 0           | 1.1257      | 1.875       | 0           | 3.44      | 0                       | 2.5                 | 0  | 0       |          |
| 301        | CT-1 M14 | 13.800 | 1    | 3           | 1.01              | 0          | 1         | 19.3283   | 21.5      | 0           | 9.1758      | 15          | 0           | 26.81     | 2.1717                  | 12.5                | 1  | 6.8283  |          |
| 302        | CT-2 M16 | 13.800 | 2    | 2           | 1.025             | 39         | 1         | 19.25     | 21.5      | 0           | 9.088       | 15          | 0           | 26.81     | 2.25                    | 12.5                | 1  | 6.75    |          |
| 303        | ST-1 M15 | 13.800 | 3    | 2           | 1.025             | 39         | 1         | 15        | 15        | 0           | 7.1406      | 12          | 0           | 18.5      | 0                       | 11                  | 1  | 4       |          |
| 304        | CT-3 M17 | 13.800 | 4    | 2           | 1.025             | 39         | 1         | 19        | 21.5      | 0           | 7.7897      | 15          | 0           | 26.81     | 2.5                     | 14                  | 1  | 5       |          |
| 305        | CT-4 M19 | 13.800 | 5    | 2           | 1.025             | 39         | 1         | 19        | 21.5      | 0           | 7.1406      | 15          | 0           | 26.81     | 2.5                     | 14                  | 1  | 5       |          |
| 306        | ST-2 M18 | 13.800 | 6    | 2           | 1.025             | 39         | 1         | 11        | 15        | 0           | 3.8949      | 12          | 0           | 18.5      | 4                       | 3                   | 1  | 8       |          |
| 804        | HC&S TG4 | 13.800 | 4    | 2           | 0.937             | 0          | 1         | 12        | 13        | 0           | 1.6233      | 5.1         | 0           | 24.5      | 8                       | 1                   | 1  | 8       |          |
| 90971      | KWPI_1   | 0.5750 | 1    | 2           | 1.0065            | 0          | 1         | 24        | 30        | 0           | 0.3887      | 14.5        | -0.2374     | 33.34     |                         |                     |    | 1       |          |
| 15         |          |        |      |             |                   |            |           |           |           |             |             |             |             | Total SR= | 17.9217                 |                     | 15 | 50.5783 | Total DR |
| SR Flag    |          |        |      |             |                   |            |           |           |           |             |             |             |             | 0         | Min Load Violation Flag | 0                   | 0  | DR Flag |          |

MACHINE SUMMARY:

| BUS# | X     | NAME   | --K | BASKV  | ID     | KW     | KVAR | QMAX   | QMIN   | ETERM  | CURRENT | PF | KVBASE | X | T | R | A | N | GENTAP | ZONE | AREA | SWING |   |
|------|-------|--------|-----|--------|--------|--------|------|--------|--------|--------|---------|----|--------|---|---|---|---|---|--------|------|------|-------|---|
| 101  | KGS-1 | 11.500 | 1   | 4800.0 | 2233.1 | 3000.0 | 0.0  | 1.0215 | 5182.5 | 0.9067 | 6250.0  |    |        |   |   |   |   |   |        |      |      | 19    | 2 |
| 102  | KGS-2 | 11.500 | 2   | 4800.0 | 2233.1 | 300    |      |        |        |        |         |    |        |   |   |   |   |   |        |      |      |       |   |

| Bus Number | Bus Name | Code | V  | Sched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Qgen (Mvar) | Qmax (Mvar) | Qmin (Mvar) | Mbase (MVA) | SR        | Minimum Load | Min load violation? | DR     |    |  |         |  |           |  |
|------------|----------|------|----|------------|-------------------|------------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-----------|--------------|---------------------|--------|----|--|---------|--|-----------|--|
| 101        | KGS-1    | 1    | 2  | 1.022      | 200               | 1          | 4.8       | 6         | 0         | 2.2331      | 3           | 0           | 6.25        | 0.2       | 2.5          | 1                   | 2.3    |    |  |         |  |           |  |
| 102        | KGS-2    | 2    | 2  | 1.022      | 200               | 1          | 4.8       | 6         | 0         | 2.2331      | 3           | 0           | 6.25        | 0.2       | 2.5          | 1                   | 2.3    |    |  |         |  |           |  |
| 103        | KGS-3    | 3    | 2  | 1.022      | 200               | 1          | 11        | 11.5      | 0         | 4.8003      | 7.1         | 0           | 15.53       | 0.5       | 7.5          | 1                   | 3.5    |    |  |         |  |           |  |
| 104        | KGS-4    | 4    | 2  | 1.022      | 200               | 1          | 12        | 12.5      | 0         | 5.2682      | 9.375       | 0           | 15.53       | 0.5       | 7.5          | 1                   | 4.5    |    |  |         |  |           |  |
| 105        | MGS-123  | 1    | -2 | 1.025      | 39                | 0          | 2.4       | 2.5       | 0         | 0.7762      | 1.875       | 0           | 3.44        | 0         | 2.5          | 0                   | 0      |    |  |         |  |           |  |
| 105        | MGS-123  | 2    | -2 | 1.025      | 39                | 0          | 2.4       | 2.5       | 0         | 0.7762      | 1.875       | 0           | 3.44        | 0         | 2.5          | 0                   | 0      |    |  |         |  |           |  |
| 106        | MGS-458  | 3    | -2 | 1.025      | 39                | 0          | 2.42      | 2.6       | 0         | 0.7526      | 1.875       | 0           | 3.44        | 0         | 2.5          | 0                   | 0      |    |  |         |  |           |  |
| 106        | MGS-458  | 4    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.3654      | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 106        | MGS-458  | 5    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.3654      | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 106        | MGS-458  | 8    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.3654      | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 107        | MGS-679  | 6    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.661       | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 107        | MGS-679  | 7    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.661       | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 107        | MGS-679  | 9    | 2  | 1.025      | 39                | 1          | 5.6       | 5.6       | 0         | 2.661       | 4.2         | 0           | 7           | 0         | 2            | 1                   | 3.6    |    |  |         |  |           |  |
| 108        | MGS-1011 | 0    | -2 | 1.025      | 39                | 0          | 11        | 12.5      | 0         | 7.0718      | 9.375       | 0           | 15.63       | 0         | 6            | 0                   | 0      |    |  |         |  |           |  |
| 108        | MGS-1011 | 1    | -2 | 1.025      | 39                | 0          | 11        | 12.5      | 0         | 5.1665      | 9.375       | 0           | 15.63       | 0         | 6            | 0                   | 0      |    |  |         |  |           |  |
| 108        | MGS-1213 | 2    | -2 | 1.025      | 39                | 0          | 11        | 12.5      | 0         | 6.4146      | 9.375       | 0           | 15.63       | 0         | 6            | 0                   | 0      |    |  |         |  |           |  |
| 109        | MGS-1213 | 3    | -2 | 1.025      | 39                | 0          | 11        | 12.5      | 0         | 3.3557      | 9.375       | 0           | 15.63       | 0         | 6            | 0                   | 0      |    |  |         |  |           |  |
| 110        | MGS-X1X  | 1    | -2 | 1.025      | 39                | 0          | 2.4659    | 2.5       | 0         | 1.1241      | 1.875       | 0           | 3.44        | 0         | 2.5          | 0                   | 0      |    |  |         |  |           |  |
| 110        | MGS-X1X  | 2    | -2 | 1.025      | 39                | 0          | 2.4659    | 2.5       | 0         | 1.1257      | 1.875       | 0           | 3.44        | 0         | 2.5          | 0                   | 0      |    |  |         |  |           |  |
| 301        | CT-1 M14 | 1    | 3  | 1.009      | 0                 | 1          | 18.9713   | 21.5      | 0         | 8.8616      | 15          | 0           | 26.81       | 2.5287    | 12.5         | 1                   | 6.4713 |    |  |         |  |           |  |
| 302        | CT-2 M16 | 2    | 2  | 1.025      | 39                | 1          | 19        | 21.5      | 0         | 8.8702      | 15          | 0           | 26.81       | 2.5       | 12.5         | 1                   | 6.5    |    |  |         |  |           |  |
| 303        | ST-1 M15 | 3    | 2  | 1.025      | 39                | 1          | 15        | 15        | 0         | 7.0561      | 12          | 0           | 18.5        | 0         | 11           | 1                   | 4      |    |  |         |  |           |  |
| 304        | CT-3 M17 | 4    | 2  | 1.025      | 39                | 1          | 19        | 21.5      | 0         | 8.8702      | 15          | 0           | 26.81       | 2.5       | 14           | 1                   | 5      |    |  |         |  |           |  |
| 305        | CT-4 M19 | 5    | 2  | 1.025      | 39                | 1          | 19        | 21.5      | 0         | 8.8702      | 15          | 0           | 26.81       | 2.5       | 14           | 1                   | 5      |    |  |         |  |           |  |
| 306        | ST-2 M18 | 6    | 2  | 1.025      | 39                | 1          | 11        | 15        | 0         | 5.3221      | 12          | 0           | 18.5        | 4         | 3            | 1                   | 8      |    |  |         |  |           |  |
| 804        | HC&S T04 | 4    | 2  | 0.937      | 0                 | 1          | 12        | 13        | 0         | 1.3758      | 5.1         | 0           | 24.5        |           | 8            | 1                   |        |    |  |         |  |           |  |
| 90971      | KWPL1    | 1    | 2  | 1          | 0                 | 1          | 24        | 30        | 0         | 0.3887      | 14.5        | -0.2374     | 33.34       |           |              |                     |        |    |  |         |  |           |  |
| 18         |          |      |    |            |                   |            |           |           |           |             |             |             |             |           |              |                     |        |    |  |         |  |           |  |
|            |          |      |    |            |                   |            |           |           |           |             |             |             |             | Total SR= |              | 14.0287             |        | 18 |  | 56.5713 |  | =Total DR |  |
|            |          |      |    |            |                   |            |           |           |           |             |             |             |             | SR Flag   |              | 0                   |        | 0  |  | 0       |  | DR Flag   |  |

MACHINE SUMMARY:

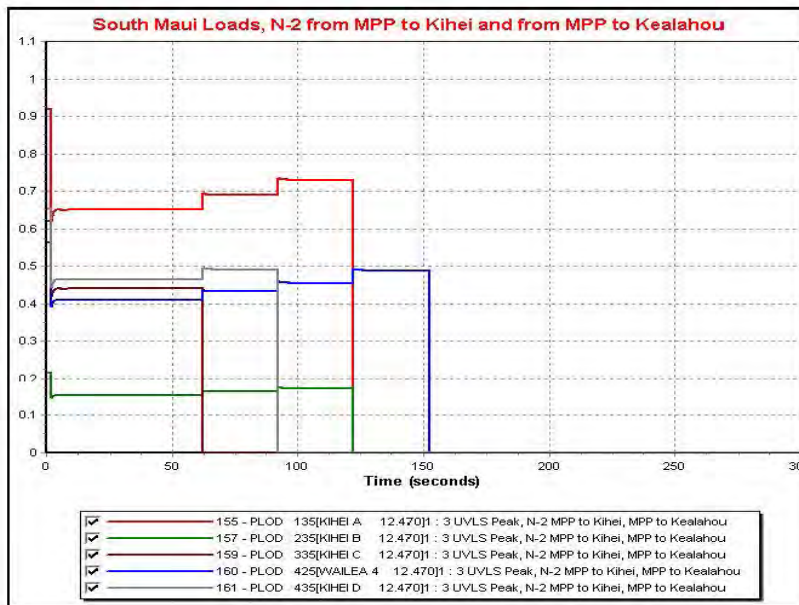
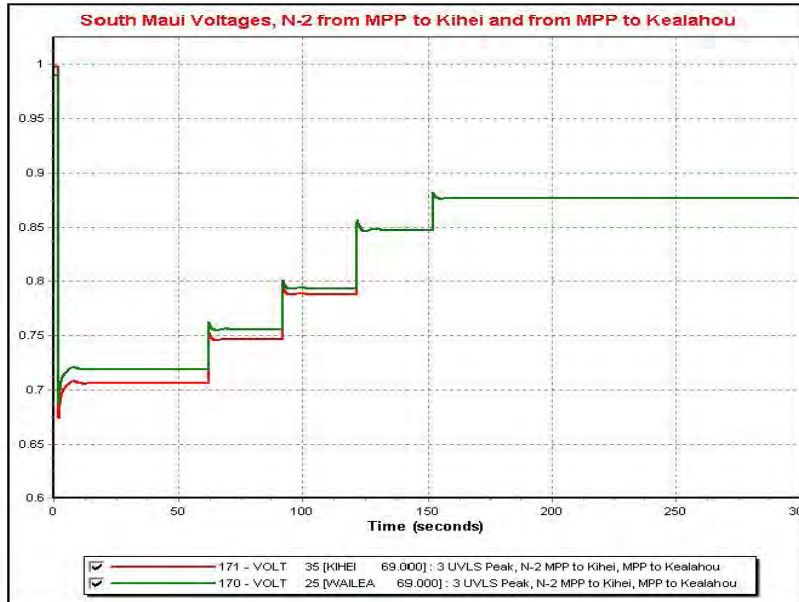
| BUS#             | X--      | NAME   | --X | BASKV    | ID      | KW        | KVAR   | QMAX   | QMIN    | ETERM  | CURRENT  | PF | KVBASE | X | T | R | A | N | GENTAP | ZONE | AREA | SWING |
|------------------|----------|--------|-----|----------|---------|-----------|--------|--------|---------|--------|----------|----|--------|---|---|---|---|---|--------|------|------|-------|
| 101              | KGS-1    | 11,500 | 1   | 4800.0   | 2233.1  | 3000.0    | 0.0    | 1.0215 | 5182.5  | 0.9067 | 6250.0   |    |        |   |   |   |   |   | 19     | 2    |      |       |
| 102              | KGS-2    | 11,500 | 2   | 4800.0   | 2233.1  | 3000.0    | 0.0    | 0.9948 | 5321.6  | 0.9067 | 6250.0   |    |        |   |   |   |   |   | 19     | 2    |      |       |
| 103              | KGS-3    | 11,500 | 3   | 11000.0  | 4860.3  | 7100.0    | 0.0    | 0.9955 | 12079.7 | 0.9147 | 13529.0  |    |        |   |   |   |   |   | 19     | 2    |      |       |
| 104              | KGS-4    | 11,500 | 4   | 12000.0  | 5298.2  | 9375.0    | 0.0    | 1.0152 | 13921.4 | 0.9148 | 15625.0  |    |        |   |   |   |   |   | 19     | 2    |      |       |
| 106              | MGS-458  | 4,1600 | 4   | 5600.0   | 2365.4  | 4200.0    | 0.0    | 0.9948 | 6110.6  | 0.9212 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 106              | MGS-458  | 4,1600 | 5   | 5600.0   | 2365.4  | 4200.0    | 0.0    | 0.9948 | 6110.6  | 0.9212 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 106              | MGS-458  | 4,1600 | 8   | 5600.0   | 2365.4  | 4200.0    | 0.0    | 0.9948 | 6110.6  | 0.9212 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 107              | MGS-679  | 4,1600 | 6   | 5600.0   | 2661.1  | 4200.0    | 0.0    | 0.9996 | 6202.7  | 0.9032 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 107              | MGS-679  | 4,1600 | 7   | 5600.0   | 2661.1  | 4200.0    | 0.0    | 0.9996 | 6202.7  | 0.9032 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 107              | MGS-679  | 4,1600 | 9   | 5600.0   | 2661.1  | 4200.0    | 0.0    | 0.9996 | 6202.7  | 0.9032 | 7000.0   |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 301              | CT-1 M14 | 13,800 | 1   | 18971.3  | 8961.6  | 15000.0   | 0.0    | 1.0090 | 20752.2 | 0.9060 | 26813.0  |    |        |   |   |   |   |   | 20     | 2    | SYST |       |
| 302              | CT-2 M16 | 13,800 | 2   | 19000.0  | 8970.2  | 15000.0   | 0.0    | 1.0090 | 20781.1 | 0.9061 | 26813.0  |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 303              | ST-1 M15 | 13,800 | 3   | 15000.0  | 7096.1  | 12000.0   | 0.0    | 1.0035 | 16536.6 | 0.9040 | 18500.0  |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 304              | CT-3 M17 | 13,800 | 4   | 19000.0  | 8970.2  | 15000.0   | 0.0    | 0.9870 | 21245.2 | 0.9061 | 26813.0  |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 305              | CT-4 M19 | 13,800 | 5   | 19000.0  | 8970.2  | 15000.0   | 0.0    | 0.9870 | 21245.2 | 0.9061 | 26813.0  |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 306              | ST-2 M18 | 13,800 | 6   | 11000.0  | 5322.1  | 12000.0   | 0.0    | 0.9752 | 12530.5 | 0.9002 | 18500.0  |    |        |   |   |   |   |   | 20     | 2    |      |       |
| 804              | HC&S T04 | 13,800 | 4   | 12000.0  | 1375.9  | 5100.0    | 0.0    | 0.9370 | 12890.7 | 0.9935 | 24500.0  |    |        |   |   |   |   |   | 9      | 1    |      |       |
| 90971            | KWPL1    | 0,5750 | 1   | 24000.0  | 388.7   | 14500.0   | -237.4 | 1.0000 | 24003.1 | 0.9999 | 33340.0  |    |        |   |   |   |   |   | 11     | 1    |      |       |
| SUBSYSTEM TOTALS |          |        |     | 204171.3 | 79359.0 | 0151275.0 | -237.4 |        |         |        | 285746.0 |    |        |   |   |   |   |   |        |      |      |       |

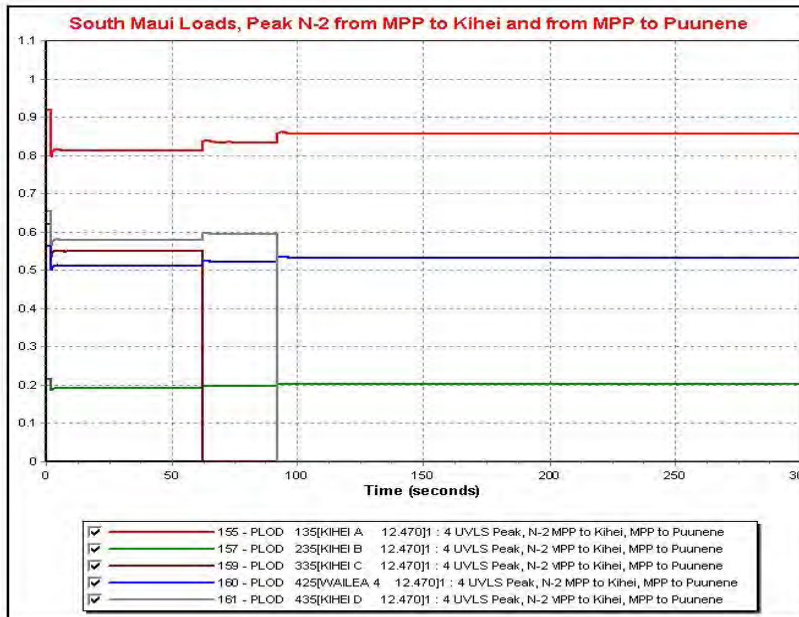
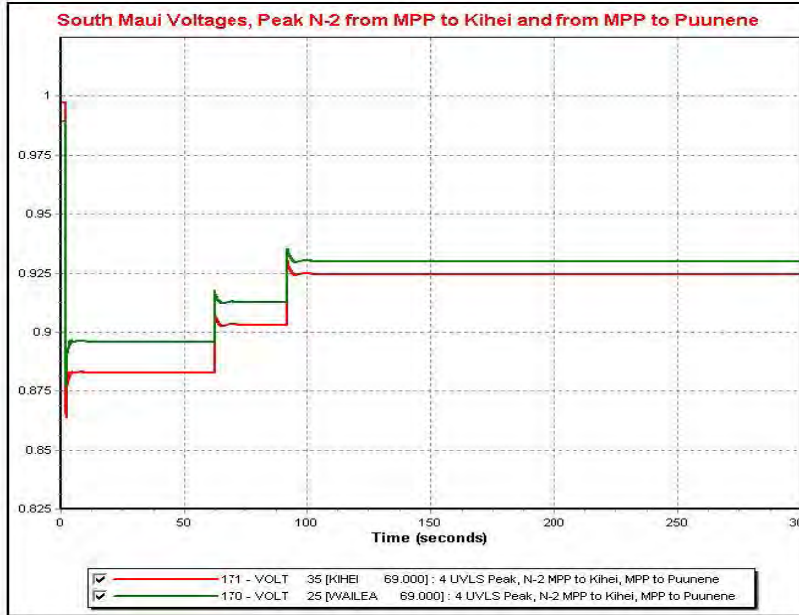
Peak Basecase M4-9 replace M10



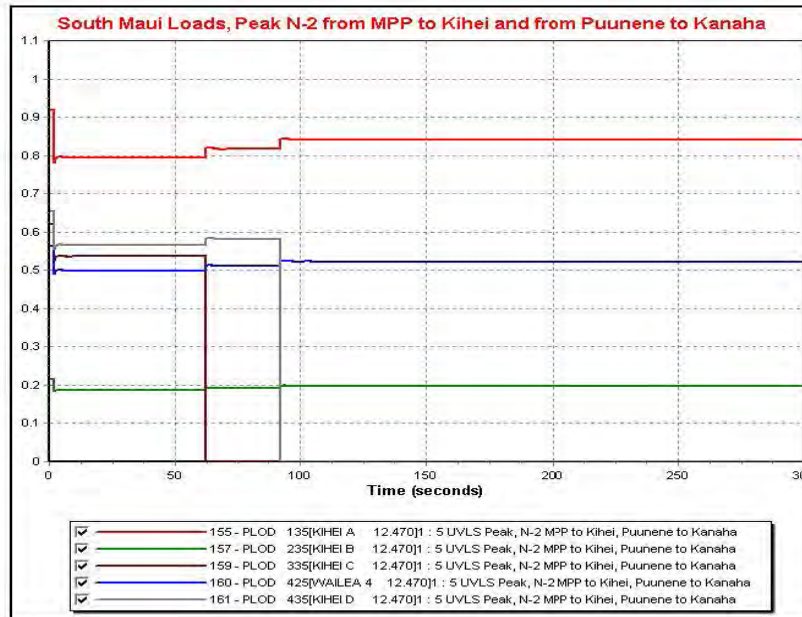
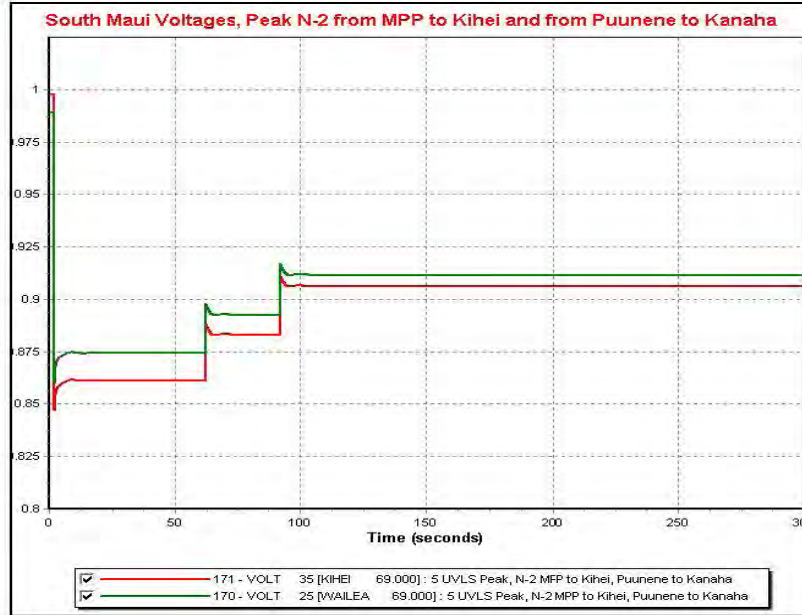
# Maalaea-Kamalii Transmission Line Alternatives

## APPENDIX B

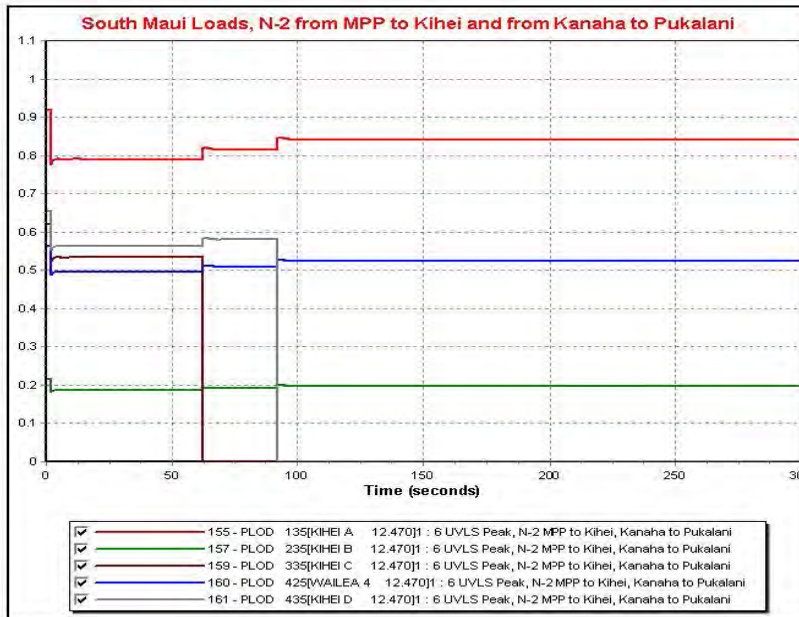
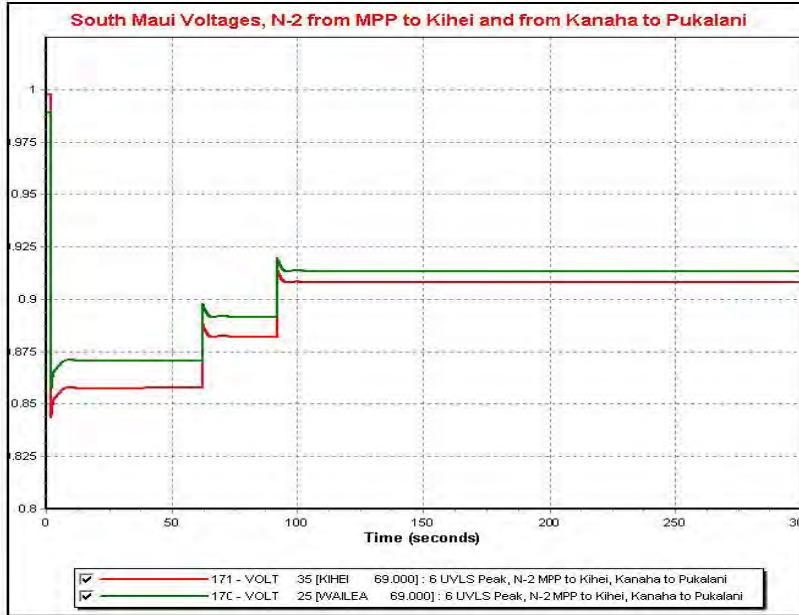




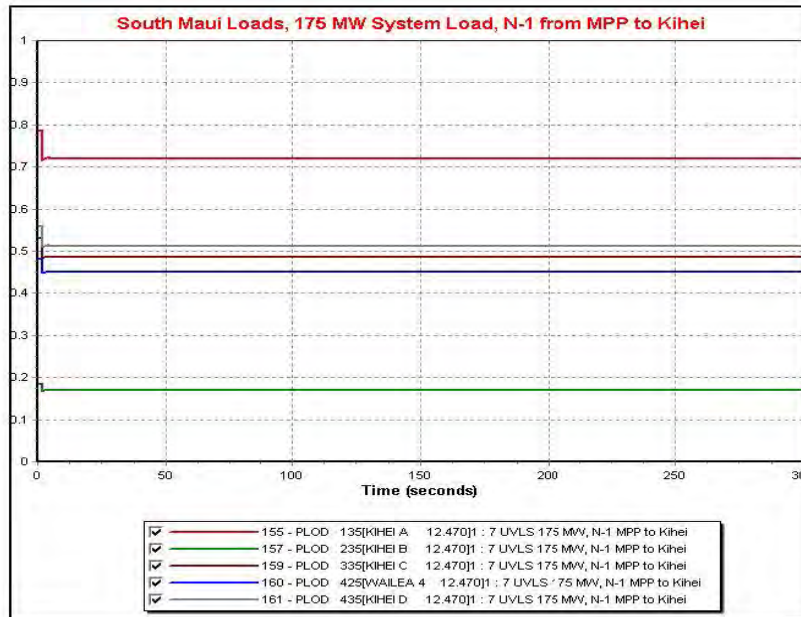
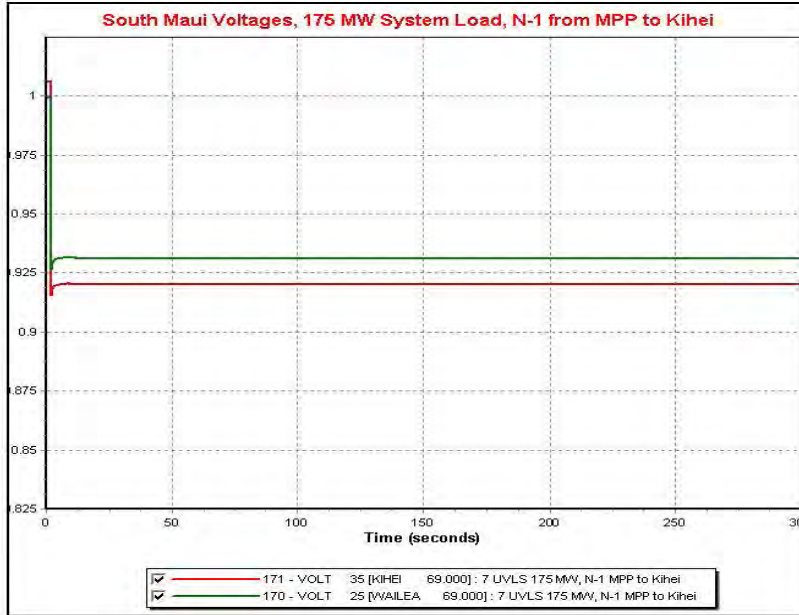
# Maalaea-Kamalii Transmission Line Alternatives

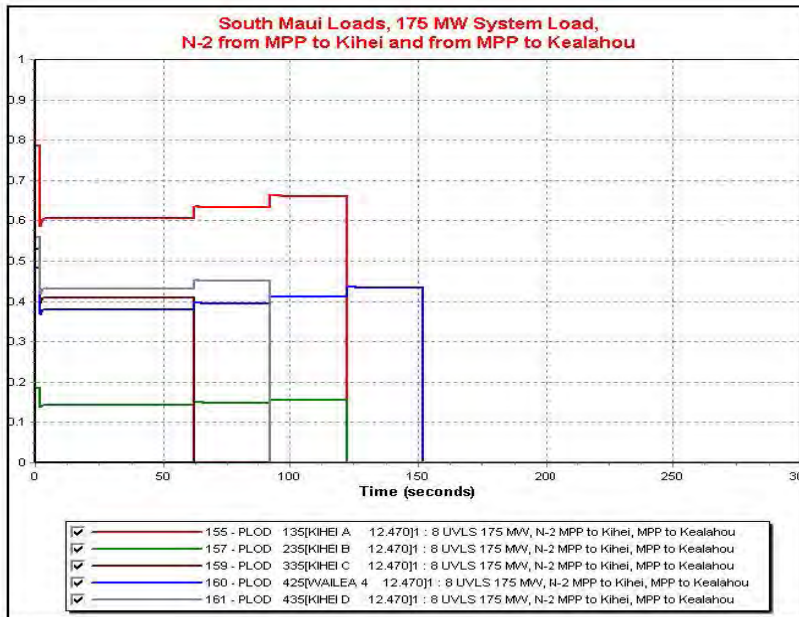
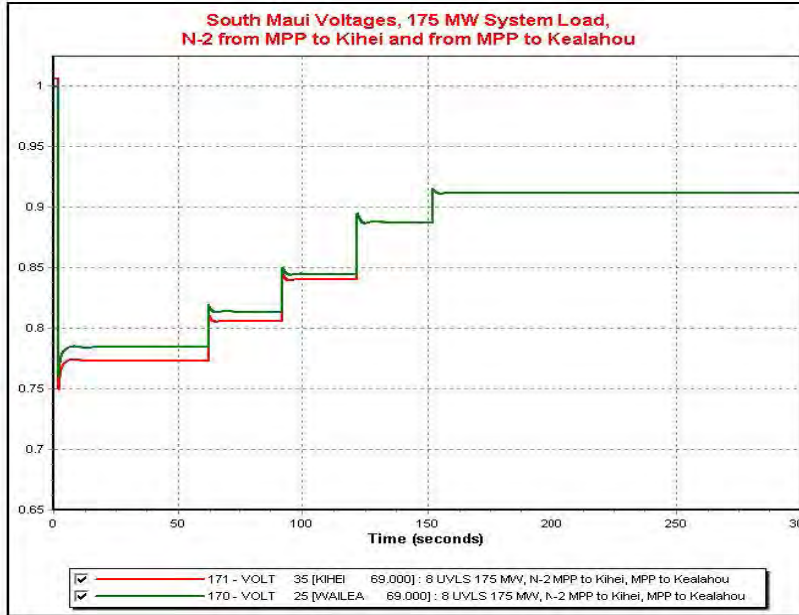




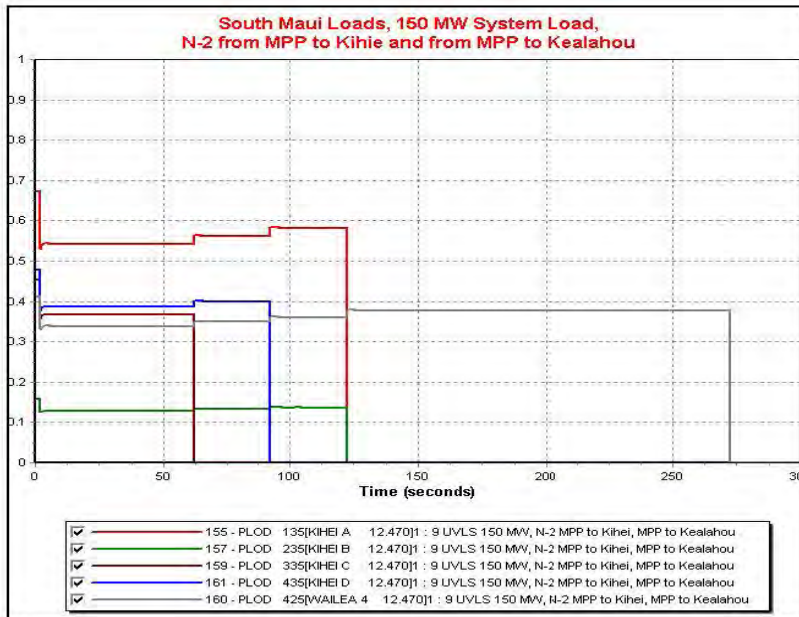


# Maalaea-Kamalii Transmission Line Alternatives





# Maalaea-Kamalii Transmission Line Alternatives



## APPENDIX C

### *Maui Electric Gross System Peak Load Forecast*

## Maalaea-Kamalii Transmission Line Alternatives

---

Table A.1: Maui Electric System Peak Forecast—Gross MW

| System Peak |                    |
|-------------|--------------------|
| Year        | Gross Instant (MW) |
| Act. 2012   | 199.1              |
| 2013        | 207.8              |
| 2014        | 212.8              |
| 2015        | 218.0              |
| 2016        | 223.0              |
| 2017        | 227.8              |
| 2018        | 232.5              |
| 2019        | 236.3              |
| 2020        | 239.2              |
| 2021        | 241.5              |
| 2022        | 243.5              |
| 2023        | 246.0              |
| 2024        | 248.9              |

**APPENDIX D**

*Single line Diagrams*

Maalaea-Kamalii Transmission Line Alternatives

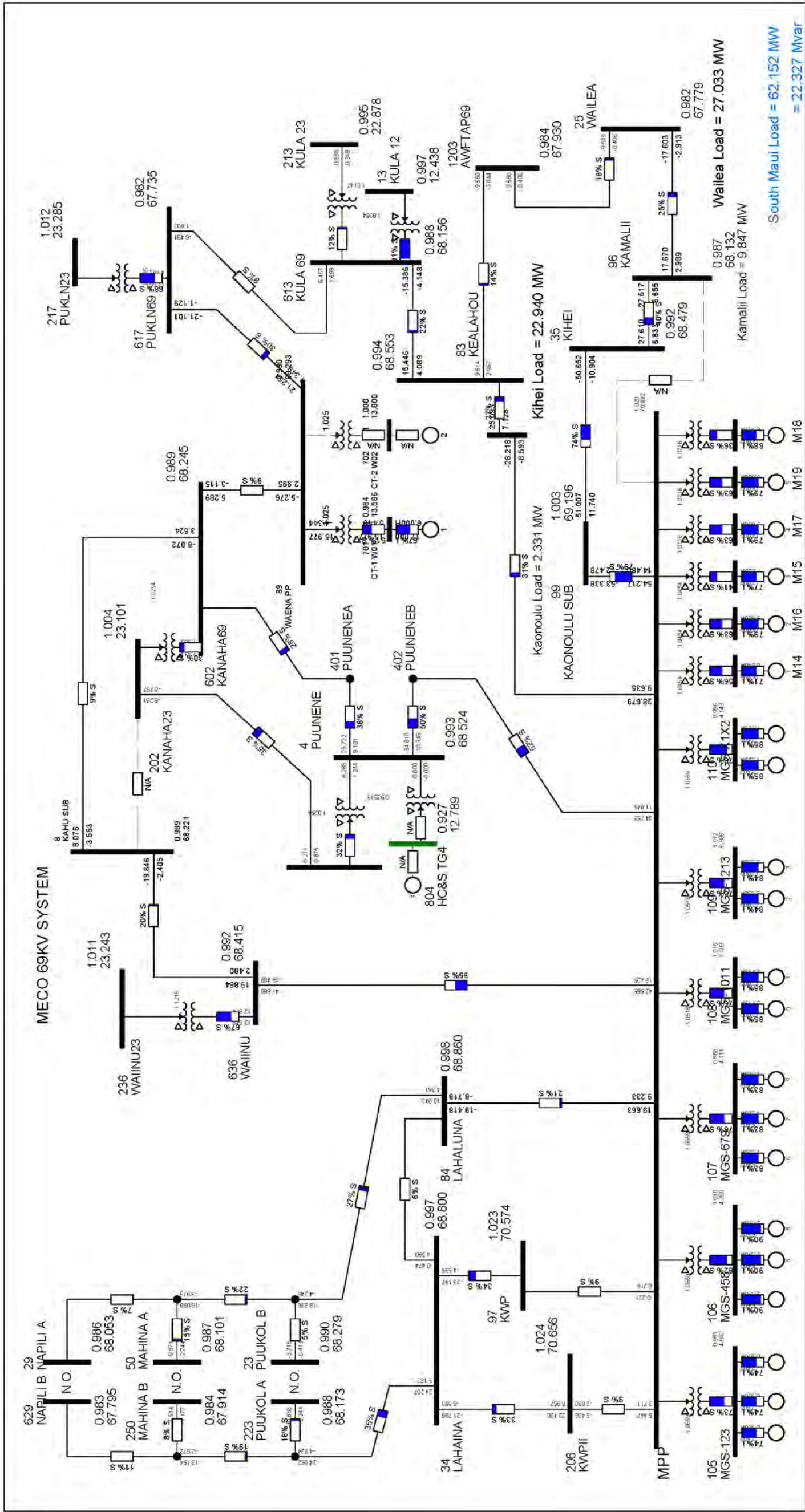


Figure B.1: 2024 normal conditions



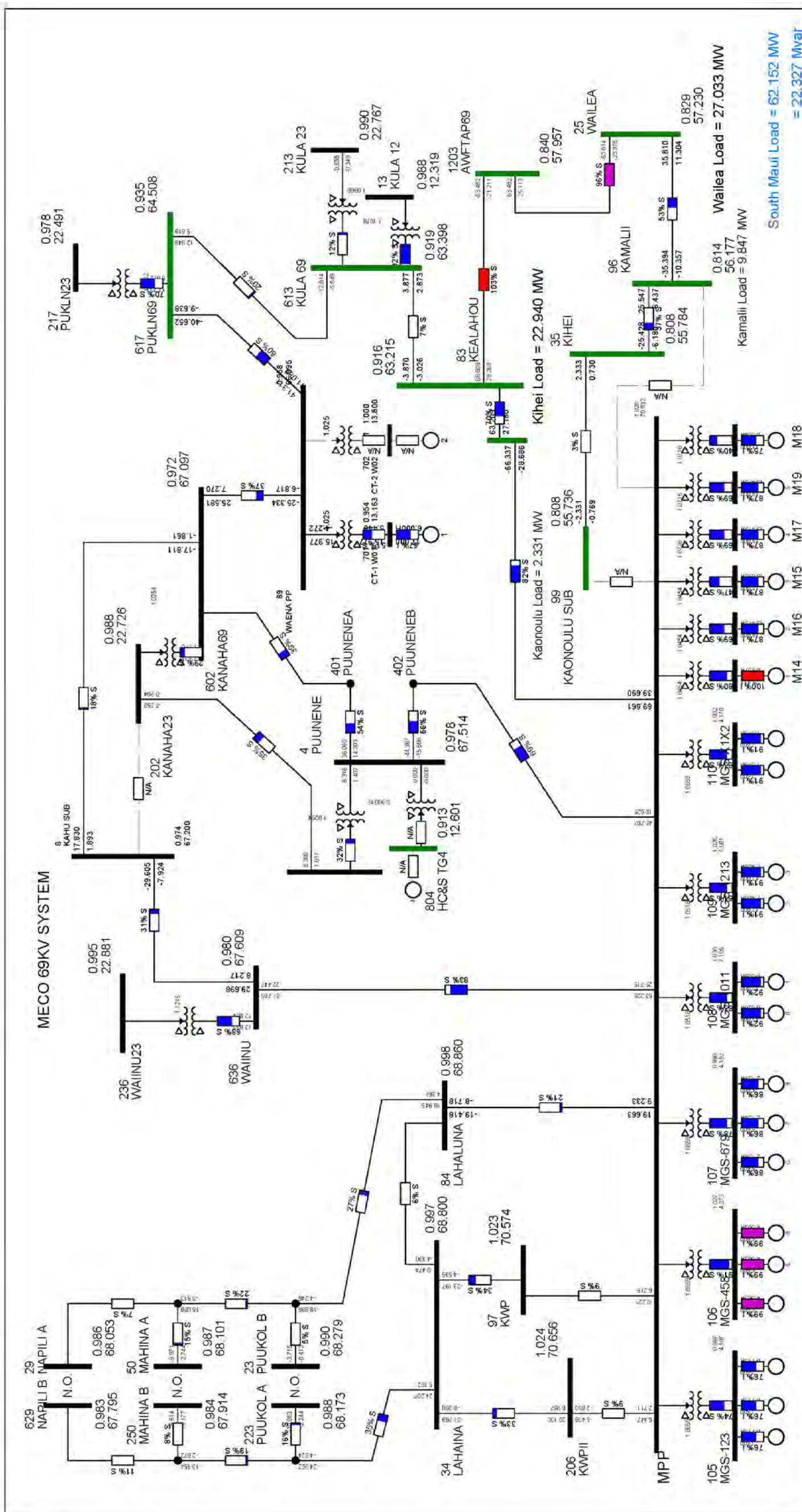
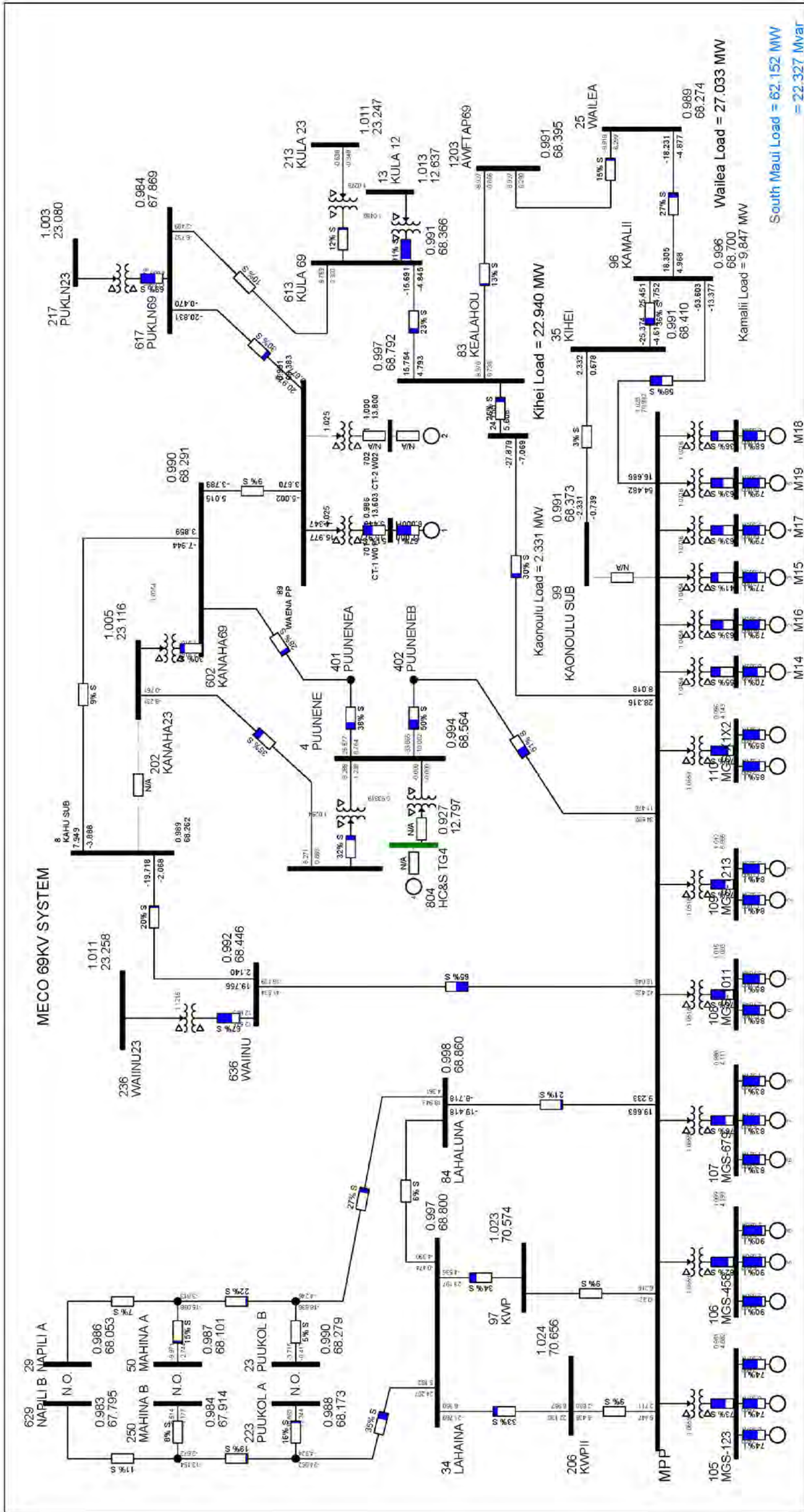


Figure B.2: Low voltage violations under N-1, loss of Maalea-Kihei

Maalaea-Kamalii Transmission Line Alternatives



MECO 2023 PM PEAK 248.9  
MECO PEAK BASECASE  
FRI, OCT 25 2013 13:56

Figure B.3: N-1 conditions with the Maalaea-Kamalii 69kV transmission line

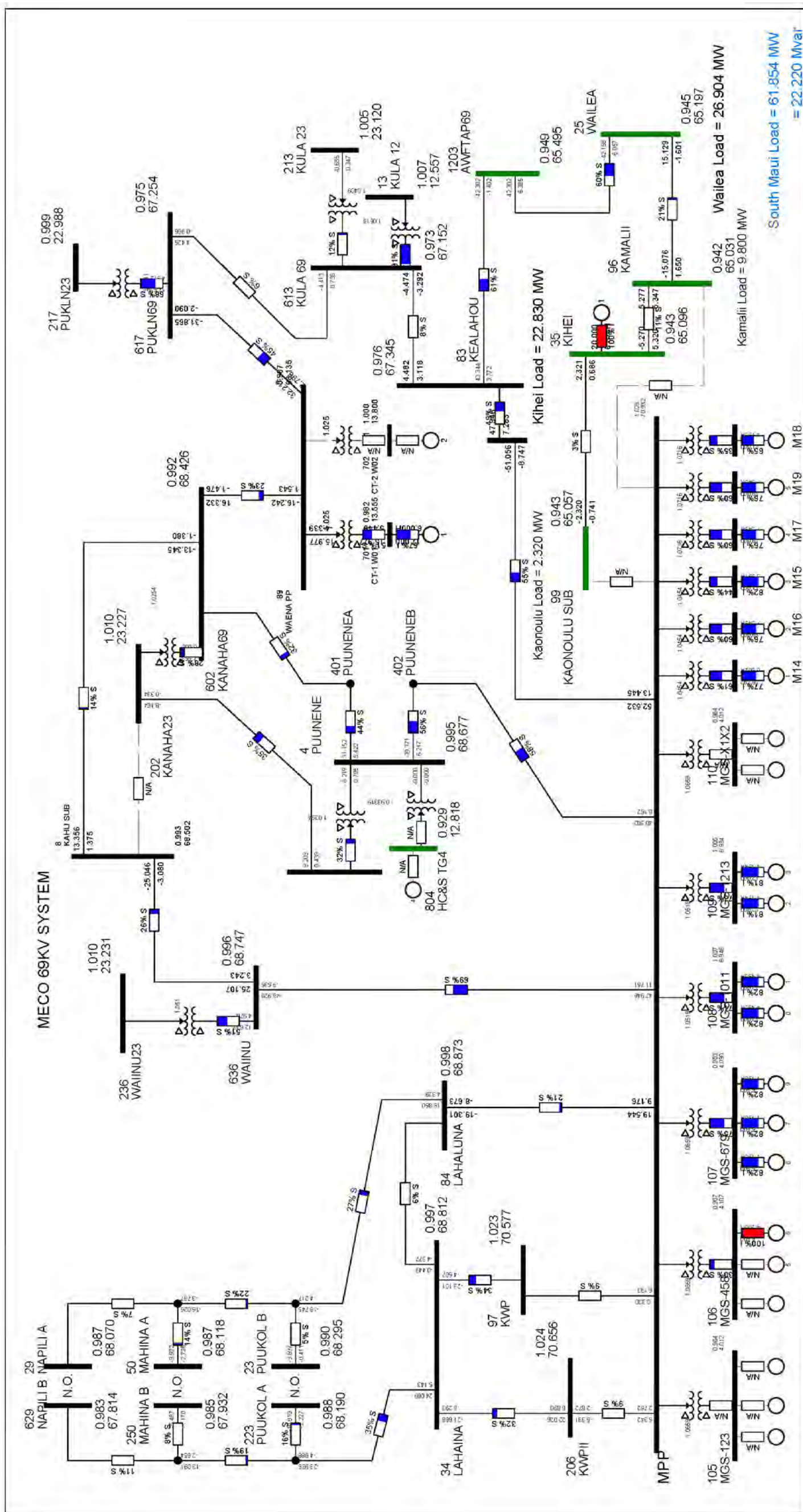
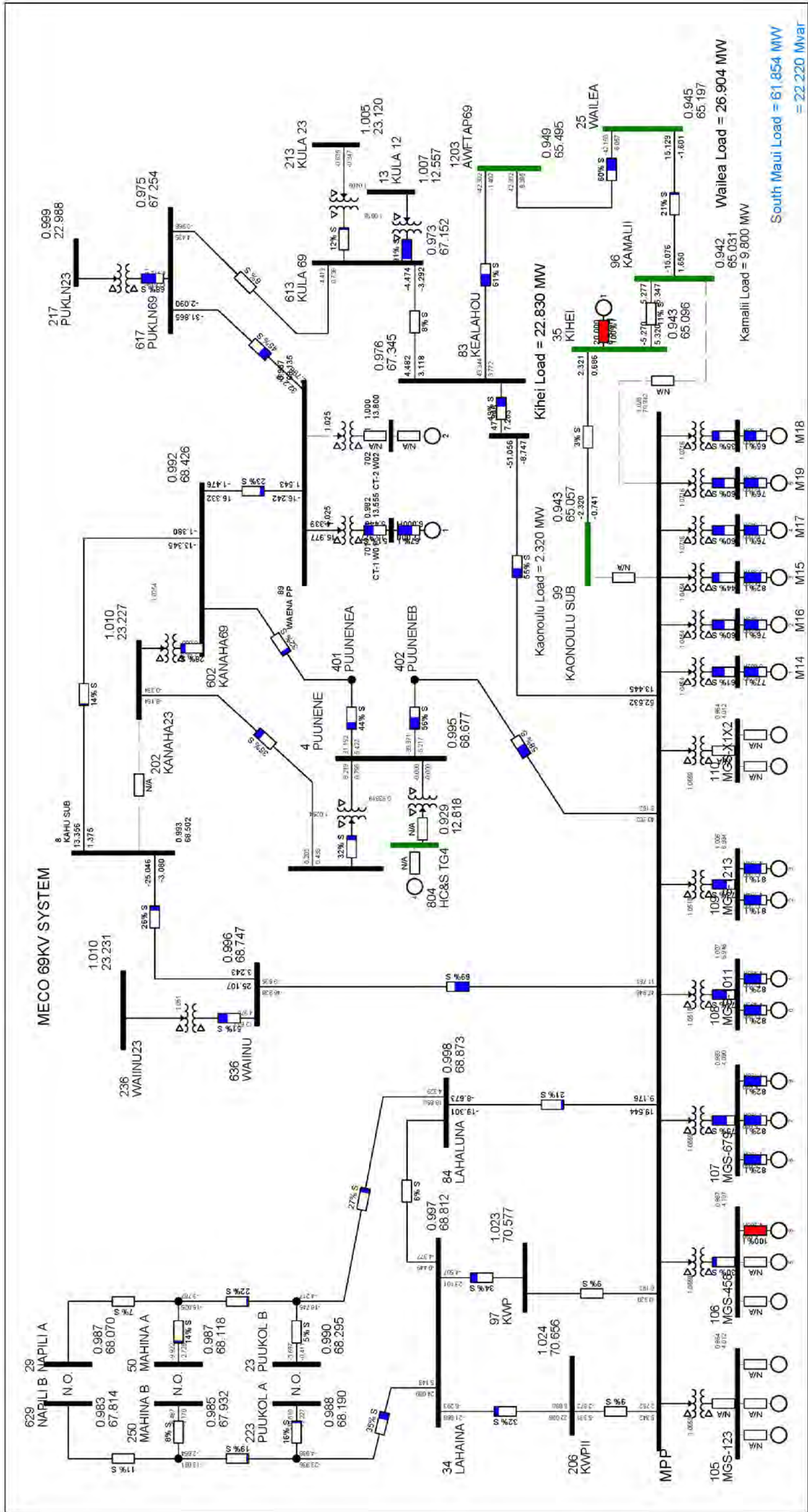


Figure B.4: N-1 conditions with Distributed Generation (DG) alternative

Maalaea-Kamalii Transmission Line Alternatives

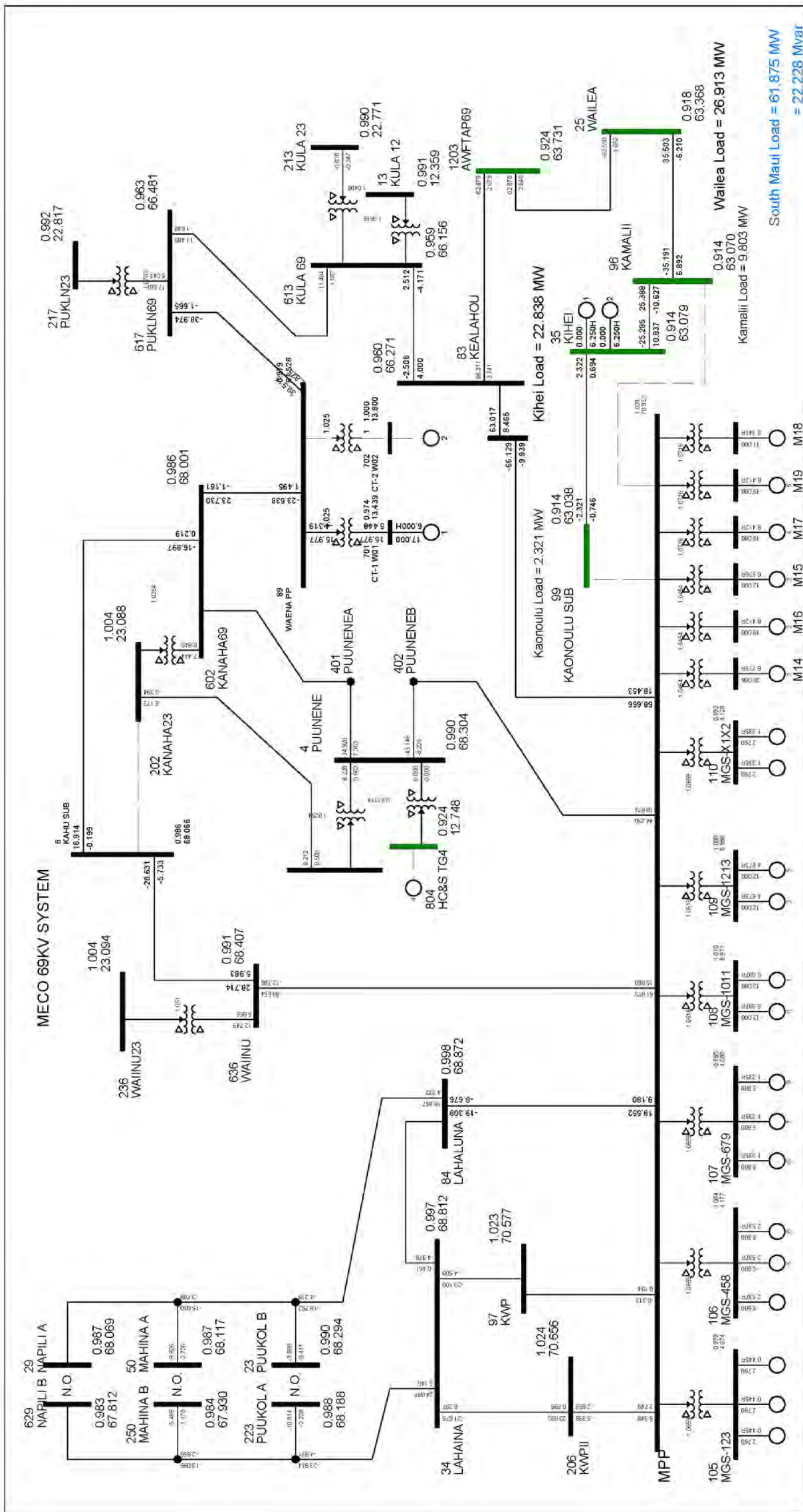


MECO 2023 PM PEAK 248.9  
 MECO PEAK BASECASE  
 WED, OCT 23 2013 9:08

Bus: 100 TACT (AUG10)  
 Busbar: MWK 2  
 Equipment: MWK 2  
 Version: 0.0010

Figure B.5: N-1 conditions with ESS (energy storage system) alternative



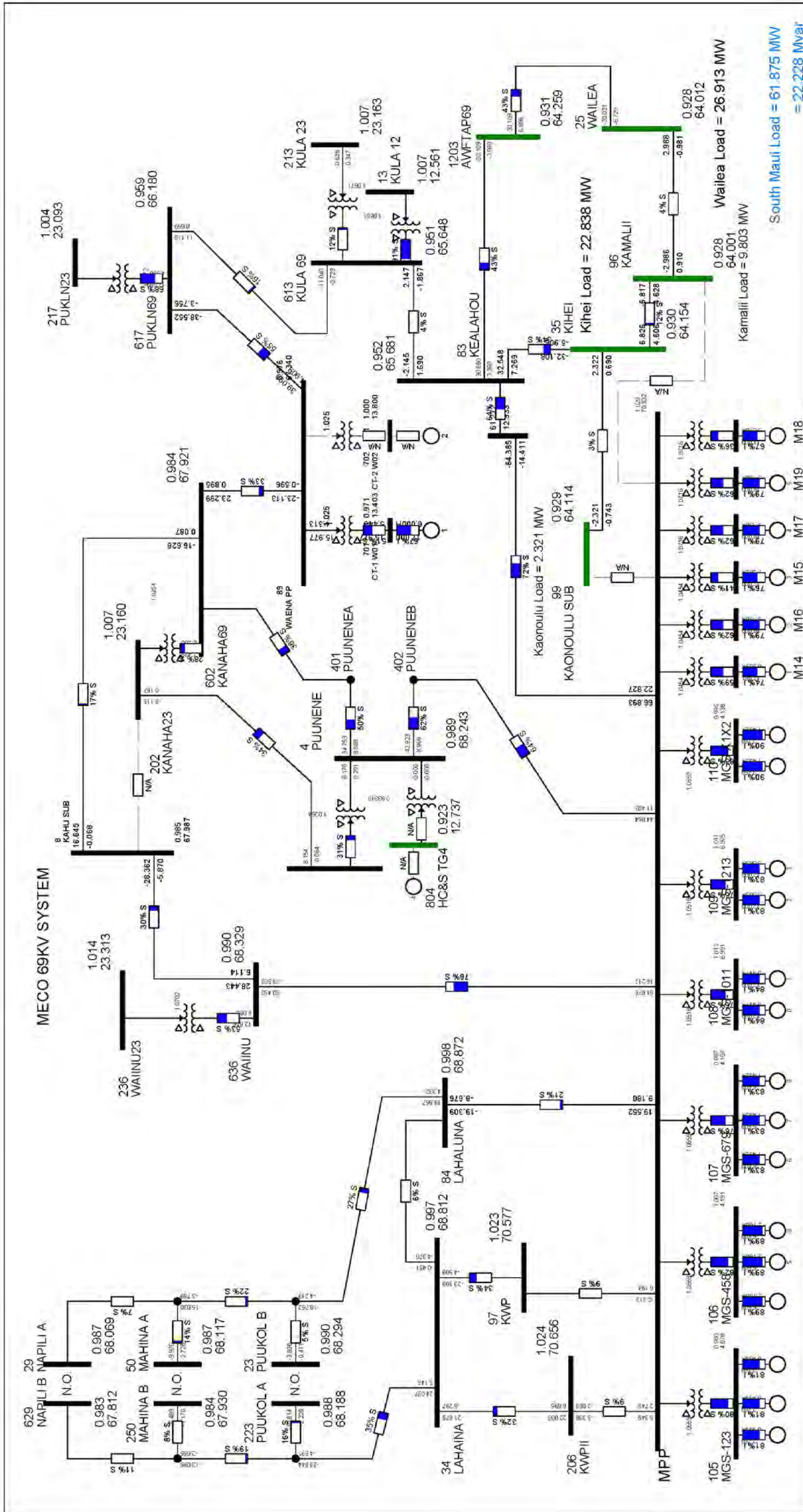


MECO 2022 PM PEAK 248.9  
MECO PEAK BASECASE  
TUE, OCT 15 2013 15:25

Bus - VOLTAGE (KV) /  
Equipment - MW/Mvar  
LUGS(V)

Figure B.6: N-1 conditions with synchronous condensers alternative

Maalea-Kamalii Transmission Line Alternatives



Bus - Voltage (V/PU)  
 Branch - Amps (A)  
 Equipment - MW/MVA  
 Line - MW/MVA

Figure B.7: N-1 conditions with Kealahou-Kihai 69kV transmission line alternative

**APPENDIX E**

***Maui Electric 5 year Historical Peak Load***

## Maalaea-Kamalii Transmission Line Alternatives

---

Table C.1: 2008-2012 Maui System Peak

| <b>Maui System Peak</b> |                         |
|-------------------------|-------------------------|
| <b>Year</b>             | <b>System Load (MW)</b> |
| <b>2008</b>             | 199.0                   |
| <b>2009</b>             | 204.3                   |
| <b>2010</b>             | 203.8                   |
| <b>2011</b>             | 194.1                   |
| <b>2012</b>             | 199.1                   |



# Kahului Power Plant Retirement – Comprehensive Assessment

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## Kahului Power Plant Retirement – Comprehensive Assessment

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**Prepared for**  
**Maui Electric Company, Ltd.**

**Prepared By:**

Hawaiian Electric Company, Inc.  
System Planning Department  
Transmission Planning Division

August 20, 2014

**Reference: TPD 2014-22**

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HECO Transmission Planning Division  
Document Title: Kahului Power Plant Retirement – Comprehensive Assessment  
Reference: TPD 2014-22

Page 1

## Kahului Power Plant Retirement – Comprehensive Assessment

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# Kahului Power Plant Retirement – Comprehensive Assessment

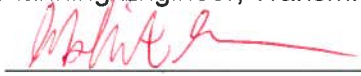
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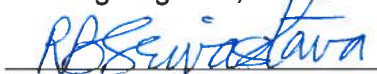
## Kahului Power Plant Retirement – Comprehensive Assessment

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## Kahului Power Plant Retirement – Comprehensive Assessment

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Appendix A – Thermal Analysis

Appendix B – Voltage Stability Assessment

Appendix C – Short Circuit Analysis

# Kahului Power Plant Retirement – Comprehensive Assessment

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## Executive Summary

Maui Electric Company anticipates a reserve capacity shortfall of approximately 40 MW by year 2019, due to the scheduled retirement of Kahului Power Plant. Maui Electric has efforts to procure new resources to meet the reserve capacity shortfall, which may potentially void the need for the Waiinu-Kanaha upgrade project. The Transmission Planning Division at Hawaiian Electric Company has examined various non-transmission alternative options and determined that installing battery storage and/or new generation units on Maui Electric's 23 kV network are viable alternatives to the Waiinu-Kanaha upgrade project. However, considering the civil, corporate and political concerns involved with each non-transmission alternative and the tradeoffs involved with not implementing the Waiinu-Kanaha upgrade project, the Transmission Planning Division recommends Maui Electric Company to continue to pursue the Waiinu-Kanaha upgrade. Maui Electric's interest in procuring new resources should not affect or void the plans to implement the Waiinu-Kanaha upgrade project.

## Introduction/Background

Maui Electric Company (MECO) plans to decommission Kahului Power Plant (KPP) on Maui island by the year 2019. The Maui transmission system consists of a 23 kV network and 69 kV network. KPP has a total capacity of approximately 35 MW and connects into the 23 kV network, and the remainder of Maui's generation connects into the 69 kV network. The two networks are interconnected via 23/69 kV tie transformers located at the Waiinu, Kanaha, and Puunene substations. KPP is the only source of generation connected to the 23 kV network. The retirement of the power plant will result in the 23 kV network becoming heavily dependent on power supplied by the 69 kV network.

The Transmission Planning Division (TPD) anticipates the Maui system to become vulnerable to numerous system reliability issues in the event of a system disturbance after decommissioning KPP. TPD conducted a study<sup>1</sup> in the year 2012 regarding MECO's plan to retire KPP, which analyzed several transmission solutions to mitigate the anticipated system issues. The study recommended upgrading the 23 kV Waiinu to Kanaha transmission line to 69 kV, relocating 23 kV load at Kahului to the 69 kV system, and reconductoring the 69 kV Maalaea Power Plant (MPP)-Puunene and 69 kV MPP-Waiinu transmission lines.

MECO will procure resources to meet an anticipated reserve capacity short fall of approximately 40 MW by year 2019, identified in Section 1.6 of the Maui Electric Adequacy of Supply (AOS) report. The procurement of additional resources may potentially void the need for the Waiinu-Kanaha upgrade project. TPD was asked to consider non-transmission alternatives (NTAs) as a possible solution to mitigate the issues that arise with the retirement of KPP. TPD performed several studies and produced reports which analyze the system impacts of various NTA options.

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<sup>1</sup> Refer to Docket No. 2011-0092 – MECO 2012 Test Year Rate Case  
Maui Electric System Improvement and Curtailment Reduction Plan

## Kahului Power Plant Retirement – Comprehensive Assessment

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This report consolidates the findings of the various studies performed by TPD and provides TPD's standpoint regarding whether the Waiinu-Kanaha project should still be pursued taking into consideration that additional generation resources will be procured by year 2019.

### Methodology

TPD used a conventional transmission planning software to perform dynamic, steady-state, and short circuit analyses simulating the Maui system with various NTA upgrades under the normal and various N-1 conditions. The results were examined with consideration of the civil, corporate, and political concerns involved with each option to determine the most favorable and engineeringly sound solution to properly address the issues involved with the retirement of KPP.

### Assumptions:

The following are the assumptions used in this study unless specified otherwise:

- Referencing of the “23 kV network” in this study does not include the 23 kV circuit from Kula to Haleakala due to its electrical distance from the rest of the 23 kV system.
- The Hana 23 kV circuit is fed from Pukalani.
- Kahului Power Plant is retired by 2019.
- The system upgrade involving the conversion of the 23 kV Waiinu to Kanaha transmission line to 69 kV, relocating 23 kV load at Kahului to the 69 kV system, and reconductoring the 69 kV MPP-Puunene and 69 kV MPP-Waiinu transmission lines will be referred to as the “Waiinu-Kanaha upgrade project” in this report.
- Contract with HC&S will expire in 2014 and HC&S will no longer contribute any generation after year 2014.
- The acceptable “power margin” is between 1.05 - 0.9 per unit (p.u.) voltage per the reliability criteria.
- The acceptable thermal margin is within thermal limits of the normal rating (Rating A) under the normal condition and within thermal limits of the emergency rating (Rating B) for N-1 condition. However, transmission lines operating near the maximum thermal limits are also taken into consideration.
- An N-1 event refers to the loss of a single transmission line or generating unit.

### Results and Analysis

Several NTA options were considered:

- New Dispatchable Firm Generation/Distributed Generation (DG).
- Battery Energy Storage System (BESS).
- Demand Response (DR).
- Conversion of some or all existing units at KPP to synchronous condensers.

## Kahului Power Plant Retirement – Comprehensive Assessment

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The conversion of existing KPP units to synchronous condensers does not address the reserve capacity shortfall issue; however, it does potentially mitigate the anticipated low voltage issues resulting from the KPP retirement and void the need for the Waiinu-Kanaha upgrade project and, therefore, was considered as an NTA.

### Thermal Limit Analysis:

The retirement of KPP subjects the 23 kV network to become heavily dependent on power to be supplied by the 69 kV network. This places additional burden on the transmission lines and tie transformers that interconnect the 23 kV and 69 kV networks – with KPP decommissioned, more power must flow through these transmission components from the 69 kV network to the 23 kV network to feed the load that had previously been served by KPP.

TPD's Thermal Analysis study identified that, with KPP decommissioned, when the Maui system experiences a disturbance, the tie transformer and transmission line connecting the 23 kV and 69 kV systems will be overloaded; see Appendix A. The study shows that in the N-1 contingency event of losing the 69 kV MPP-Waiinu transmission line, the tie transformer at Kanaha substation and the 69 kV MPP-Puunene transmission line will be overloaded beyond their emergency ratings. Similarly, in the N-1 contingency event of losing the 69 kV MPP-Puunene transmission line, the tie transformer at Waiinu substation is overloaded beyond its emergency rating.

The study also shows that, in addition to thermal overloads of transmission components, suffering a system disturbance will also cause low voltage profiles, below the acceptable voltage margin defined in the reliability criteria, at numerous locations on the 23 kV network. This is expected as the main generation source on the 23 kV system is removed and power must be supplied via the 69 kV network; suffering a system disturbance such as losing a transmission line subjects voltage sources to be electrically farther from load centers and power transfer limits are reduced.

The NTA's were examined focusing on their capability of mitigating the above mentioned issues. If the additional procured resources are interconnected on the 69 kV network, they will not mitigate the burden placed on the tie transformers and transmission lines that connect the 23 kV and 69 kV networks because power must still be supplied from the 69 kV network to the 23 kV network. TPD's Thermal Analysis study examines the system impacts of interconnecting the procured resources on the 23 kV network. The study shows that by installing active power resources on 23 kV network, the tie transformers and transmission lines are able to operate within the acceptable thermal limit margin during an N-1 condition because majority of the load on the 23 kV network is being served by the new resources installed on the 23 kV network, relieving the amount of power needed to travel through the tie transformers and transmission lines. Both BESS and DG options show these results and mitigate low voltage profiles that violate the reliability criteria; however, voltage instability can occur despite voltage profiles being within the acceptable margin; this will be covered more in detail below. The synchronous condenser option does not resolve the thermal overload issues and is not a viable alternative to the Waiinu-Kanaha upgrade project.

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HECO Transmission Planning Division

Document Title: Kahului Power Plant Retirement – Comprehensive Assessment

Reference: TPD 2014-22

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## Kahului Power Plant Retirement – Comprehensive Assessment

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### Voltage Stability Analysis:

In addition to the thermal overloading of transmission components, the retirement of KPP poses several voltage instability concerns. TPD's Voltage Stability Assessment studies the system impacts of the removal of KPP from the voltage stability standpoint; see Appendix B. The study identifies that the removal of generation at KPP results in voltage sources becoming electrically farther from the 23 kV network load centers, and significantly diminishes the transfer limits of power to the 23 kV network, subjecting the system to operate in conditions of voltage instability, or possibly suffer from an event of voltage collapse, if a system disturbance takes place.

The Voltage Stability Assessment study examines the mitigation capabilities of various NTA options for avoiding violations of voltage criteria and operation in unstable voltage circumstances. The study identified that installing new active power resources (BESS and DG options) on the 69 kV network will not mitigate the voltage issues on the 23 kV network that arise from the removal of KPP; this is because generation must still be supplied from the 69 kV network, thus voltage sources are still electrically far from load centers and/or power transfer capability limits have been reached – installing new procured resources on the 69 kV network will still result in voltage violations and voltage instable/voltage collapse conditions.

The study shows that adding active power resources to the 23 kV network and converting existing KPP units to synchronous condensers will allow voltage profiles within the voltage criteria; however, the study focused on how the NTA options impact the power transfer capability limits and proximity of voltage collapse as voltage instability and voltage collapse may occur despite voltage profiles being well within the acceptable margin.

Adding active power resources to the 23 kV network and converting existing KPP units to synchronous condensers show promising results in improved power transfer capability limits and avoiding voltage instability/voltage collapse, depending on the size of units installed; see Voltage Stability Assessment for detailed analysis. The study identifies that in the event of a disturbance, the DR program option must curtail load on the 23 kV network to maintain total system load of 170 MW, approximately 15 MW (required amount of load needed to be curtailed increases for later years as load continues to grow), in order to maintain system reliability.

### Short Circuit Analysis:

TPD performed a study concerning the effects the retirement of KPP will have on the short circuit current, see Appendix C. The study analyzes and compares the short circuit current on the existing Maui transmission system to the Maui system with various changes to its topology (i.e. Maui system with Waiinu-Kanaha upgrade, various NTA options, etc.). The study indicated that the retirement of KPP will induce a possible change in fault current of as much as 5,000 amperes, which may affect relay operations and violate system reliability. The study recommends that with the retirement of KPP and implementation of new system element, the company should re-evaluate the effect of reduced fault current on the Maui system and make necessary changes to protection schemes.



## Kahului Power Plant Retirement – Comprehensive Assessment

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### Discussion

Both BESS and DG options are viable alternatives to the Waiinu-Kanaha upgrade project, however, they must be installed on the 23 kV network in order to mitigate the issues that arise with the removal of KPP. Presently, TPD is only aware of the Waena Power Plant (WPP) and South Maui sites as suggested locations to accommodate new addition generation resources – these locations are on the 69 kV network. TPD is skeptical whether suitable land can be acquired to house the new generation resources since the Central Maui area is densely populated by many private and commercial residents. The original KPP site was also considered for possible space to house new resources, however, recent updates to the Maui island tsunami evacuation maps show that the KPP site now resides in a tsunami inundation zone. Converting existing KPP units to synchronous condensers will mitigate voltage issues but will not address the thermal overloading of transmission components issues, thus is not a viable alternative to the Waiinu-Kanaha upgrade project. The DR program is a viable alternative but involves the curtailment of customer load – presently, the expected required amount of load on the 23 kV network to be curtailed is 20 MW for year 2019 to avoid thermal and voltage issues; more load will be required for curtailment as system load continues to grow.

The Waiinu-Kanaha upgrade project involves converting the existing 23 kV Waiinu-Kanaha to 69 kV, and in the process will relocate load at Kahului to the 69 kV network. In addition to the line conversion, 69 kV MPP-Waiinu and 69 kV MPP-Puunene transmission lines will be reconducted to 556 AAC lines. Converting the 23 kV Waiinu-Kanaha line to 69 kV will relieve some burden placed on the transmission components that interconnect the 23 kV and 69 kV networks as load at Kahului (on the 23 kV network) will be relocated to 69 kV network – less power will be required to flow through interconnecting transmission components. The reconducting of the 69 kV MPP-Waiinu and 69 kV MPP-Puunene transmission lines serves to strengthen the transmission route for power to travel to the 23 kV network to address the issue of those lines operating near or beyond their emergency rating limit in the event of a system disturbance, identified in Thermal Limit Analysis study. The Waiinu-Kanaha upgrade project will mitigate the thermal limit and voltage issues involved with the removal of KPP. As identified in the Voltage Stability Analysis study, if the upgrade project produces favorable results in improving the power transfer capability limits of the Central Maui area and allows the system to operate at a significantly greater proximity away from circumstances which could lead to voltage instability/voltage collapse.

### Conclusion

TPD has examined various NTA options that could potentially void the need for the Waiinu-Kanaha Upgrade project. TPD has determined the option involving the conversion of existing KPP units to synchronous condensers is not viable as it will not address thermal limit overload issues that arise with the KPP removal. TPD also does not recommend the DR program option as an alternative to the Wainu-Kanaha upgrade because it requires curtailing more customer load on the 23 kV network than was identified as potential on all of Maui. TPD has determined the NTA options which involve installing BESS and/or DG units on the 69 kV network is not a

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HECO Transmission Planning Division

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Reference: TPD 2014-22

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## Kahului Power Plant Retirement – Comprehensive Assessment

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viable alternative because it will not address the thermal limit overload and voltage issues. But installing BESS and/or DG units on the 23 kV network will address both thermal overload and voltage issues involved with the KPP removal and is a viable alternative to the Waiinu-Kanaha upgrade. However, the only known locations available to accommodate the new resources are the WPP site and a site within the South Maui area, which both are on the 69 kV network. Considering the limited availability of suitable land to accommodate new generation resources on the 23 kV network and the tradeoffs impacting the Maui system without the Waiinu-Kanaha upgrade, TPD concludes that MECO should proceed with the implementation of the Waiinu-Kanaha upgrade project. MECO's procurement of resources to address the anticipated reserve capacity shortfall of 40 MW by year 2019 should not affect or void the plans for the Waiinu-Kanaha upgrade project.

# Kahului Power Plant Retirement – Comprehensive Assessment

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## Appendix A – Thermal Analysis

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HECO Transmission Planning Division

Document Title: Kahului Power Plant Retirement – Comprehensive Assessment

Reference: TPD 2014-22

# Kahului Power Plant Retirement: Transmission System Steady State Analysis

Prepared for  
Maui Electric Company, Ltd.

Prepared by  
Hawaiian Electric Company, Inc  
System Planning Department  
Transmission Planning Division

June 12, 2014

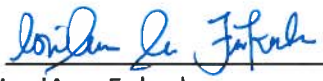
Reference # TPD2014-23

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# KPP Retirement Steady State Analysis

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## Kahului Power Plant Retirement: Transmission System Steady State Analysis

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## KPP Retirement Steady State Analysis

### Introduction

Kahului Power Plant (KPP) is scheduled to be decommissioned in 2019. The Maui transmission system consists of a 23kV system and a 69kV system. KPP serves majority of the load on the 23kV system.

Figure 1 identifies the power plants, substations, and transmission lines associated with the KPP retirement. With the retirement of KPP, all of the load on the 23kV system will need to be served from the 69kV system. The Maui transmission system utilizes three 69/23kV tie transformers to interconnect the 69kV system and the 23kV system. These 69/23kV transformers are located at Waiinu Substation, Puunene Substation, and Kanaha Substation.

This study was conducted to identify the transmission system impacts with the retirement of KPP and analyze various solutions necessary to provide safe reliable power to the customers.

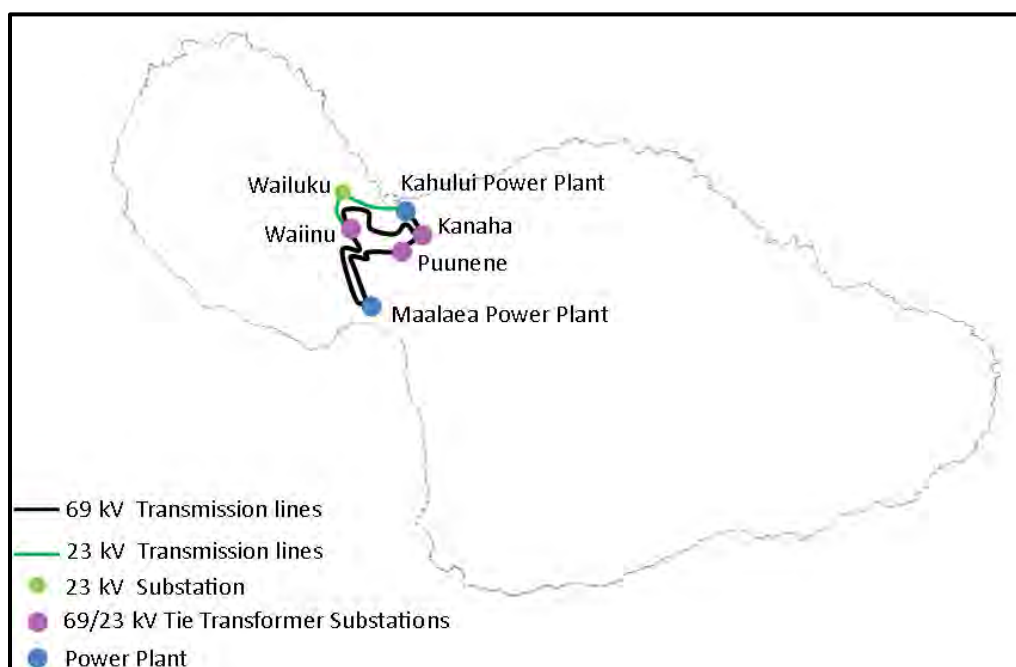


Figure 1: Key central Maui transmission components

### Assumptions

The “23kV system” referred in this document consists of the substations within central Maui—Wailuku, Kanaha, Kahului Sub 8, and substations fed by these major substations. Hana is being fed from Pukalani and the distance from the central substations to Haleakala and Kula do not have the same effect from the rest of the 23kV system; therefore, they are not included in the reference to the “23kV system.”

This study only evaluates the impact to the system from a steady state point; stability analysis will also need to be conducted.



### Model Assumptions

To model the Maui transmission system, we used actual 2013 historical load data to create a benchmark case. From the benchmark case, the following planned transmission system changes were implemented to create the cases for the interested years of study:

- 2014—KPP units K1 and K2 deactivated
- 2014—HC&S Offline
- 2015—Kaonoulu Substation
- 2019—All KPP units decommissioned
- 2019—Waiinu 69/23kV tie transformer enabled to auto-adjust

After the changes are implemented, the cases are uniformly scaled to the forecasted system gross loads.

### Load Assumptions

The gross peak and minimum with DSM/NEM/SIA/FIT load forecast used in this study is based on the May 2014 Adopted Maui Electric Sales and Peak Forecasts. This study focused on the 2014 with a load forecast of 197.9 MW and 2019 with a load forecast of 218.3 MW to represent the current system and the system after the retirement of KPP, respectively. Refer to Appendix A for the entire 2014-2030 load forecasts.

### Generation Assumptions

Currently, MECO operates two power plants—Kahului Power Plant (KPP) and Maalaea Power Plant (MPP). In addition, the following renewable generation serves the Maui load:

- HC&S—12 MW biomass
- KWP I—30 MW wind farm
- KWP II—21 MW wind farm
- Auwahi—21 MW wind farm
- Makila Hydro—0.5 MW hydro

The system also has two 1 MW units in Hana Substation for emergencies. Appendix B provides an overview of the current Maui system generation.

### Thermal Overloads

The amount of power that can flow through the transmission system components, such as conductors and transformers, is limited by its characteristics. Too much current flowing through the conductors and transformers will cause damage due to overheating. Under scenarios with no contingencies, the transmission equipment is evaluated using the normal rating (Rating A). For N-1 contingencies, the system is evaluated with emergency ratings (Rating B). See Appendix C for a single line diagram overview of the central Maui system showing line ratings.

### Voltage Violations

The MECO criteria for transmission planning states that under any operating condition, voltages for any bus shall have a maximum of +5% and a minimum of -10% of the nominal voltage. The per unit (pu) values are shown in Table 1.

## KPP Retirement Steady State Analysis

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Table 1: MECO Voltage Criteria for Transmission Planning

| Criteria                | Normal Conditions | Emergency Conditions |
|-------------------------|-------------------|----------------------|
| Over voltage violation  | > 1.05 pu         | > 1.05 pu            |
| Under voltage violation | < 0.90 pu         | < 0.90 pu            |

This report refers to “low voltages”, which meet the planning criteria by being above 0.90 pu but are of concern as these voltages can be an under voltage violation in the future. Maintaining voltages within the criteria provides customers with good power quality; so there are no damages to customer equipment. Furthermore, if voltages fall too far below 0.9 pu, the system may not be able to recover and a voltage collapse will occur.

### Steady State Analysis

To assess the impact on the transmission system with the retirement of KPP, the cases were subjected to N-1 contingencies. An N-1 contingency occurs when there is an outage of one transmission system component, while all others are in service. The following two contingencies are evaluated, as these contingencies are crucial paths that transfer power from the 69kV system to the 23kV system:

- Contingency 1: Loss of 69kV MPP-Waiinu
- Contingency 2: Loss of 69kV MPP-Puunene

The steady state analysis will identify any thermal overloads or voltage violations that can occur during these contingencies. To see the effects of retiring KPP, analysis was conducted with a case modeling the current system in 2014 and a case with the current system in 2019. Thermal and voltage violations occurred in the 2019 case if no upgrades to the system were made. The following are solutions considered to address the thermal and voltage violations:

- 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiinu and MPP-Puunene from 336AAC to 556AAC
- 25MW Battery Energy Storage System (BESS)
- 40MW Distributed Generation (DG)
- Synchronous condensers from retiring KPP units

Table 2 shows the case assumptions used when analyzing the impacts KPP retiring and the solutions considered. The amount of demand response (DR) needed would need to be similar to the generation provided by the BESS or DG to reduce the load on the 23kV system.

Table 2: KPP Retirement Steady State Case Assumptions

| Case | Solution                                      | Description   |
|------|---|---|
| 0    | ---   | <ul style="list-style-type: none"> <li>• 2014 peak</li> <li>• Load Forecast = 197.9MW</li> </ul>  |
| 1    | ---   | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> </ul>   |
| 2    | Transmission Upgrades                         | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 23kV Waiinu-Kanaha upgrade to 69kV</li> <li>• MPP-Waiinu reconducted from 336 to 556</li> <li>• MPP-Puunene reconducted from 336 to 556</li> <li>• Remove FDR C from KPP-Kanaha 23kV</li> </ul> |
| 3    | 25 MW BESS                                    | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 25MW BESS interconnected at KPP</li> </ul>  |
| 4    | 40 MW DG                                      | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 40MW DG interconnected at KPP</li> </ul>  |
| 5    | KPP Units converted to synchronous condensers | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• KPP units converted to synchronous condensers</li> </ul>  |

## KPP Retirement Steady State Analysis

### Results

Currently with KPP online (2014), there are no thermal or voltage violations under normal or N-1 contingency events. The 23kV system is less dependent on the 69kV system because KPP is serving the load on the 23kV system. This reduces the loading on the 69/23kV tie transformers.

For the 2019 case, under normal conditions, if no system upgrades are made, the Waiinu 69/23kV tie transformer was heavily loaded at 92% of the normal rating. When subjected to an N-1 contingency, the loss of MPP-Waiinu showed overloads on the Puunene and Kanaha 69/23kV tie transformers, overloading on the MPP-Puunene 69kV line, as well as under voltage violations for the 23kV system and the Waiinu 69kV bus.

Figure 2 is a magnified excerpt of the 69kV system and identifies the violations of the system under the loss of MPP-Waiinu contingency.

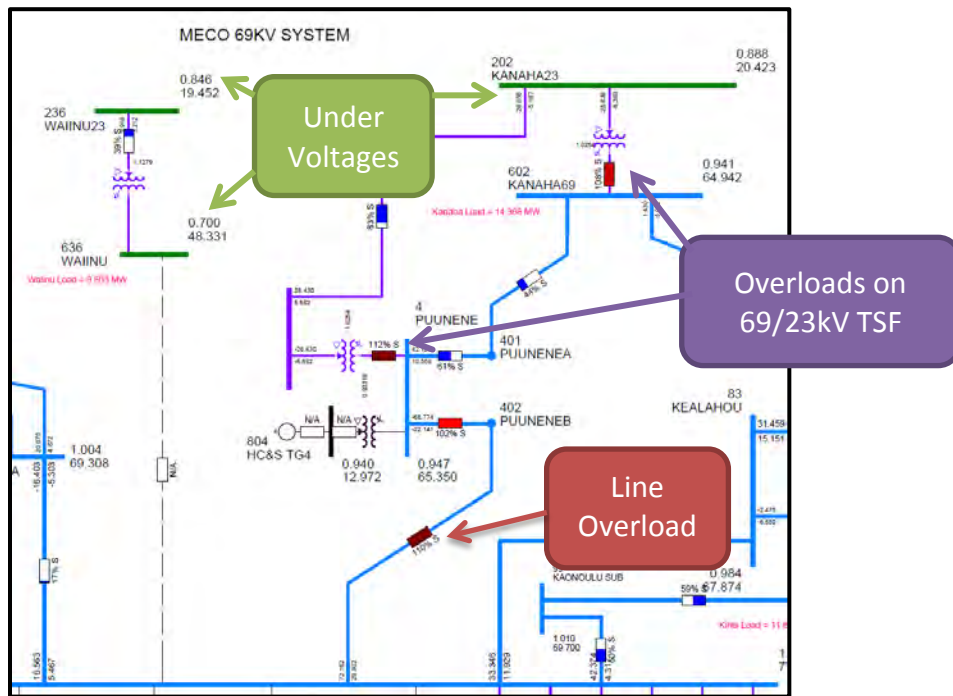


Figure 2: 69kV system current conditions for 2019 under N-1 contingency, loss of MPP-Waiinu





With these transmission upgrades, the 2019 system will have no thermal or voltage violations under normal or N-1 contingency events. Figure 5 shows the system in 2019 with the transmission upgrades under N-1 contingency. By relocating more loads on the 69kV system, there is less dependency on the tie transformers and transmission lines that provide support to the 23kV system.

# KPP Retirement Steady State Analysis

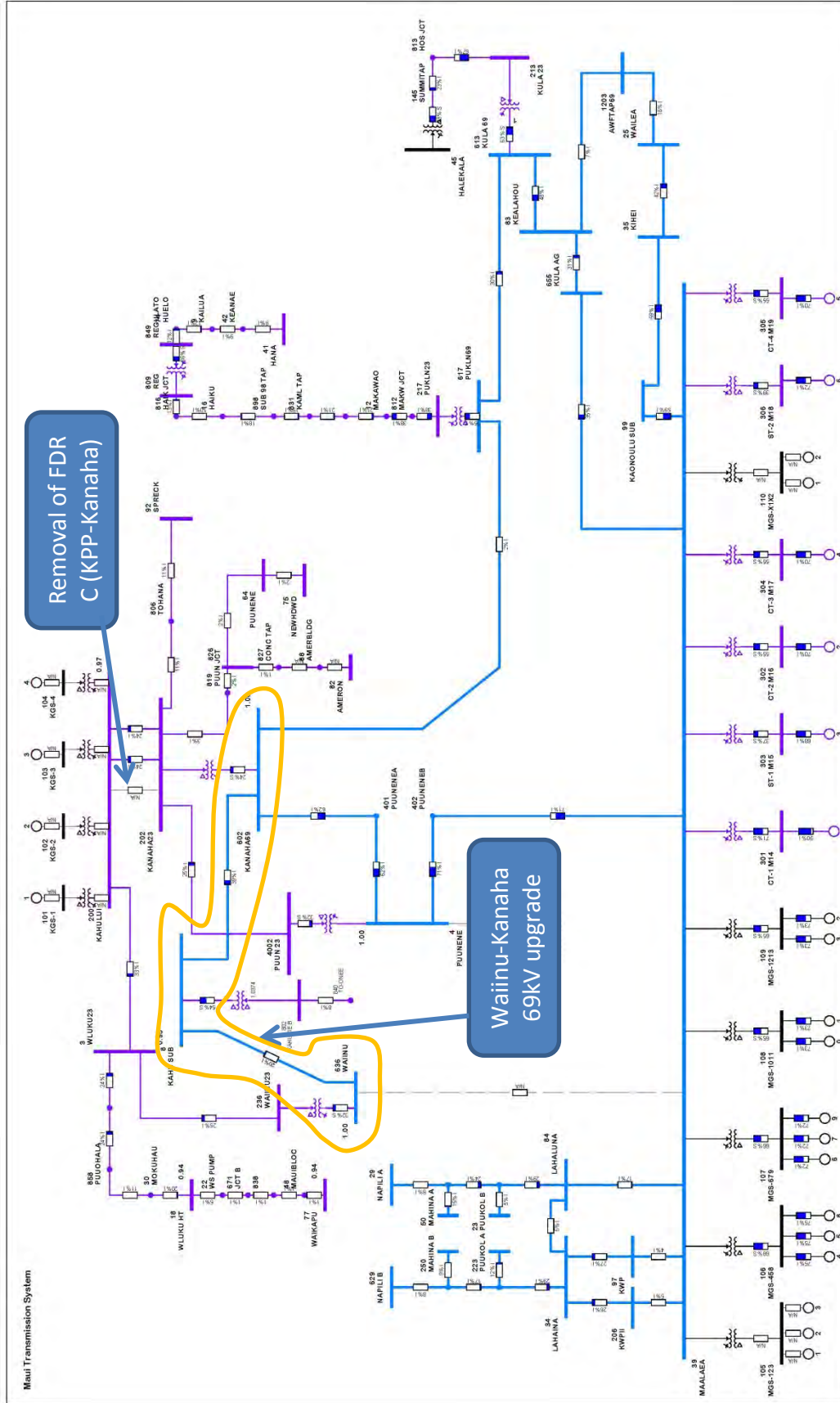


Figure 5: Maui system in 2019 with Transmission Upgrades under N-1 contingency, loss of MPP-Waiinu



### **25MW Battery Energy Storage System (BESS)**

The first non-transmission alternative (NTA) considered was the addition of a 25MW BESS interconnected to the 23kV system; this 25MW:30min BESS was addressed in the 2013 Integrated Resource Plan. For modeling purposes, the 25MW BESS was added to the retiring KPP site. However, the BESS will effectively provide the same support if added anywhere on the 23kV system. The BESS has the ability to respond to system disturbances immediately but will be limited by the MWh parameters. Due to the voltage and thermal issues seen with an N-1 contingency, the BESS will need to be able to supply the 23kV system during this system condition, which could possibly be for multiple hours. Other control settings, operation and parameters of the BESS are beyond the scope of this study.

A BESS has the capabilities to instantaneously respond to system disturbances depending on the controls of the BESS. Due to the under voltages occurring when the system is subject to the N-1 contingencies, if the system peaks occur from the hours of 10:00 AM to 8:00 PM and the contingency occurs during this peak period the BESS would need to supply power during this time. Therefore, the 25MW BESS should have at least an 8 hour duration (200MWh), to allow line crews to repair the line. The BESS can also be paired with DG—discussed in the next section—to reduce the duration needed.

## KPP Retirement Steady State Analysis

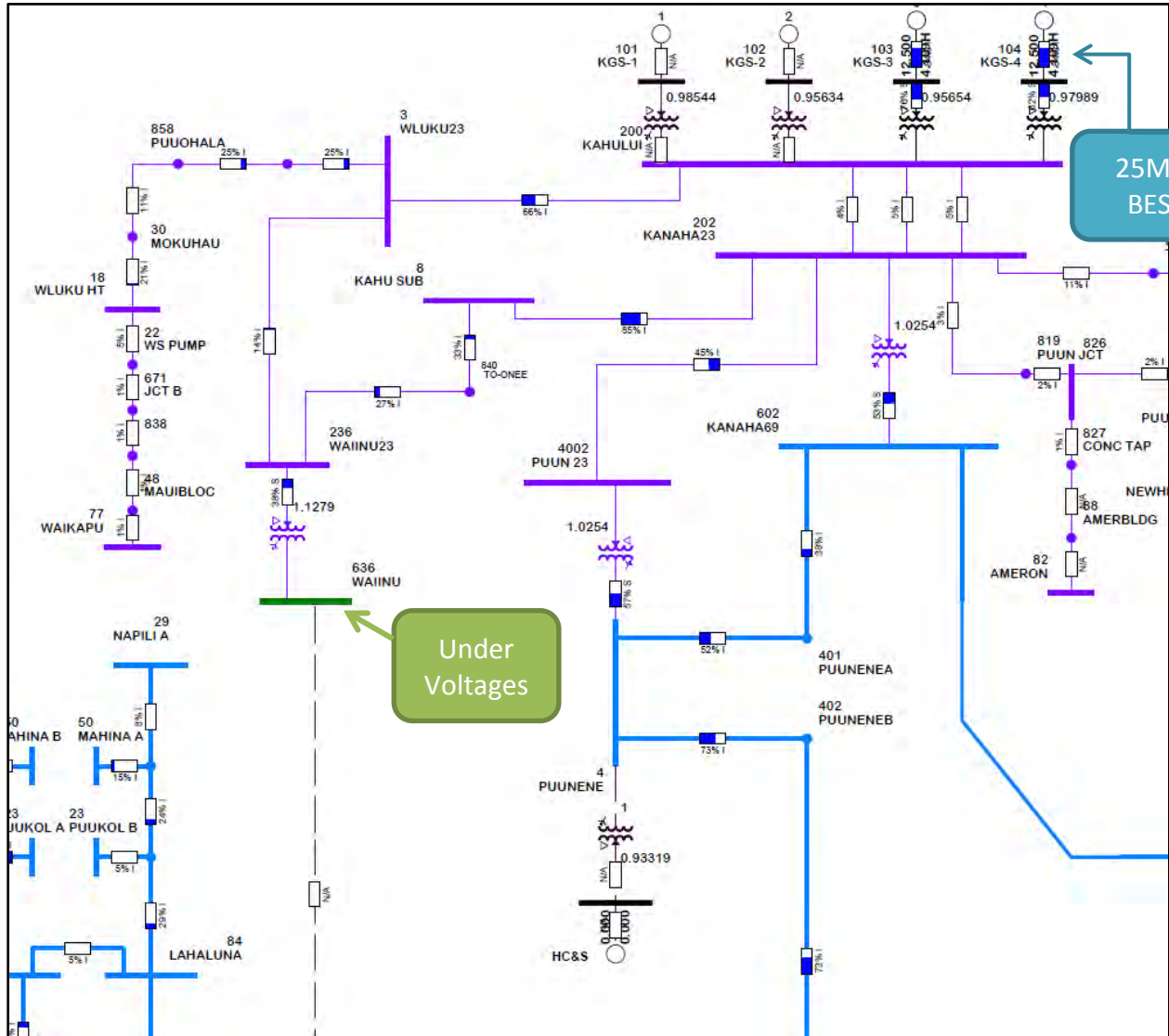


Figure 6: 25MW BESS modeled on the 23kV system improves voltages under N-1 contingency, loss of MPP-Waiinu

With the addition of a 25MW BESS on the 23kV system, when subjected to an N-1 contingency, low voltages occur at the 69kV Waiinu bus. There are no overloads on the 69/23kV tie transformers or the MPP-Puunene line. Furthermore, the low voltages at Waiinu 69kV are due to the control for the Waiinu 69/23kV tie transformer controlling the Waiinu 23kV bus voltage. With capability to control the Waiinu 69/23kV tie transformer tap settings, the Waiinu 69kV bus voltage could be kept within the planning criteria, above 0.90 pu.

### 40MW Distributed Generation (DG)

Another NTA considered is to have firm DG interconnected into the 23kV system. Having quick starting DG units would minimize the outage seen by the customer. Sizing, fuel, daily operation, and other unit characteristics is beyond the scope of this study, further analysis will need. Adding generation to the 23kV system will help alleviate the loading on the 69/23kV tie

transformers, and the 23kV system dependency on the 69kV system would be eliminated. Furthermore, with the retirement of KPP, the system will be deficient of supply by 40MW, so the addition of 40MW of DG to the system would meet the adequacy of supply requirements.

For modeling purposes, five 8.5MW units were added to the KPP site to total approximately 40MW of DG. The specific characteristics of the units can differ from the 8.5MW units that are modeled as well as the interconnection site on the 23kV system. Further analysis will need to be conducted based on the potential locations and parameters of the units which the system will require for stability. The issue of land zoning and air quality permits will also need to be addressed.

Due to the start-up times required for the DG, customers will experience outages. Fast starting units can have start-up times around 5 minutes. Stability analysis will show if the system can maintain a stability until these DG units can provide power. As mentioned before, a combination of BESS and DG can be used to eliminate the outages customers will experience. The BESS will serve the customers until the DG can start-up and output power.

With the 40MW of DG, no thermal or voltage issues occur during normal conditions and with the loss of MPP-Puunene. However, the loss of MPP-Waiinu resulted in under voltage violations for Waiinu 69KV. Similar to the under voltage violation for the BESS NTA for Waiinu 69kV, if the Waiinu 69/23kV tie transformer controls were adjusted properly, the Waiinu 69kV bus voltage could be kept above 0.9pu. Figure 7 shows the 69kV system, under voltage violation for the 69kV Waiinu bus with the loss of MPP-Waiinu. Figure 8 shows the 23kV system with no thermal or under voltage violations under the MPP-Waiinu contingency.

## KPP Retirement Steady State Analysis

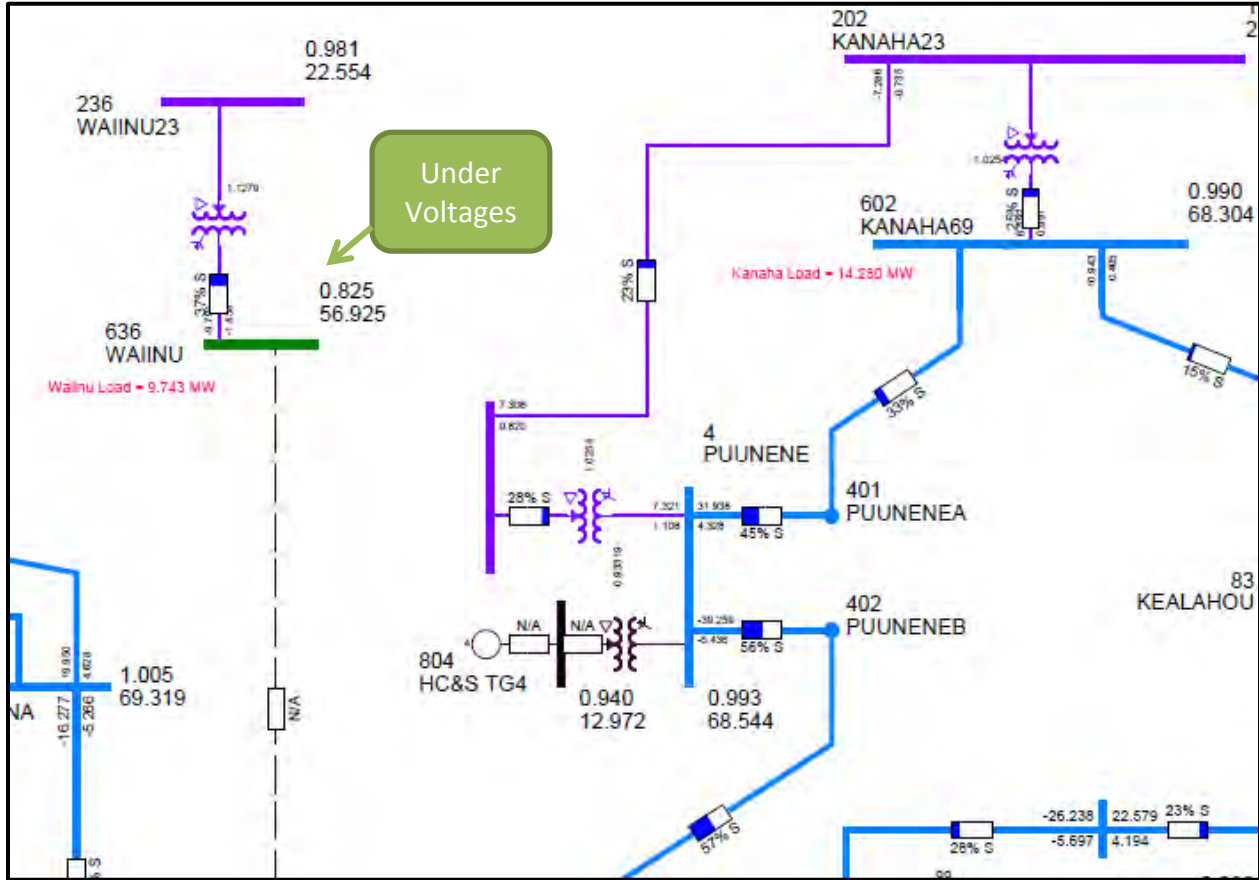


Figure 7: 69kV system with 40MW DG on 23kV system, under N-1 Contingency (loss of MPP-Waiinu) resulting in under voltage violation at Waiinu 69kV bus

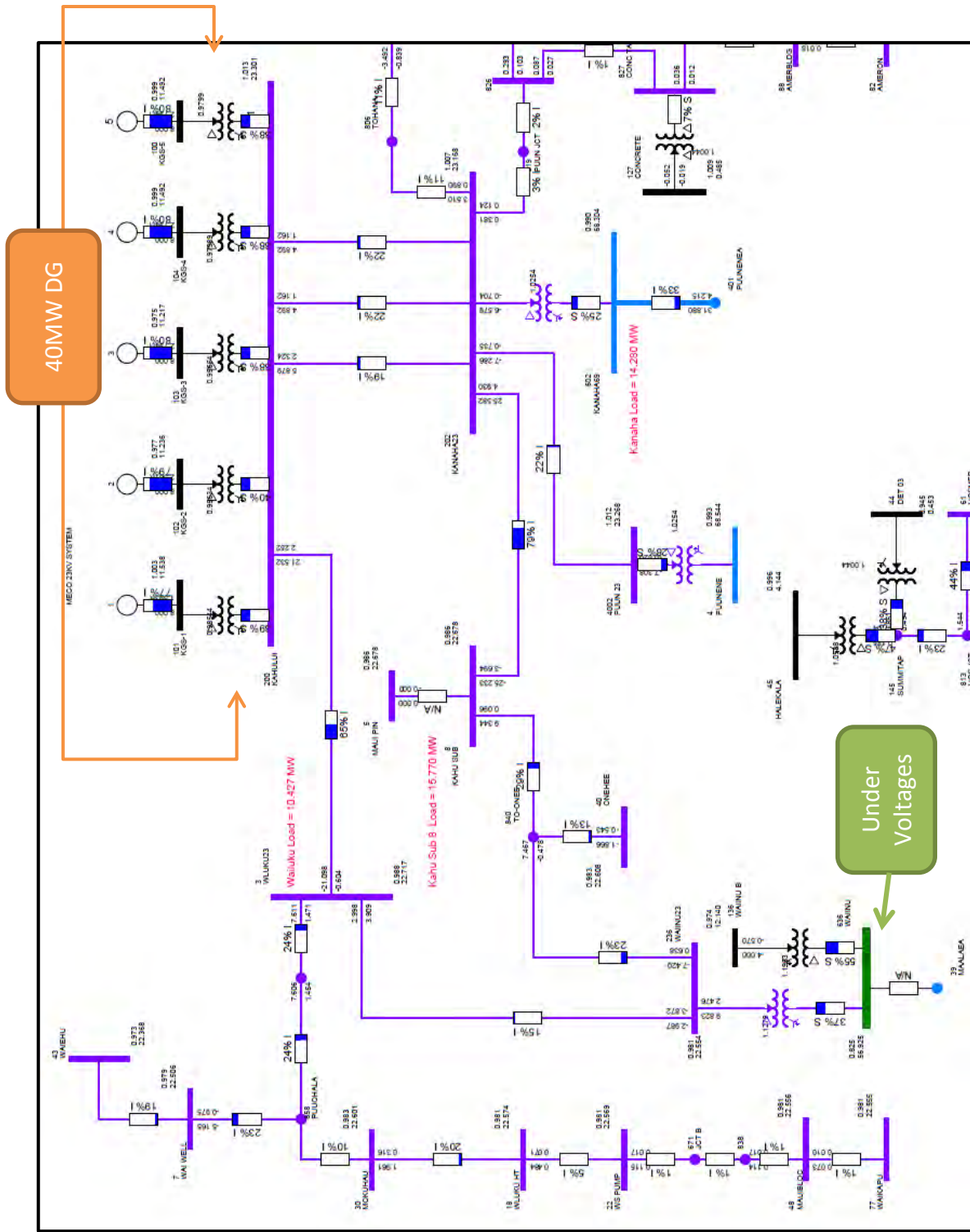


Figure 8: 23kV system with five 8.5MW units for 40MW DG interconnected on 23kV system providing support during N-1 contingency, loss of MPP-Waiwaku

## KPP Retirement Steady State Analysis

### Synchronous Condensers

To provide voltage support, another NTA considered was converting the existing KPP units to synchronous condensers. A synchronous machine operating without a prime mover is a synchronous condenser. Controlling of the field excitation allows a synchronous condenser to either absorb or supply reactive power to the system.

Under normal conditions, because of the transferring of load from MPP to the 23kV system, the Waiinu 69/23kV tie transformer is heavily loaded at 93% of its normal rating. As the load increases on the 23kV system, the Waiinu 69/23kV tie transformer will be overloaded. For the MPP-Waiinu N-1 contingency, although the synchronous condensers help the 23kV system voltages remain within the planning criteria, the Puunene and Kanaha 69/23kV tie transformers are overloaded. In addition, the MPP-Puunene is above 100% of its emergency rating and the Waiinu 69kV bus violated the voltage criteria.

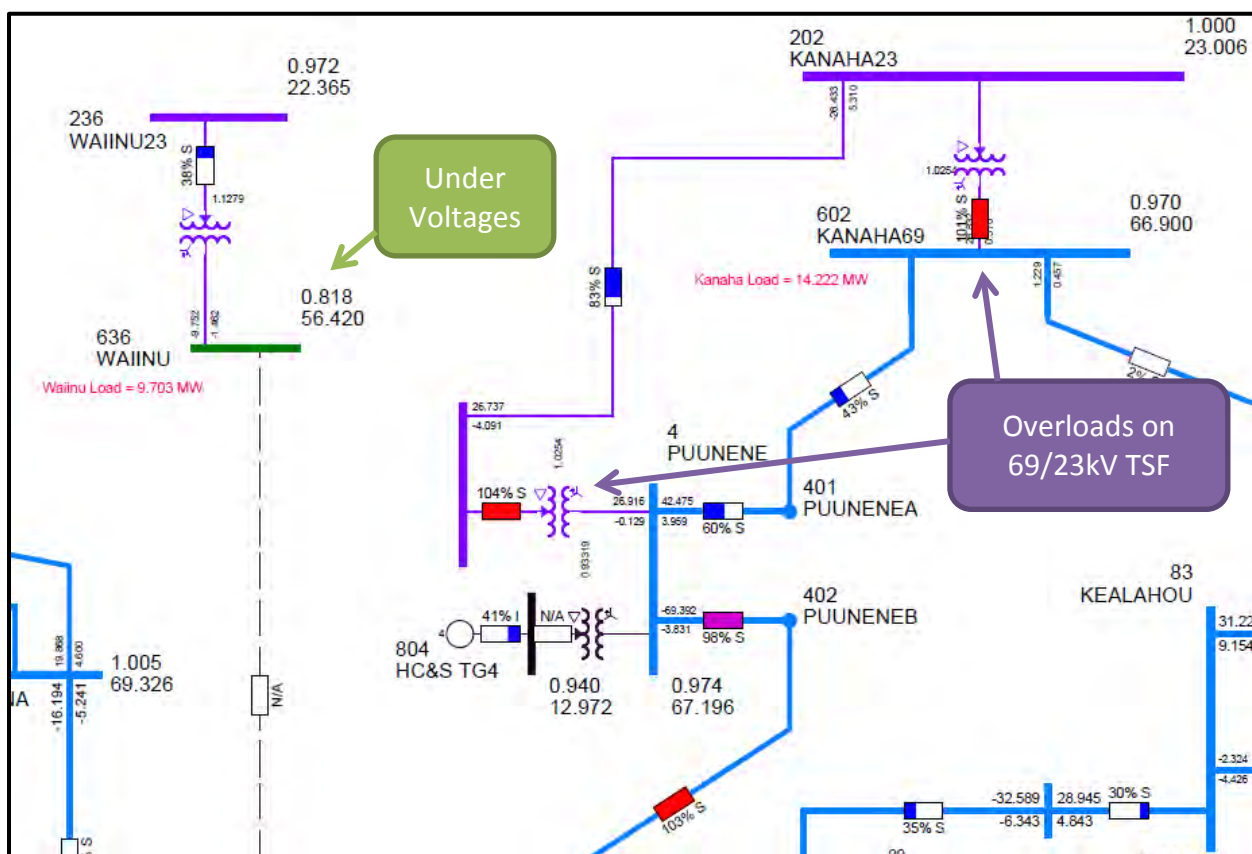


Figure 9: 2019 69kV system with KPP units converted to synchronous condensers subjected to MPP-Waiinu contingency

Due to the overloading issues with using KPP units as synchronous condensers, transmission upgrades will also be needed. The Waiinu 69kV under voltage violation occurs because the transformer taps are being controlled to regulate the 23kV Waiinu bus.

### Summary of Results

To address the under voltage violations and overloads on the transmission system with the retirement of KPP, this steady state analysis considered the following system improvements:

- 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiinu and MPP-Puunene from 336AAC to 556AAC
- 25MW BESS
- 40MW DG
- Synchronous condensers from retiring KPP units

The retirement of KPP impacts the 23kV system greatly. With no upgrades to the transmission system and the retirement of KPP violations to the criteria for transmission planning are eminent.

The transmission upgrades resulted in the system having no thermal or voltage issues for normal or N-1 conditions. While the 25MW BESS and 40MW DG had some under voltage violations and high thermal loadings. The KPP units a synchronous condensers managed the under voltages but thermal overloads occur. Table 3 lists the issues of concerns for the various cases that were used in the study.

## KPP Retirement Steady State Analysis

Table 3: Summary of Analysis

| Case | Case Description                          | Condition   | NOTES   |
|------|---|---|---|
| 0    | 2014 Current System                       | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | No thermal or voltage violations<br>No thermal or voltage violations<br>No thermal or voltage violations  |
| 1    | 2019 No Upgrades                          | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | Waiinu 69/23kV loaded at 92% of normal rating<br>Overloads on MPP-Puunene, Puunene 69/23kV TSF, Kanaha 69/23kV TSF, and under voltages in central Maui 23KV system and Waiinu 69kV bus<br>Overloading on the Waiinu 69/23 kV TSF and low voltages at Puunene, Kanaha and Pukalani 69 subs   |
| 2    | 2019 Transmission Upgrades                | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | No thermal or voltage violations<br>No thermal or voltage violations<br>No thermal or voltage violations  |
| 3    | 2019 25MW BESS                            | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | No thermal or voltage violations<br>Under voltage violation for Waiinu 69kVbus and high loading (97%) on Kanaha-Kahului Sub 8 23kV line (percentages based on emergency ratings)  |
| 4    | 2019 40MW DG                              | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | No thermal or voltage violations<br>No thermal or voltage violations<br>Under voltage violation for Waiinu 69kV bus and Kanaha-Kahului Sub 8 23kV line loading at 79% (percentages based on emergency loadings)   |
| 5    | 2019 K1, K2, K3, K4 Synchronous Condenser | Normal<br>Contingency 1: MPP-Waiinu<br>Contingency 2: MPP-Puunene | No thermal or voltage violations<br>Waiinu 69/23kV TSF loading at 93% of normal rating and MPP-Puunene 69kV line at 79% of normal rating<br>Under voltage violation for Waiinu 69kV bus, overloading on MPP-Puunene 69kV line, and overloading on Puunene 69/23kV TSF and Kanaha 69/23kV TSF; Kanaha-Kahului Sub 8 line loading at 86% and Puunene-kanaha 23kV line loading at 83% (percentages based on emergency ratings)<br>Overloading on the Waiinu 69/23 kV TSF |



Along with the results from the steady state simulations that were modeled, other issues should be considered. Table 4 identifies various pros and cons associated with the various solutions. These pros and cons will need to be further assessed.

Table 4: Pros and Cons for solutions evaluated

| Solution                   | Pros   | Cons  |
|----------------------------|--|---|
| Transmission Upgrade       | <ul style="list-style-type: none"> <li>• Does not require large area of land</li> <li>• No zoning, air quality permits required</li> <li>• Product life</li> </ul>                           | <ul style="list-style-type: none"> <li>• Transmission capital investment</li> </ul>   |
| 25MW BESS                  | <ul style="list-style-type: none"> <li>• Prolong need for transmission infrastructure</li> <li>• Instantaneous response (compared to DG)</li> <li>• No emissions (compared to DG)</li> </ul> | <ul style="list-style-type: none"> <li>• Need to acquire land</li> <li>• Product life</li> <li>• Limited run time</li> <li>• Cost</li> </ul>  |
| 40MW DG                    | <ul style="list-style-type: none"> <li>• Prolong need for transmission infrastructure</li> <li>• Contribute to Adequacy of Supply</li> <li>• Renewable generation with biodiesel</li> </ul>  | <ul style="list-style-type: none"> <li>• Need to acquire land</li> <li>• Need to acquire air quality permits</li> <li>• Requires zoning for land (Heavy Industrial)</li> <li>• Noise</li> <li>• Disruption to customers (time required for units to start)</li> </ul> |
| KPP Synchronous Condensers | <ul style="list-style-type: none"> <li>• Use existing machines</li> </ul>  | <ul style="list-style-type: none"> <li>• KPP in Tsunami flood zone</li> <li>• Still require transmission infrastructure upgrades</li> </ul>   |

## KPP Retirement Steady State Analysis

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### **Conclusion**

A steady state analysis was conducted to identify system impacts of the KPP retirement, and evaluated possible solutions. This analysis identified overloading and under voltage violations on the system. To provide safe and reliable power to customers, the system would need an upgrade, to not violate the MECO criteria for Transmission Planning. A transmission upgrade along with several non-transmission upgrades were evaluated for improving the system during normal and contingency scenarios.

Based on the steady state analysis, the transmission upgrades are recommended to maintain a safe reliable system with the retirement of KPP. The transmission upgrades for the 23kV Waiinu-Kanaha conversion to 69kV with MPP-Waiinu and MPP-Puunene reconductoring had a greater effect on improving the system compared to the other solutions. With the transmission upgrades, there were no thermal or voltage violations during normal or N-1 contingency conditions.

**Appendix A**  
Load Forecasts

## KPP Retirement Steady State Analysis

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Based on the May 2014 Maui Adopted Sales and Peak Forecasts

Table A.1: Gross Minimum and Peak System Load Forecast with DSM/NEM/FIT/SIA

| Year  | Min* (MW) | Peak* (MW) |
|---|-----------|------------|
| 2014  | 84.4      | 197.9      |
| 2015  | 86.2      | 199.7      |
| 2016  | 88.1      | 202.1      |
| 2017  | 91.5      | 208.2      |
| 2018  | 94.9      | 214.4      |
| 2019  | 97.3      | 218.3      |
| 2020  | 98.9      | 220.0      |
| 2021  | 100.6     | 221.9      |
| 2022  | 101.9     | 222.6      |
| 2023  | 103.2     | 223.3      |
| 2024  | 104.3     | 223.0      |
| 2025  | 105.9     | 223.3      |
| 2026  | 107.1     | 222.1      |
| 2027  | 108.2     | 220.4      |
| 2028  | 108.9     | 217.1      |
| 2029  | 110.3     | 214.8      |
| 2030  | 111.3     | 210.8      |
| *Gross NEM/FIT/SIA are assumed to be zero ;<br>PV has no impact during early morning or evening hours |           |            |

**Appendix B**  
Generation Overview

## KPP Retirement Steady State Analysis

Table B.1: Current Maui Electric Generation Overview

| Maui Electric Generation Overview |                         |                    |                    |                      |                              |
|-----------------------------------|-------------------------|--------------------|--------------------|----------------------|------------------------------|
| Maalaea Power Plant               |                         |                    |                    |                      |                              |
| Unit                              | Unit Type               | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation | Ramp Rates<br>(Gross MW/min) |
| MX1                               | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| MX2                               | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M1                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M2                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M3                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M4                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M5                                | ICE                     | 5.6                | 2.0                | Cycling/Peaking      | 1.0                          |
| M6                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M7                                | ICE                     | 5.6                | 2.0                | Cycling/Peaking      | 1.0                          |
| M8                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M9                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M10                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M11                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M12                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M13                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M14                               | CT                      | 58                 | 12.5               | DTCC-Baseload        | 2.0                          |
| M15                               | ST                      |                    | 11.0               | DTCC-Baseload        | DTCC-1.0;<br>STCC-0.5        |
| M16                               | CT                      |                    | 12.5               | DTCC-Baseload        | 2.0                          |
| M17                               | CT                      | 58                 | 14.0               | STCC-Cycling         | 2.0                          |
| M18                               | ST                      |                    | 3.0                | STCC-Baseload        | DTCC-1.0;<br>STCC-0.5        |
| M19                               | CT                      |                    | 14.0               | STCC-Baseload        | 2.0                          |
|                                   | TOTAL:                  | 212.1              |                    |                      |                              |
| Kahului Power Plant               |                         |                    |                    |                      |                              |
| K1                                | Boiler/Steam<br>Turbine | 5.0                | 2.50               | Cycling              | 0.10                         |
| K2                                | Boiler/Steam<br>Turbine | 5.0                | 2.50               | Cycling              | 0.10                         |
| K3                                | Boiler/Steam<br>Turbine | 11.5               | 3.50               | Baseload             | 0.10                         |
| K4                                | Boiler/Steam<br>Turbine | 12.5               | 3.50               | Baseload             | 0.10                         |
|                                   | TOTAL:                  | 34.0               |                    |                      |                              |

| Hana Substation             |              |                    |                    |                      |  |
|-----------------------------|--------------|--------------------|--------------------|----------------------|--|
| Unit                        | Unit Type    | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation |  |
| H1                          | ICE          | 1.0                | 0.0                | Emergency            |  |
| H2                          | ICE          | 1.0                | 0.0                | Emergency            |  |
| Independent Power Producers |              |                    |                    |                      |  |
| Unit                        | Unit Type    | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation |  |
| HC&S                        | Biomass      | 12                 | 8.0                | Baseload             |  |
| Kaheawa I                   | Wind Farm    | 30.0               |                    | As-Available         |  |
| Makila Hydro                | Run-of-river | 0.5                |                    | As-Available         |  |
| Auwahi                      | Wind Farm    | 21.0               |                    | As-Available         |  |
| Kaheawa II                  | Wind Farm    | 21.0               |                    | As-Available         |  |
|                             | TOTAL:       | 72.5               |                    |                      |  |

## KPP Retirement Steady State Analysis

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### Appendix C

#### Single Line Overview with Line Ratings



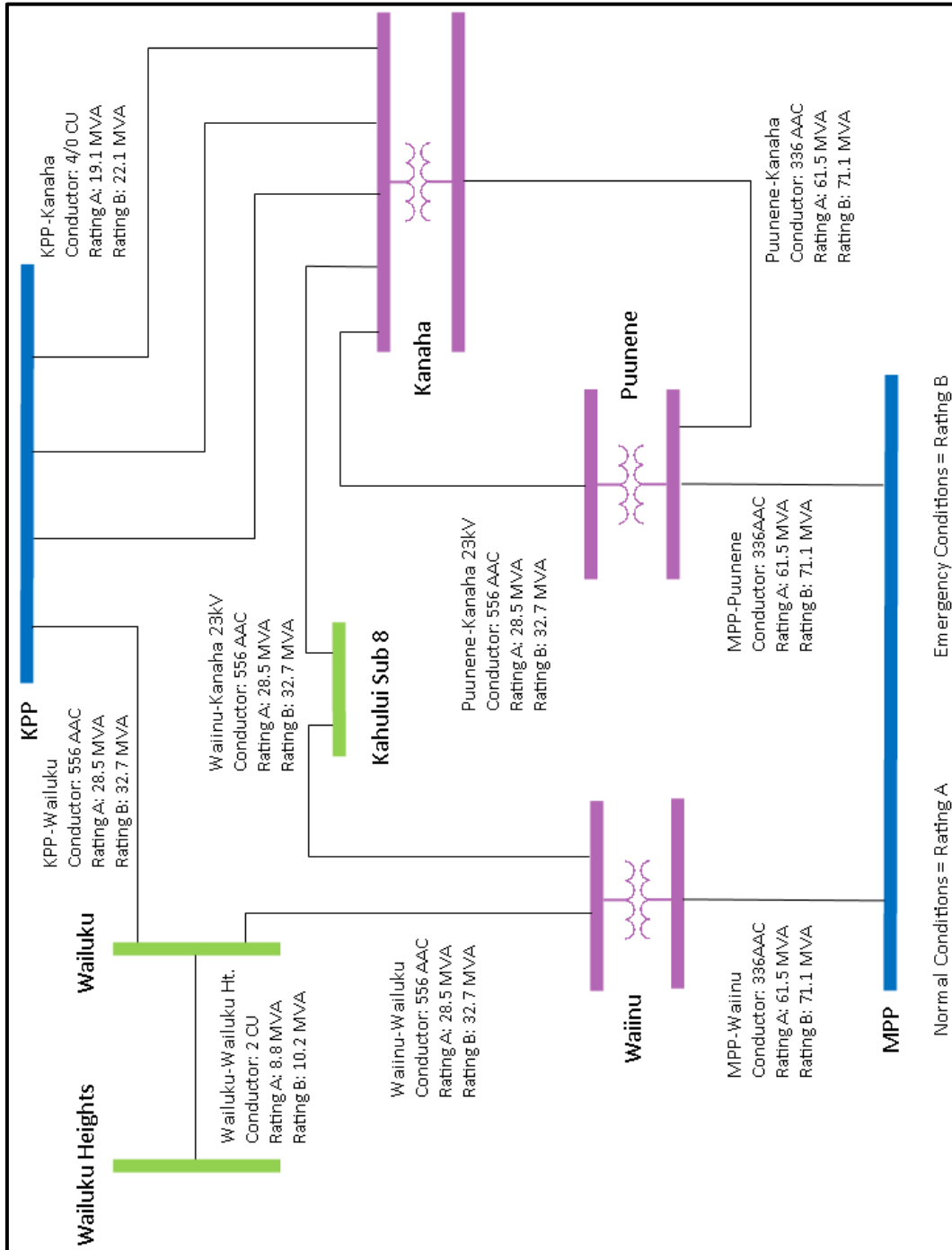


Figure C.1: Overview of Central Maui system showing line ratings

## Kahului Power Plant Retirement – Comprehensive Assessment

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### Appendix B – Voltage Stability Assessment

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HECO Transmission Planning Division

Document Title: Kahului Power Plant Retirement – Comprehensive Assessment

Reference: TPD 2014-22

# Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment

Prepared for

**Maui Electric Company, Ltd.**

**Prepared By:**

Hawaiian Electric Company, Inc.  
System Planning Department  
Transmission Planning Division

May 19, 2014

**Reference: TPD 2014-21**

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment


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## Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Executive Summary:

Hawaiian Electric Company's Transmission Planning Division (TPD) has revisited the topic regarding Maui Electric Company's plan to fully decommission Kahului Power Plant (KPP) by the year 2019. TPD has re-examined the various recommended upgrades suggested in previous studies conducted by TPD with the latest updated system models and also considered several non-transmission alternatives. This study addresses the voltage violation and voltage stability issues involved with the retirement of KPP and outlines how each alternative will potentially impact the system. After revisiting the transmission alternatives in the previous study with the latest system models and load forecast, and considering several non-transmission alternatives (NTAs), TPD recommends that proceeding with the Waiinu-Kanaha upgrade project is the most favorable, economical, and engineeringly sound solution to address voltage issues involved with the retirement of KPP, however, thermal limit and system stability issues involved with the retirement of the power plant should be also considered.

### Introduction/Background:

The Maui transmission system consists of a 23 kV network and 69 kV network. KPP has a total capacity of approximately 35 MW and connects into the 23 kV network, and the remainder of Maui's generation connects into the 69 kV network. The two networks are interconnected via 23/69 kV tie transformers located in Waiinu, Kanaha, and Puunene substations. KPP is the only source of generation connected to the 23 kV network. The retirement of the power plant will result in the 23 kV network becoming heavily dependent on power supplied by the 69 kV network via the three tie transformers and induce a diminished limit of power transfer to the 23 kV network, cause voltage sources to be electrically farther from the load center (i.e. the 23 kV network), and remove a reactive power source from the 23 kV network; this potential subjects the 23 kV network to voltage profiles that violate the reliability criteria or are prone to voltage instability in the event suffering a system disturbance. Voltage instability accompanied by a sequence of events (e.g. the loss of a transmission line) will lead to voltage collapse – low, unacceptable voltage profiles in significant parts of the power system – and a possible blackout system event.

TPD performed a study in the past concerning Maui Electric's plan to reduce operation at KPP and its eventual retirement, which analyzed several transmission solutions to address the aforementioned issues. The study recommended upgrading the 23 kV Waiinu to Kanaha transmission line to 69 kV, relocating 23 kV load at Kahului to the 69 kV system, and reconductoring the 69 kV MPP-Puunene and 69 kV MPP-Waiinu transmission lines. TPD has re-examined all recommendations made in the previous study using the latest updated base case models and load forecasts to re-establish the validity of the recommendation. TPD has also examined several non-transmission alternatives, which align with the Public Utilities Commission's (PUC) vision for the company, to be considered as possible solutions to address the issues.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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This study will identify the system impacts resulting from the retirement of KPP from a voltage stability standpoint, examine various plausible transmission and non-transmission solutions to rectify observed system issues, and recommend the most suitable solution from a transmission stand point.

### Methodology:

TPD used a conventional power-flow program to derive the Power-Voltage (P-V) characteristics of the existing Maui transmission system to determine the system power transfer limits and proximity to a voltage instability event, and the key factors that contribute to its occurrence. The characteristics were compared and contrasted to the P-V characteristics of cases of the existing system with various transmission and non-transmission upgrades to determine the most engineeringly sound solution to avoid violations of the reliability criteria, or even worse, the compromise of system reliability.

### Assumptions:

The following are the assumptions used in this study unless specified otherwise:

- Referencing of the “23 kV network” in this study does not include the 23 kV circuit from Kula to Haleakala due to its electrical distance from the rest of the 23 kV system.
- The Hana 23 kV circuit is fed from Pukalani.
- Kahului Power Plant is retired by 2019.
- Contract with HC&S will expire and HC&S will no longer contribute any generation after year 2014.
- The acceptable “power margin” is between 1.05 - 0.9 per unit (p.u.) voltage per the reliability criteria.
- An N-1 event in this study refers to the loss of a transmission line.
- Existing System refers to the present Maui transmission network and reference of the existing (peak) load is the forecasted peak load of year 2014 which is approximately 200 MW.
- Initial reference point (the y-intercept) in P-V plots is the existing system at peak load.

### Results and Analysis

The P-V characteristics of the various scenarios are derived for the normal condition and N-1 contingency events identified to result in the most severe system issues. These contingencies are:

- Loss of the 69 kV transmission line between Maalaea Power Plant (MPP) and Waiinu substation, which will be referred to as the 69 kV MPP-Waiinu line. This is a critical line that connects MPP to the 23/69 kV tie transformer at Waiinu, supplying power to the heavily loaded Central Maui and Wailuku area. Losing this line will require power to

## Kahului Power Plant Retirement: Voltage Stability Assessment

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travel a greater electrical distance via the 23/69 kV tie transformer at Kanaha and Puunene to serve the Wailuku load.

- Loss of the 69 kV transmission line between MPP and Puunene substation, which will be referred to as the 69 kV MPP-Puunene line. This line powers from MPP to the 23/69 kV tie transformers at Kanaha and Puunene. The loss of this line will require power to travel a greater electrical distance via the 23/69 kV tie transformer at Waiinu to serve the Central Maui load.
- Loss of the 23 kV line between Wailuku substation and Waiinu substation, which will be referred to as the 23 kV Wailuku-Waiinu line. This line serves as an important means of providing power from Waiinu to the Wailuku area. Losing this line will require power to travel a greater electrical distance via Kanaha substation.
- Loss of the 23 kV line between Kanaha substation and Kahului substation, which will be referred to as the 23 kV Kanaha-Kahului line unless specified otherwise.

Figure 1 and Figure 2 show the P-V characteristics of the existing system with and without operation of KPP, respectively, for the normal and most severe N-1 conditions. The initial reference point on the P-V curve is at the point where the curve intercepts the y-axis; it depicts the voltage profile of the 23 kV network on the existing system at peak load level. Moving to the right along the x-axis represents natural growth in load on the 23 kV network. Increases to the load on the 23 kV network result in a decline in voltage profile – continual increase of load on the 23 kV network will inevitably violate the reliability criteria. The end of the P-V curve indicates that the power-flow was unable to solve beyond that point which is indicative of voltage collapse. Thus, as the system approaches the vicinity of voltage collapse, it is subject to voltage instability; the system is typically planned to operate well away from these points. The P-V curve exhibits the limits of power transfer to the 23 kV network.

The limitations of power transfer are dependent on the inherent traits of the system and can be extended or reduced through changes to the system. This aspect can be seen in Figure 1, where an N-1 contingency event shifts the power transfer limit of the normal condition curve to the left – this represents a diminished power transfer limit. It can be seen that the loss of 69 kV MPP-Waiinu line is the most severe out of all the N-1 contingencies due the indication of a steeper decline in voltage profile (curve) and quicker occurrence to voltage collapse (as load increases). It can also be seen that voltage collapse can occur well within the acceptable power margin - a voltage profile that does not violate the reliability criteria isn't necessarily safe of voltage instability/voltage collapse. Thus, the alternatives are evaluated on their capabilities of avoiding violations to the reliability criteria and voltage instability/voltage collapse.

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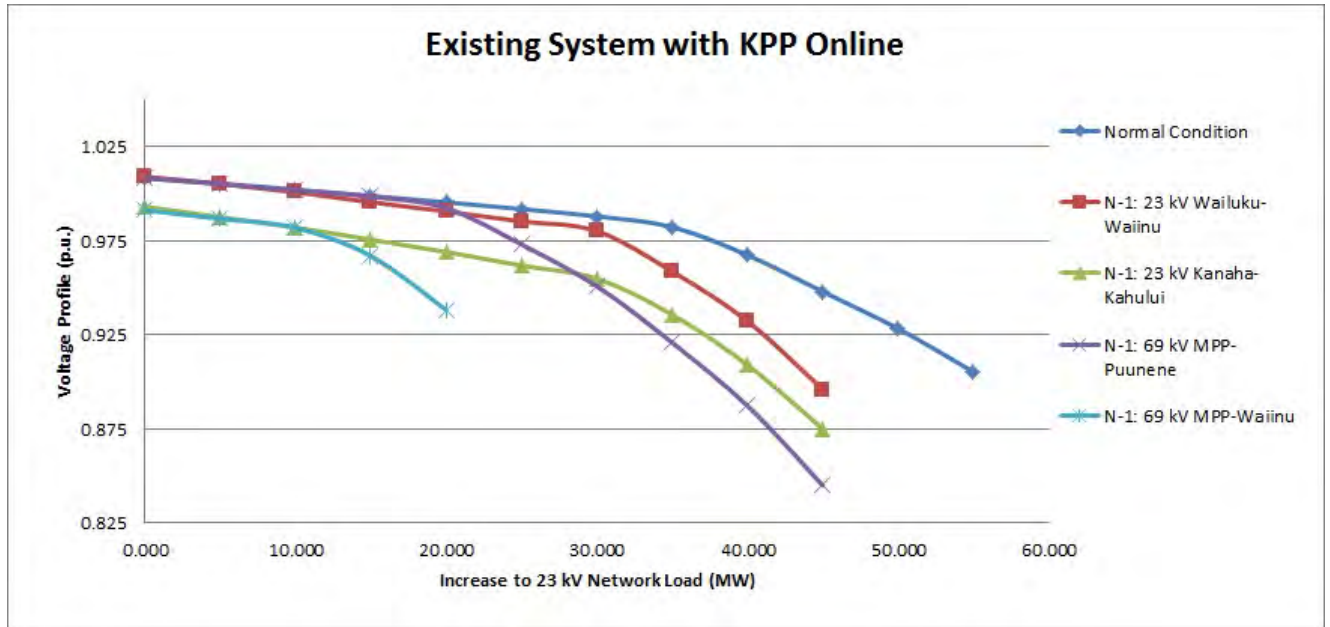


Figure 1: P-V characteristics of existing Maui system with operation of KPP.

As mentioned previously, the power transfer limits can be extended or reduced through changes to the system. A diminished power transfer limit can be expected as a result of the decommissioning of KPP. Without the operation of KPP, the 23 kV network will lose the only source of power generation connected to the 23 kV network and must rely on power supplied by the 69 kV network. This will place an additional burden on the 69 kV transmission lines and 23/69 kV transformers that connect the two networks because the 69 kV network must pick up the demand previously met by KPP.

The system will become vulnerable to voltage instability due to the voltage sources (voltage source for 23 kV network is KPP prior to its decommission; the voltage source will be the generation sources on 69 kV network after KPP retirement) being further away from the load center (i.e. the 23 kV network) and insufficient load reactive compensation on the 23 kV network. This can be seen in Figure 2. It can be observed that with the retirement of KPP, under the N-1 event of losing the 69 kV MPP-Waiinu transmission line, the voltage profile of the 23 kV network is below the sufficient “power margin” and is subjected to voltage collapse at the current 2014 peak load level.

## Kahului Power Plant Retirement: Voltage Stability Assessment

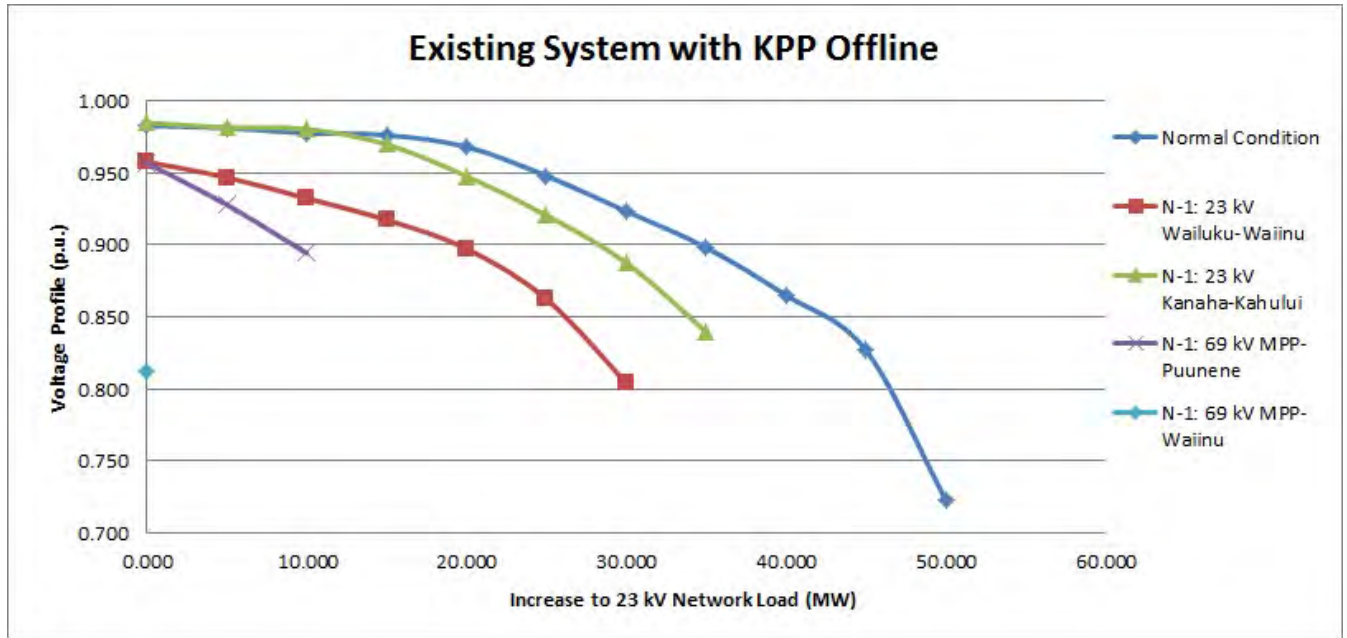


Figure 2: P-V characteristics of existing Maui system without operation of KPP.

Figure 3 compares the P-V characteristics for the normal condition and the most severe N-1 contingency event of the system with and without operation of KPP. It exhibits what changes to the power transfer limit of the 23 kV network is to be expected if KPP is decommissioned without any upgrades to the system.

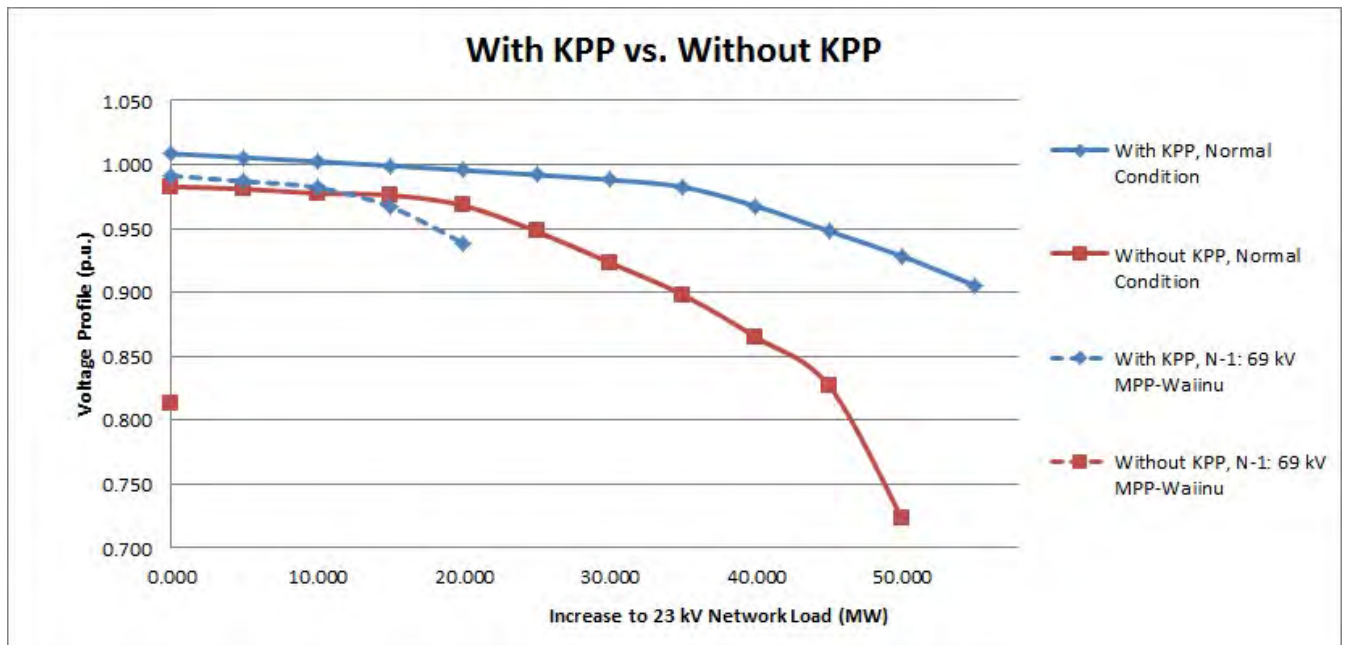


Figure 3: P-V characteristics comparison between system with and without the operation of KPP.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Transmission Solutions

In the past, TPD analyzed several transmission options that would rectify the system's vulnerability to possible voltage instability and voltage collapse events, and avoid any system reliability criteria violations. TPD has revisited the issue and options studied with the latest updated Maui system models and load forecasts. The options are:

- Alternative 1: Construct a new 69 kV transmission line from Waiinu substation to Kanaha substation.
- Alternative 2: Relocate the existing 23 kV transmission line between Waiinu substation and Kanaha substation and its connected elements to the 69 kV network.
- Alternative 3: Build new additional 69 kV MPP-Waiinu, 69 kV MPP-Puunene, and 69 kV Puunene-Kanaha lines of 556 AAC conductor size.
- Alternative 4: Create a link between Kealahou and Kanaha on the 69 kV network via the anticipated new Waena Power Plant (WPP).
- Alternative 5: Install an additional 23/69 kV tie transformer between WPP and Central Maui Landfill Substation (Sub 95), and reconductor the 23 kV section of transmission line from Kanaha to Sub 95.

Figures 4 and 5 below compare the P-V characteristic curves of the various alternatives for the normal condition and the worst N-1 contingency, respectively. It can be seen that Alternative 2 is the most favorable option under normal conditions and most N-1 contingencies. Figure 5 indicates that Alternative 3 is a significantly better option for surviving the most severe N-1 event, the loss of the 69 kV MPP-Waiinu line; this is due to the option involving the construction of three new transmission lines resulting in an extended transfer limit of power to the 23 kV network and improved system reliability in the event of the loss of a transmission line.

Alternative 3 is a considerably more expensive solution that is only favorable under the condition of losing the 69 kV MPP-Waiinu line; in all other cases, its performance is similar or second to the Alternative 2 option. Figure 5 also indicates that Alternatives 4 and 5 are viable solutions for surviving the event of losing the 69 kV MPP-Waiinu. Figures 6, 7, and 8 compare the P-V characteristics of the various alternatives for the loss of the 69 kV MPP-Puunene line, 69 kV Wailuku-Waiinu line, and 69 kV Kanaha-Kahalui line, respectively. From comparing the P-V characteristics of the five alternatives under various N-1 contingency events, TPD has determined:

- Alternatives 1, 2, and 3 are the only viable solutions,
- Alternatives 4 and 5 will result in voltage collapse in the event of losing the 69 kV MPP-Waiinu line
- Alternative 1 is the least favorable solution - has poorer power transfer limit than Alternative 2 and 3, and will violate voltage criteria when 23 kV network load increases by 5 MW .
- Alternative 2 is most favorable solution under normal condition and most N-1 events, and only consists of the upgrade of existing system elements.

## Kahului Power Plant Retirement: Voltage Stability Assessment

- Alternative 3 is a viable solution and significantly more favorable in the event of losing 69 kV MPP-Waiinu line but involves the construction of 3 new transmission lines.

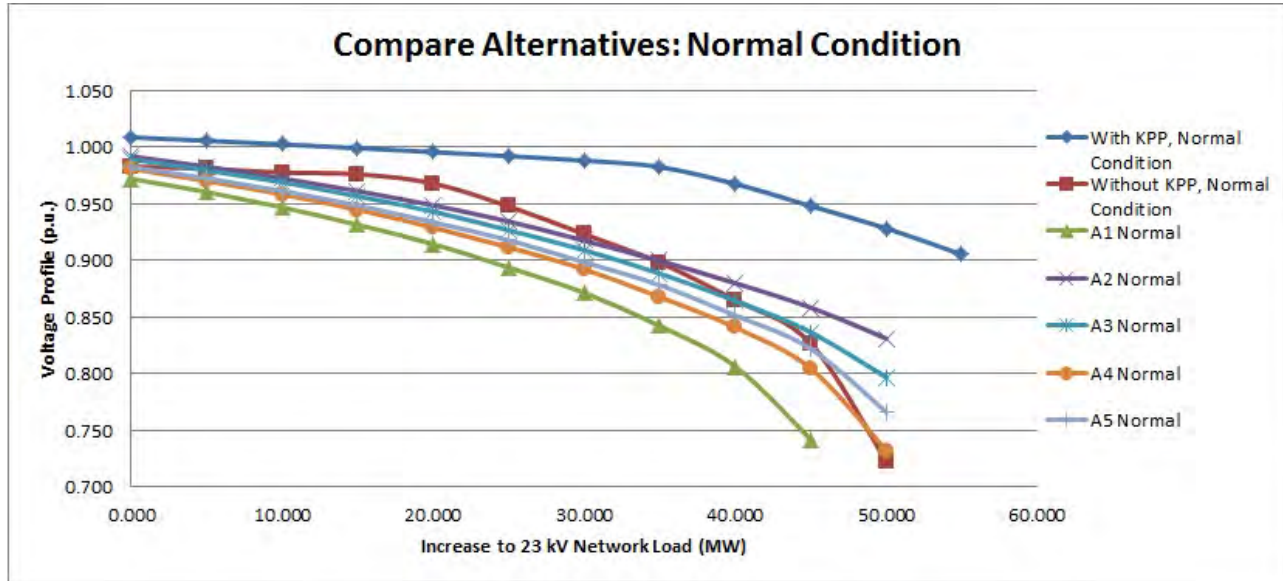


Figure 4: Comparison of P-V characteristics of transmission Alternatives for the normal condition. Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5 are represented by A1, A2, A3, A4, and A5 respectively.

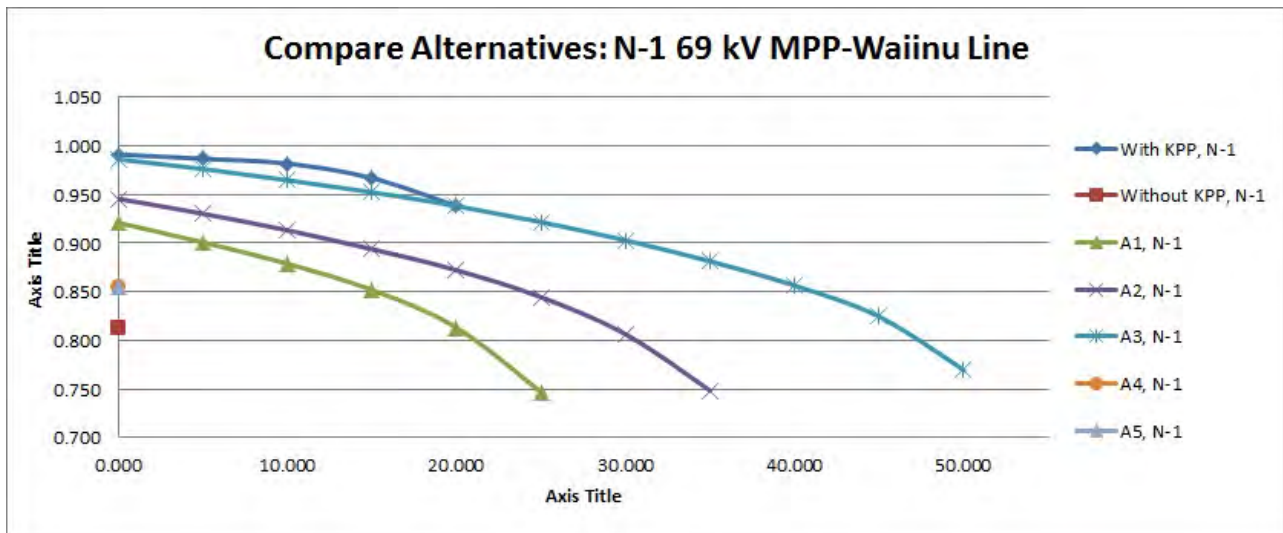


Figure 5: Comparison of P-V characteristics of transmission Alternatives for losing the 69 kV MPP-Waiinu Line. Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5 are represented by A1, A2, A3, A4, and A5 respectively.

Figures comparing P-V characteristics of the scenarios for the rest of the most severe contingencies can be seen in the Appendix.



## Kahului Power Plant Retirement: Voltage Stability Assessment

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TPD recommends Alternative 2 out of the five alternatives considered. Alternative 2 will adequately avoid voltage criteria violations and voltage instability until the 23 kV network has a load growth of 10 MW. Load growth beyond 10 MW will bring about a voltage profile below the acceptable power margin and possibly subject the 23 kV network to an unstable voltage profile. The 23 kV network will reach a growth of 10 MW when the total system peak load grows to approximately 270 MW, which is beyond the forecasted load.

Alternatives 1, 2, and 3 are viable solutions capable of preventing a voltage instability event from occurring on the current system but may not be adequate to endure thermal limit overloading conditions. Several combinations of the five mentioned alternatives with additional system upgrades were considered to address the thermal limit issues; the advantages of combining the alternatives with an additional system upgrade from a voltage stability standpoint will be discussed. The combinations are:

- Combination 1: Alternative 1 combined with the reconductoring of the 69 kV MPP-Waiinu line and 69 kV MPP-Puunene lines to 556 AAC conductor size transmission lines.
- Combination 2: Alternative 1 combined with the construction of a new secondary 69 kV MPP-Puunene transmission line.
- Combination 3: Alternative 1 combined with Alternative 4.
- Combination 4: Alternative 2 combined with the reconductoring of the 69 kV MPP-Waiinu line and 69 kV MPP-Puunene transmission lines to 556 AAC conductor size transmission lines - Combination 4 is the recommended Waiinu-Kanaha Transmission Line Upgrade project.
- Combination 5: Alternative 2 combined with the construction of a new secondary 69 kV MPP-Puunene transmission line.
- Combination 6: Alternative 2 combined with Alternative 4.
- Combination 7: Alternative 3 combined with Alternative 5.

### Waiinu-Kanaha Transmission Line Upgrade project:

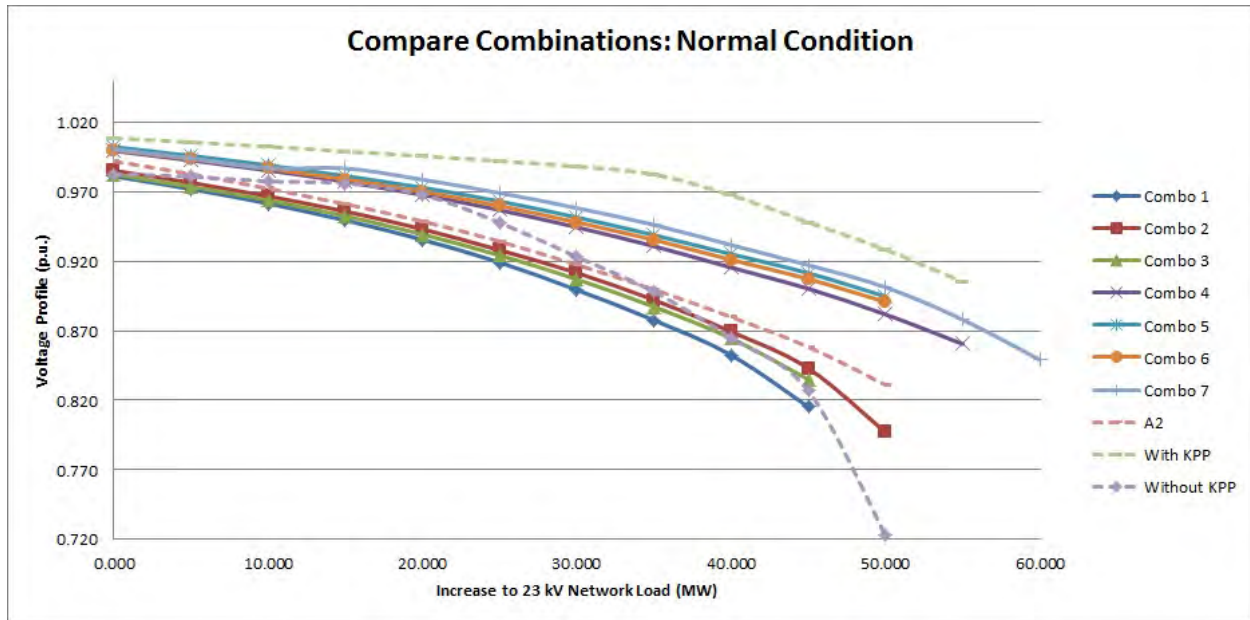
Figures 6 and 7 below show a P-V characteristic comparison of the Maui system with KPP, without KPP, with the Alternative 2 option, and with various combinations of one of the aforementioned alternative options with an additional system upgrade for the normal condition and most severe N-1 condition, respectively.

From a voltage stability standpoint, all combinations mentioned are viable long term solutions capable of maintaining a voltage profile well within the acceptable margin and mitigate unstable voltage profile issues, but it can be seen that only options Combo 5, Combo 6, and Combo 7 produce significantly better P-V characteristics than the suggested Combo 4, which is the recommended alternative in the previous study. However, Combos 5, 6, and 7 involve the construction of one or more new transmission lines. Combo 4 only involves the upgrade of existing transmission lines already on the system (where majority of the line is already capable of being transitioned to 69 kV).

## Kahului Power Plant Retirement: Voltage Stability Assessment

After revisiting the study with the latest system models and load forecast information, Combo 4 (the Waiinu-Kanaha upgrade project) is still the recommended solution to address the voltage instability issues involved with the retirement of KPP alternative out of all the transmission alternatives.

Figure 8 below shows a P-V characteristic comparison of the Maui system operating with and without KPP, and the system operating without KPP under the scenario that Combo 4 is implemented for the normal condition and most severe N-1 contingency.



**Figure 6: Comparison of P-V characteristics of transmission Combinations for the normal condition. Combination 1, Combination 2, Combination 3, Combination 4, Combination 5, Combination 6, Combination 7, and Alternative 2 are represented by Combo 1, Combo 2, Combo 3, Combo 4, Combo 5, Combo 6, Combo 7, and A2 respectively.**

# Kahului Power Plant Retirement: Voltage Stability Assessment

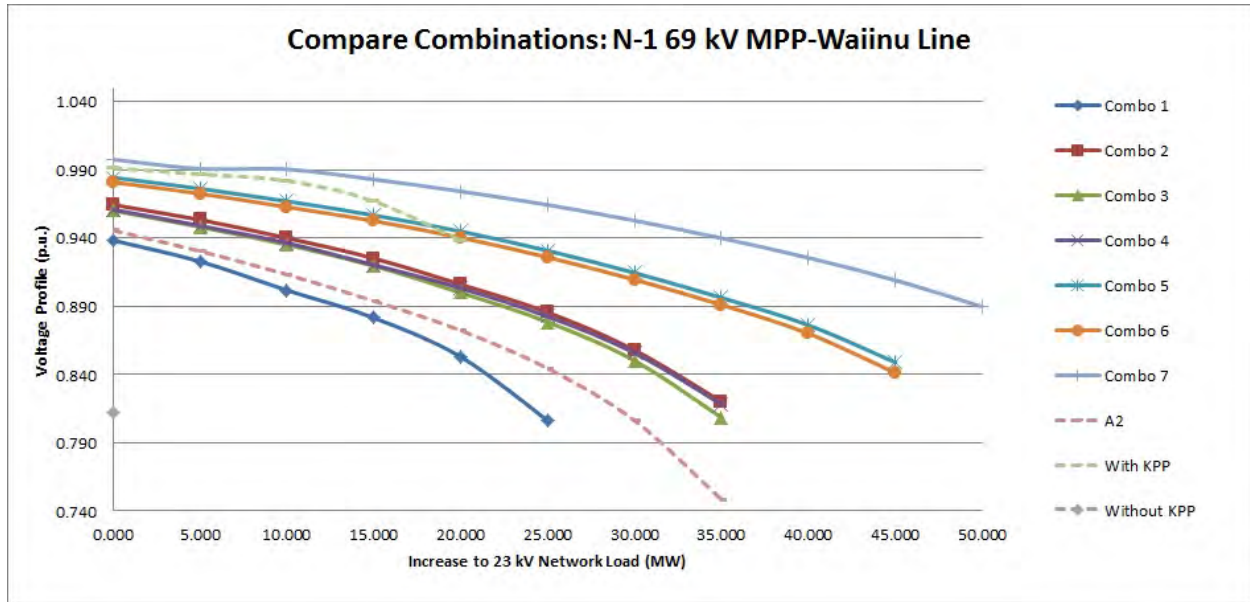


Figure 7: Comparison of P-V characteristics of transmission Combinations for losing the 69 kV MPP-Waiinu Line. Combination 1, Combination 2, Combination 3, Combination 4, Combination 5, Combination 6, Combination 7, and Alternative 2 are represented by Combo 1, Combo 2, Combo 3, Combo 4, Combo 5, Combo 6, Combo 7, and A2 respectively.

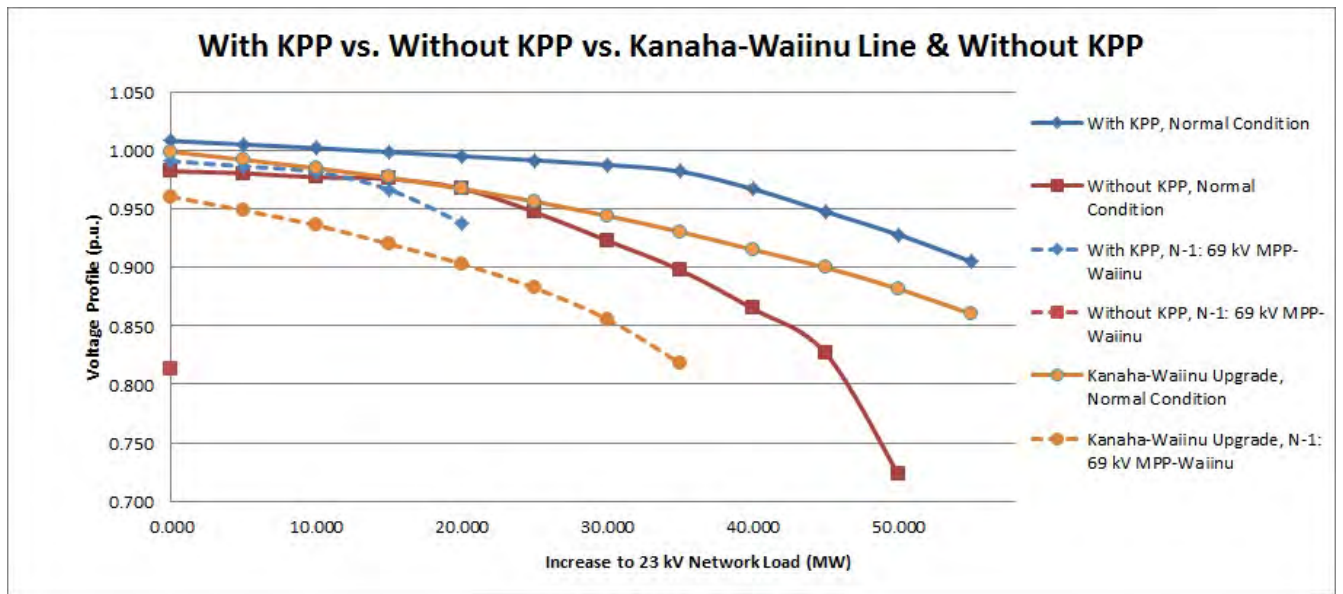


Figure 8: P-V characteristic comparison of the Maui system operating with and without KPP and the system operating without KPP under the scenario that Combo 4 is implemented for the normal condition and most severe N-1 contingency.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Non-Transmission Alternative (NTA) Solutions

There is an anticipated reserve capacity short fall of approximately 40 MW by year 2019, identified in Section 1.6 of the Maui Electric Adequacy of Supply (AOS) report. TPD has considered the possibility that efforts to procure resources to meet the reserve capacity short fall may void the need for the 23 kV Waiinu-Kanaha line upgrade project and the additional reconductoring of the 69 kV MPP-Puunene and 69 kV MPP-Waiinu transmission lines, and has considered the following Non-Transmission Alternatives (NTA):

- Conversion of some or all existing units at KPP to synchronous condensers.
- New Dispatchable Firm Generation.
- Battery Energy Storage System (BESS).
- Demand Response (DR).

### Synchronous Condenser Option:

A favorable aspect of the synchronous condenser option is that it would take a considerably shorter amount of time to execute than the other NTA alternatives. However, synchronous condensers are reactive support elements that will only supply reactive power to the system. As mentioned before, removing KPP would mean active power demands on the 23 kV network must be supplied solely by the 69 kV network; this will subject the transformers and transmission lines connecting the 23 kV and 69 kV network to heavier loadings that may possibly violate their thermal limit ratings.

From a voltage stability standpoint, the synchronous condenser option is a viable solution for avoiding violations to the voltage criteria and avoiding voltage instability and voltage collapse events; however, it will not mitigate issues regarding thermal overloads on transmission lines and/or tie transformers because synchronous condensers do not provide active power, thus, will not alleviate the extra burden that can be expected to be placed on transformers and transmission lines connecting the 23 kV and 69 kV network when KPP is retired.

KPP is comprised of two large units, K4 and K3, and two smaller units, K1 and K2. K4, K3, K2, and K1 have reactive capabilities of 9.3 MVar, 7.0 MVar, 3.7 MVar, 3.7 Mvar, respectively. Several scenarios were considered: only the largest unit converted to synchronous condenser, the two largest units converted to synchronous condenser, two largest units and one smaller unit converted to synchronous condenser, and all units converted to synchronous condenser. Figures 9 and 10 show the P-V characteristics of the different scenarios of KPP units converted to synchronous condensers for the normal condition and most severe N-1 contingency event.

# Kahului Power Plant Retirement: Voltage Stability Assessment

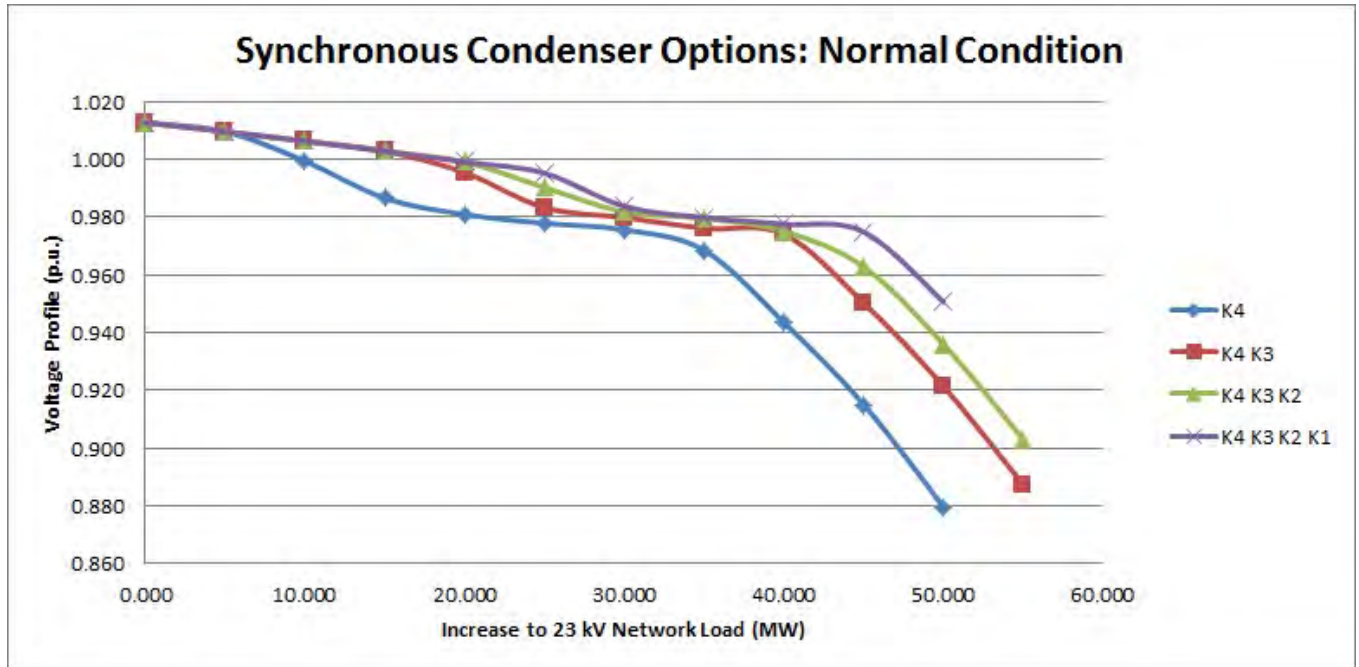


Figure 9: P-V characteristic comparison of different scenarios of KPP units converted to synchronous condensers for the normal condition.

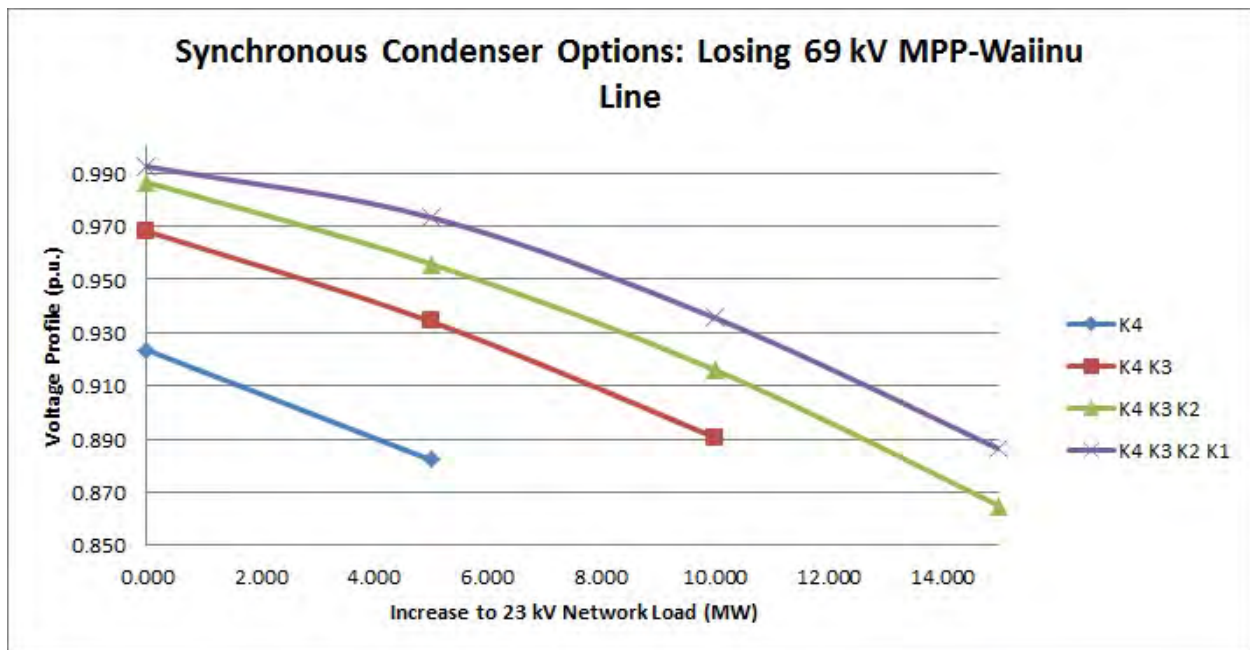


Figure 10: P-V characteristic comparison of different scenarios of KPP units converted to synchronous condensers for the most severe N-1 contingency event.

## New Dispatchable Firm Generation:

If the company intends to procure new generation to meet the reserve capacity shortfall, the new generation units may potentially void the need for the Waiinu-Kanaha upgrade project

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depending on the location of interconnection of the new units. If the new generation is interconnected on the 23 kV network, from a voltage profile standpoint, the system can be expected to behave similar to the existing system with KPP in operation as this would only involve replacing the existing older generation units with new ones – this will not place a burden on the transmission lines and tie transformers that connect the 23 kV and 69 kV network and voltage sources are still close to the 23 kV network load center. However, if the new generation is interconnected to the 69 kV network, the system is expected to experience the same system issues source of generation on the 23 kV being removed; placing new generation units on the 69 kV network will not alleviate burden placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network, and will not provide reactive support to the 23 kV network – this will still result in the 23 kV network becoming heavily dependent on the 69 kV network for power and may possibly overload the transmission lines and tie transformers that connect the 23 kV and 69 kV network past their rated thermal limits and subject voltage sources to be electrically farther from the 23 kV network load center. A few scenarios of new firm generation on the 23 kV network were considered and compared to the existing operating KPP which has an approximate 35 MW capacity; they are: one new 8 MW unit, one new 15 MW unit, and two new 8 MW units. The P-V characteristic comparison of these scenarios for the normal condition and most severe N-1 contingency are shown in Figure 11 and Figure 12, respectively. For the scenario of new generation connecting to the 69 kV network, the capacity of new generation is arbitrary from a voltage standpoint as the option would not mitigate the issues mentioned. For the study, the scenario considered for study is the first stage of the Waena Power Plant (WPP) project proposed by First Wind – a new 17 MW unit at the WPP site near Pukalani; The P-V characteristics of this scenario is compared with the existing system with and without the operation of KPP, shown in Figure 13.

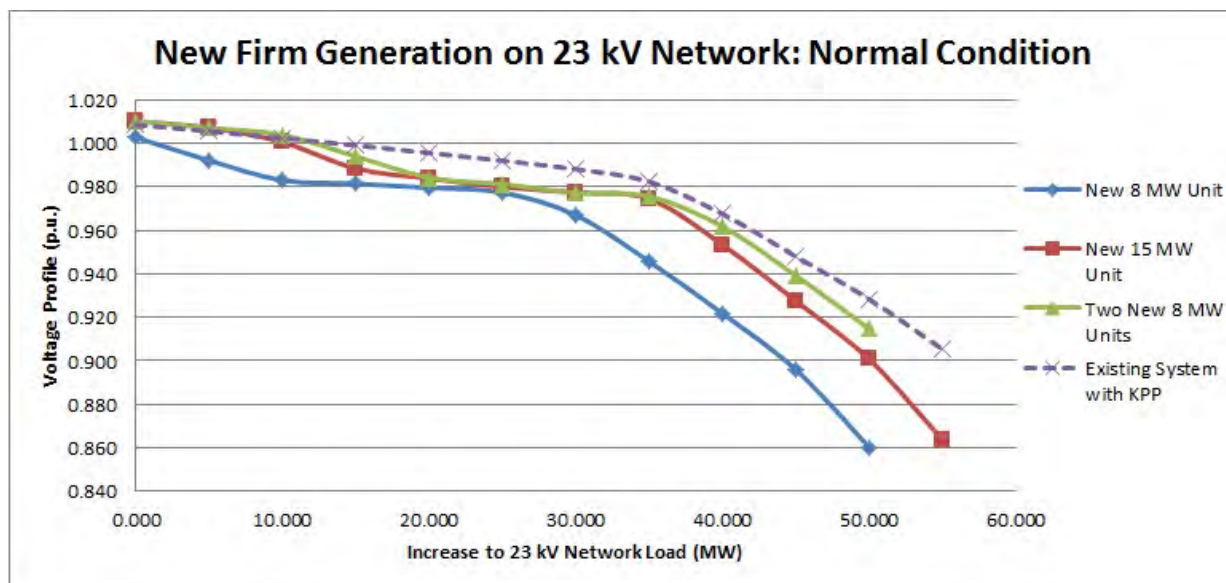


Figure 11: P-V characteristic comparison of different scenarios of new generation of various capacities on the 23 kV network and the existing system for the normal condition.

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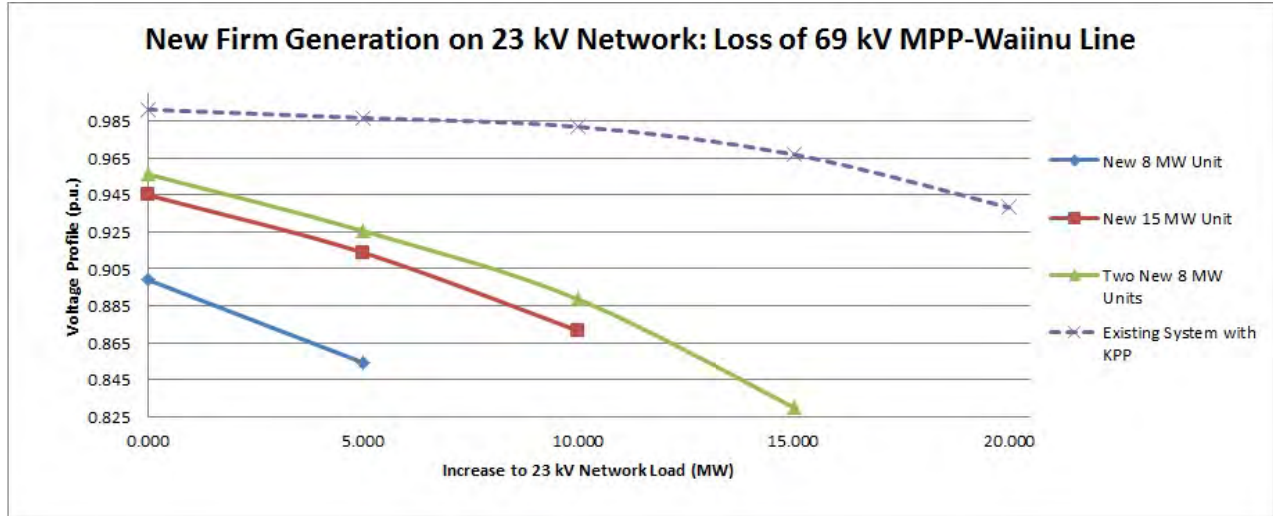


Figure 12: P-V characteristic comparison of different scenarios of new generation of various capacities on the 23 kV network and the existing system for the most severe N-1 contingency event.

It can be observed that the more capacity of new generation added to the 23 kV network, the closer the P-V curve representing new generation approaches the P-V curve that represents the existing system with KPP, which has an approximate 35 MW capacity. This indicates that in order to achieve system characteristics better than the existing system with KPP, the capacity of new generation must be greater than the existing capacity at KPP (i.e. 35 MW). It can be seen that at the existing system load, the new 8 MW unit and new 15 MW unit scenarios settle at point close to the end of a curve – these are unstable voltage points. The two new 8 MW unit scenario is much more favorable as it settles at a point farther away from voltage collapse. Installing more capacity of new generation on the 23 kV network will allow the system to operate farther away from the point of voltage collapse.

Voltage issues arise when total system load reaches 170 MW and is accompanied by a severe N-1 contingency if KPP is decommissioned and no additional system upgrades are implemented. The new generation units must be brought online when total system load reaches 170 MW to avoid violations to the reliability criteria and possible compromise of system reliability. Historically, system load has been observed to remain at 170 MW or above for approximately 7 hours, see Appendix.

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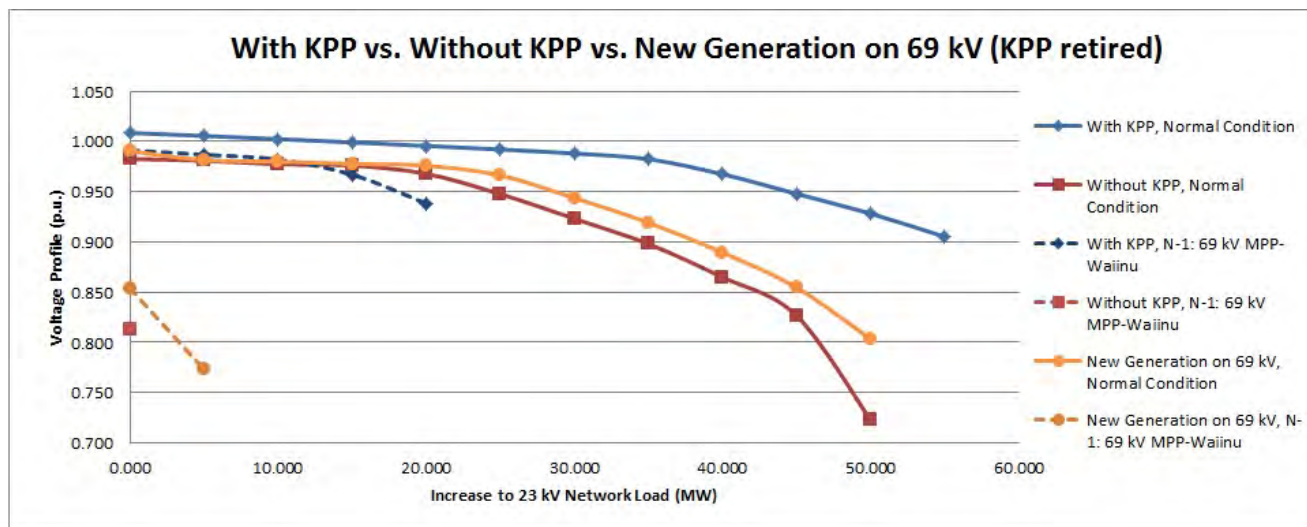


Figure 13: P-V characteristic comparison of the scenario of new generation on the 69 kV network, the existing system with KPP, and the existing system without KPP for the normal condition and most severe N-1 contingency event.

### Battery Energy Storage System (BESS) Option:

It is assumed in this study that BESS will be operated to predominantly provide active power because pursuing a battery for the purpose of providing reactive support would be uneconomical as there are less expensive alternatives available that fulfill these needs such as capacitor banks or the already mentioned synchronous condenser option; in this study, the BESS units are modeled to operate at a 0.95 power factor to reflect a unit which predominantly provides active power and minimum reactive power. The BESS option, if located on the 23 kV network, is anticipated to mitigate the thermal limit violation issues involved with the retirement of KPP because it will supply active power to the 23 kV network which will alleviate the stress placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network when KPP is decommissioned and is also anticipated to mitigate the voltage violation, voltage instability, and voltage collapse issues. However, there are several ambiguities concerning the battery that need to be clarified before it can be determined if the BESS option is a viable, economic, or engineering sound solution to address the issues involved. These ambiguities include: where will the battery be located (on the 23 kV or 69 kV network), will the battery operate as a normal dispatchable unit or solely for the purpose of mitigating system issues during emergency events, what is the size of the battery. For planning purposes, these ambiguities need to be addressed.

Similar to the afore mentioned issue in the discussion concerning the new dispatchable firm generation option, if the battery is placed on the 69 kV, the battery will contribute no significant mitigation measures as the voltage sources are still electrically far from the 23 kV network load center and the burden placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network is not lessened. However, placing the battery on the 23 kV network will alleviate much of the burden placed on the transmission lines and tie transformers that connect



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the 23 kV and 69 kV network because the battery (i.e. an active and reactive power source) is placed near the load and thus assuages the dependency on power to be supplied by the 69 kV network and aids in mitigating voltages violation, voltage instability, and voltage collapse issues on account that the battery, a voltage source, is closer to the 23 kV network load center. If the battery is operated as a normal dispatchable unit, where the battery will be dispatched to serve peaking system load demands when needed, it raises the issue whether or not there will be sufficient charge in the battery to mitigate system issues in the event of an emergency. However, if the battery is operated to solely be dispatched during emergency events, it raises the question whether or not the battery option is an economical solution. The battery would need to be sized to provide power long enough for the N-1 contingency to be resolved or until total system load recedes below afore mentioned threshold of 170 MW. It has been mentioned that the battery could be used to mitigate system issues just long enough for addition distributed generation sources (fuel units) to be brought online; this option would only be viable if the distributed generation sources, which need to be procured, are on the 23 kV network and would be uneconomical to pursue as the distributed generation source alone would be adequate to mitigate the issues, as seen in the new dispatchable firm generation option.

Several scenarios of different size batteries were considered: a 15 MW BESS, a 20 MW BESS, and a 25 MW BESS. Figures 14 and 15 compare the P-V characteristics of the various sized BESS for the normal condition and most severe N-1 contingency event, respectively. It can be seen in Figure 15 that for all scenarios, the BESS option is viable long term solution capable of mitigating voltage issues; this option is adequate until the 23 kV network load increases by approximately 10 MW, in other words, until the total system load reaches approximately 247 to 250 MW, which is beyond the scope of load forecast.

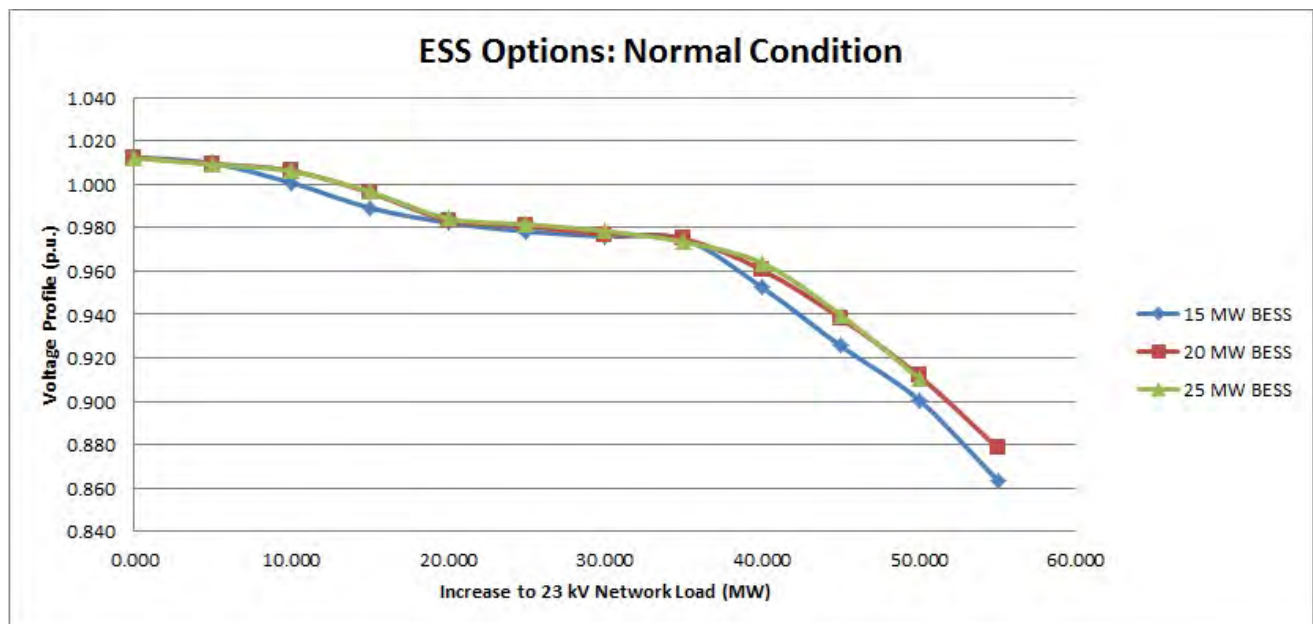


Figure 14: Comparison of P-V characteristics of various sized BESS for the normal condition.

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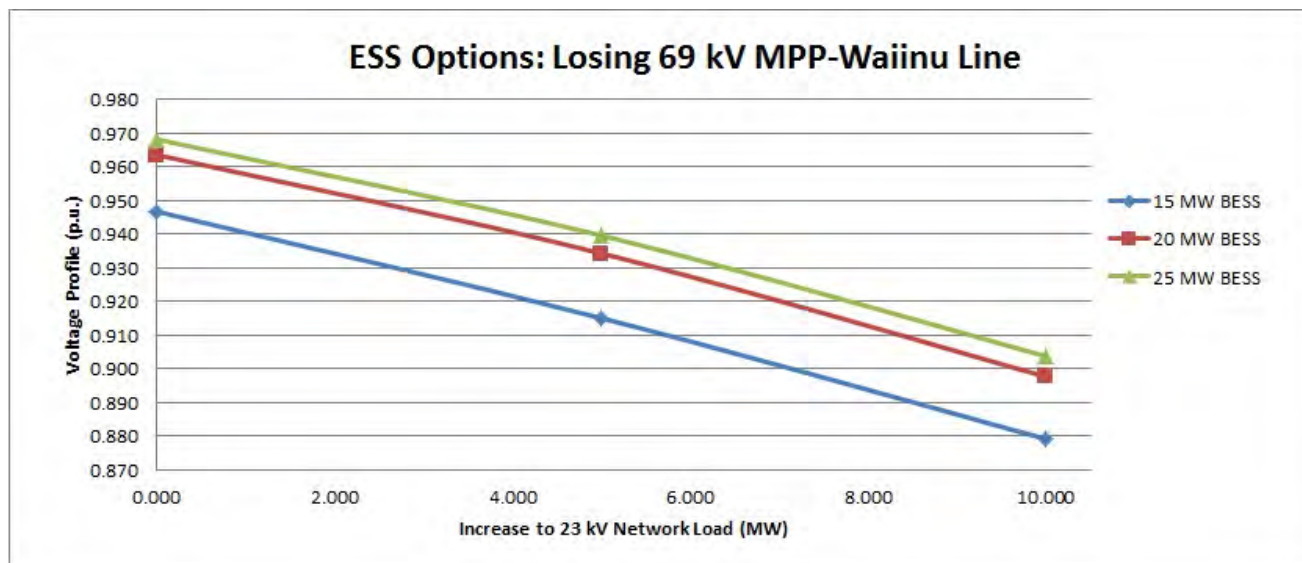


Figure 15: Comparison of P-V characteristics of various sized BESS for the most severe N-1 contingency event.

### Demand Response:

The concept of the Demand Response (DR) option to be utilized for the effort of mitigating issues involved with the retirement of KPP is end-use customer consumption of power will be reduced in response to a contingency event to avoid the risk of jeopardizing system reliability. This should operate similarly to existing load shedding schemes – DR program must execute within several cycles of detecting indications that system reliability is at risk of being compromised. As mentioned, voltage issues arise when total system load reaches 170 MW and is accompanied by a severe N-1 contingency if KPP is decommissioned and no additional system upgrades are implanted. The DR program must drop end-use customer load to maintain total system load within the 170 MW benchmark to avoid voltage violation, voltage instability, and voltage collapse issues in the event of a contingency.

### Comparing the NTA options:

For the purpose of comparing the NTA options, if numerous scenarios were considered for a NTA option, the scenario that produced the most favorable results was selected to be compared against the other options. The scenario of converting all existing units at KPP to synchronous condensers was selected for the synchronous condenser option, the scenario of two new 8 MW units was selected for the option of installing new firm generation units on the 23 kV network option, and the 25 MW BESS scenario was selected for the BESS option to represent its respective NTA option for comparison. Figure 16 and Figure 17 shown below compare the P-V characteristics of the various NTA options against the Kanaha-Waiinu upgrade and existing system with and without the operation of KPP for the normal condition and most severe N-1 contingency, respectively.

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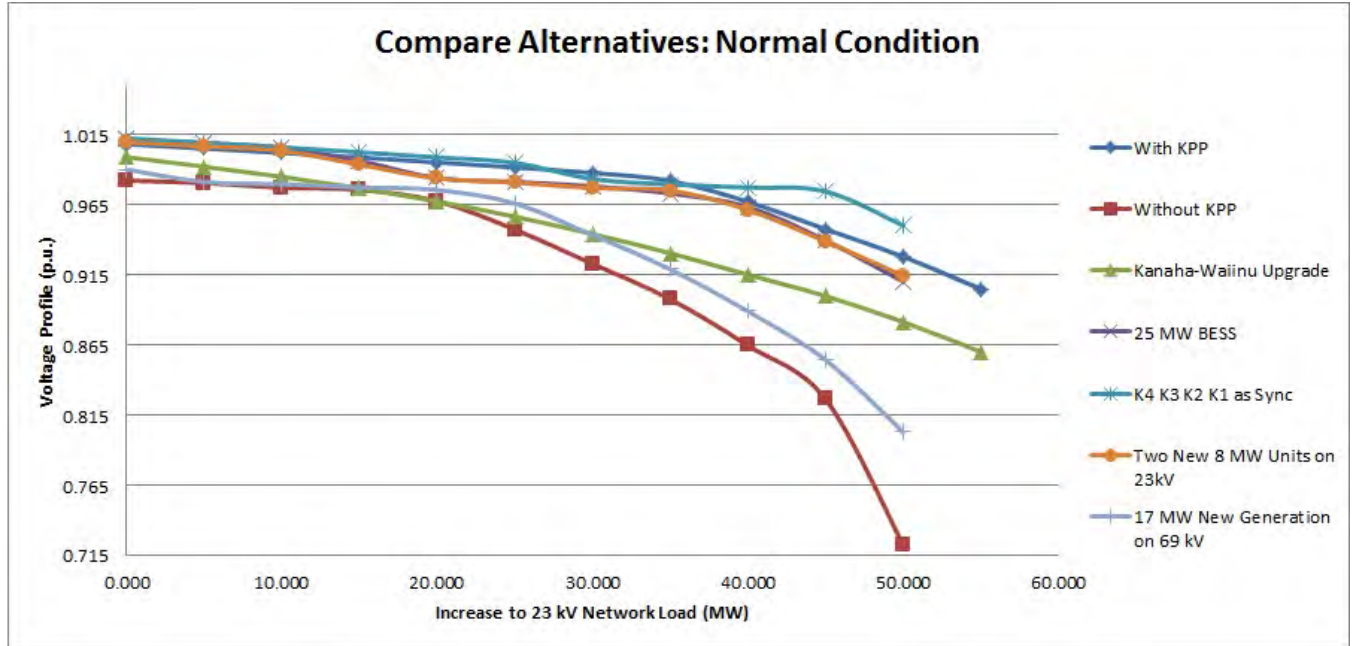


Figure 16: Comparison of P-V characteristics of various NTA options against the Kanaha-Waiinu upgrade and existing system with and without operation of KPP for the normal condition.

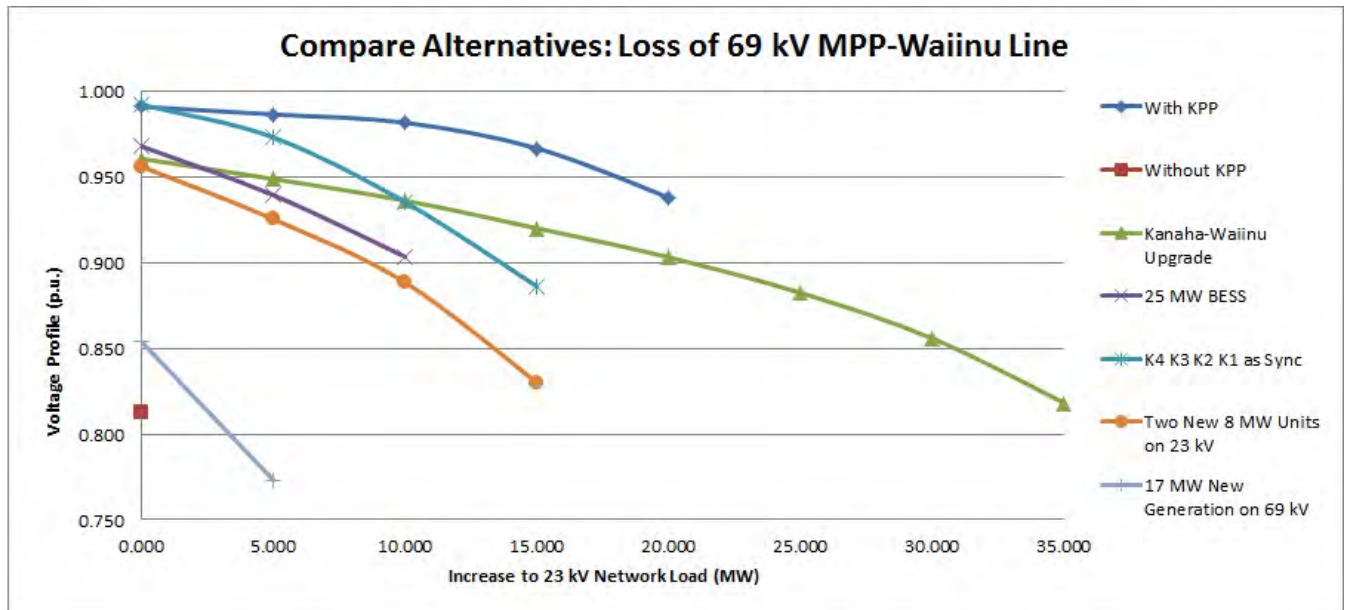


Figure 17: Comparison of P-V characteristics of various NTA options against the Kanaha-Waiinu upgrade and existing system with and without operation of KPP for the most severe N-1 contingency.

Several points should be considered when interpreting Figure 17. The synchronous condenser option seemingly has more favorable results than the BESS and new firm generation on the 23 kV network option, however, results shown are strictly examining the voltage profile; there thermal limit issues involved with the KPP retirement that the synchronous condenser option will

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not mitigate. The capacity values of new firm generation and BESS considered were arbitrarily selected; it should be noted that choosing to install greater capacity values of BESS and new generation (to be installed on the 23 kV network) units will produce P-V characteristics closer to the curve representing existing system with operation of KPP.

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### Compare and Contrast Options:

Table 1: Comparison of Transmission and Non-Transmission options studied.

| Options                       | Adequate Until...                             |  |  | Load forecast indicates this will occur in: |
|-------------------------------|---|--|--|---|
|                               | Growth on 23 kV Network load (in MW) reaches: | In other words, when system peak load (in MW) reaches: |  |   |
| Waiinu-Kanaha Upgrade project | 20  | Over 270   |  | N/A*  |
| 15 MW BESS on 23 kV           | 5   | 225  |  | N/A*  |
| 20 MW BESS on 23 kV           | 5 – 8   | 225 – 240  |  | N/A*  |
| 25 MW BESS on 23 kV           | 10  | 247  |  | N/A*  |
| K4 as Sync                    | 2 – 3   | 200 – 203  |  | 2016 – 2017                                 |
| K4 & K3 as Sync               | 5 – 8   | 225 – 240  |  | N/A*  |
| K4, K3, & K2 as Sync          | 10  | 247  |  | N/A*  |
| K4, K3, K2, & K1 as Sync      | 10 – 12                                       | 247 – 260  |  | N/A*  |
| New 8 MW unit on 23 kV        | 0   | 200  |  | 2014 – 2015                                 |
| New 15 MW unit on 23 kV       | 5   | 225  |  | N/A*  |
| Two new 8 MW unit on 23 kV    | 5 – 8   | 225 – 240  |  | N/A*  |
| New 17 MW unit on 69 kV       | 0   | 200  |  | 2014 – 2015                                 |

N/A\* - indicates that the option will be adequate until the system peak load reaches load value that is beyond what is reported in load forecast; the load forecast has forecasted system peak load values until year 2030, thus, these options are adequate even beyond the year 2030 (from a voltage standpoint).

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### Conclusion

From a voltage standpoint, the Waiinu-Kanaha upgrade project, BESS option, synchronous condenser option, and installing new firm dispatchable generation on the 23 kV network option are viable long term solutions to mitigate voltage issues involved with the retirement of KPP. However, considering the possibility of thermal overloads occurring on the transmission lines and tie transformers that connect the 23 kV and 69 kV network when KPP is decommissioned, TPD does not recommend the synchronous condenser option as an alternative to the Waiinu-Kanaha upgrade project. If new firm dispatchable generation is procured to meet the reserve capacity shortfall, installing the new units on the 23 kV network will mitigate voltage issues and is anticipated to mitigate thermal issues involved with the retirement of KPP, however, installing the generation units on the 23 kV network conflicts with MECO's ultimate plan of converting the entire Maui transmission system to 69 kV. On the other hand, the Waiinu-Kanaha upgrade project mitigates voltage and thermal issues, aligns with MECO's ultimate plan, and also increases the reliability of the system in the aspect that the project will provide a second line to feed Waiinu – in the event of the current most severe N-1, losing the MPP-Waiinu line, the upgraded Waiinu-Kanaha line will provide power to the Waiinu substation to feed the 23 kV network load. The BESS option produces similar results to the option which involves installing new firm generation on the 23 kV network if the BESS is placed on the 23 kV network, however, TPD considers it to be uneconomical to pursue the BESS option considering the possible dispatch scenarios of the BESS unit and its similar characteristics to the new firm generation option. TPD recommends that the company's interest in the procurement of new firm generation, BESS, DR, or any other means to meet the approximate 40 MW reserve capacity short fall by 2019 should not affect or void the plan of the Waiinu-Kanaha upgrade project. TPD still recommends the implementation of the Waiinu-Kanaha upgrade project as it will ensure that the retirement of KPP will not jeopardize system reliability and transition portions of the existing 23 kV network to 69 kV, thus progressing MECO's ultimate plan of converting the entire Maui transmission network to 69 kV and improve the overall system reliability.

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# Appendix

## Kahului Power Plant Retirement: Voltage Stability Assessment

The comparison of P-V characteristics for the N-1 events of losing the 23 kV Kanaha-Kahului line, 69 kV Maalaea-Puunene line, and 23 kV Wailuku-Waiinu lines are shown below.

Existing system with and without operation of KPP:

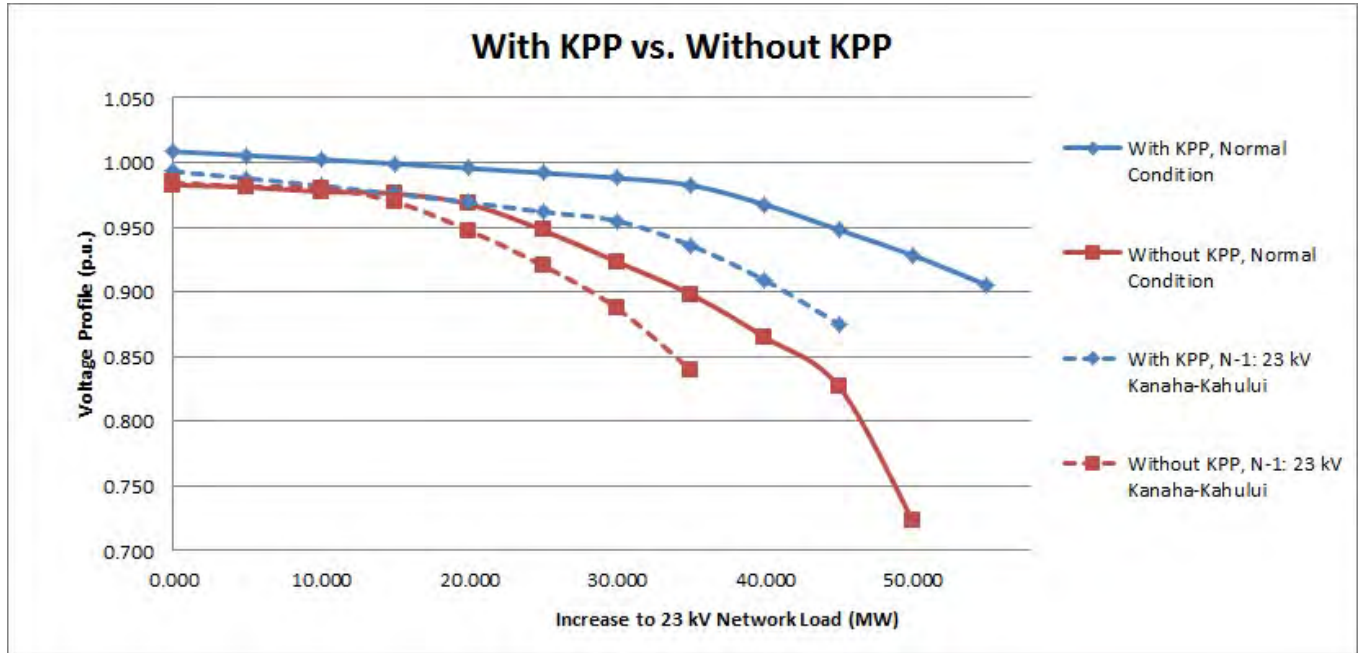


Figure 18: P-V characteristics of existing system with and without KPP for losing 23 kV Kanaha-Kahului Line.

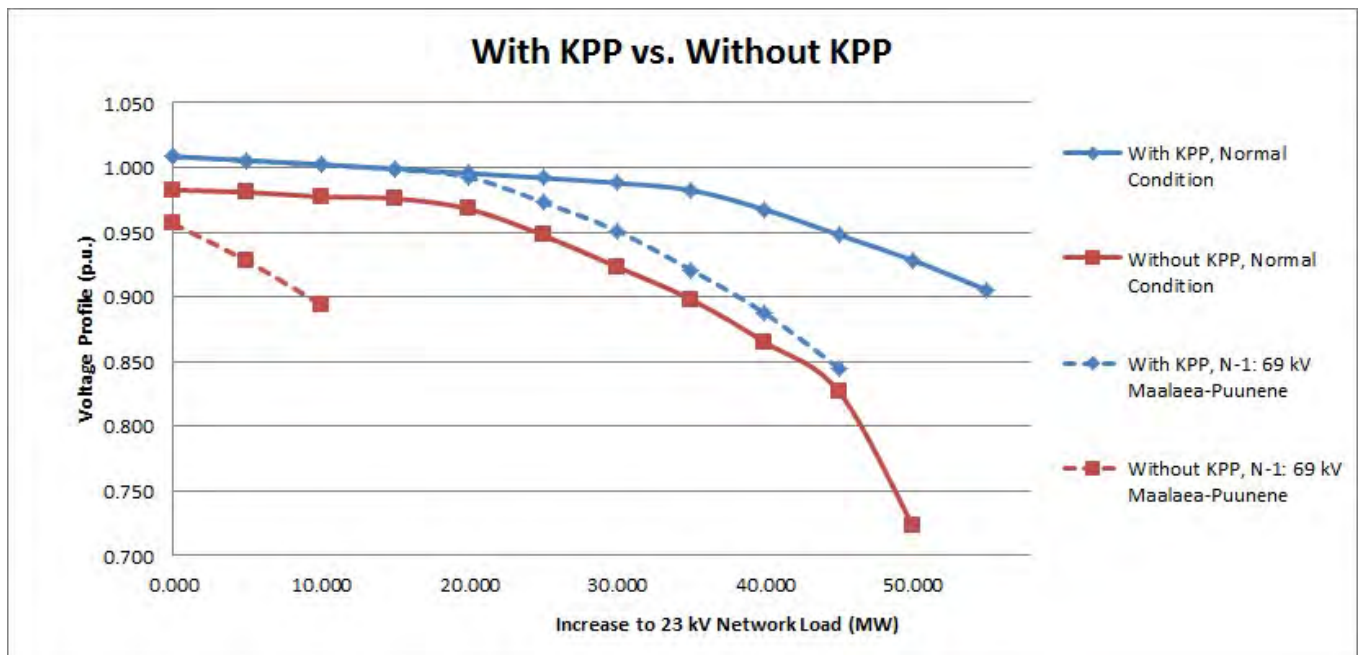


Figure 19: P-V characteristics of existing system with and without KPP for losing the 69 kV MPP-Puunene Line.



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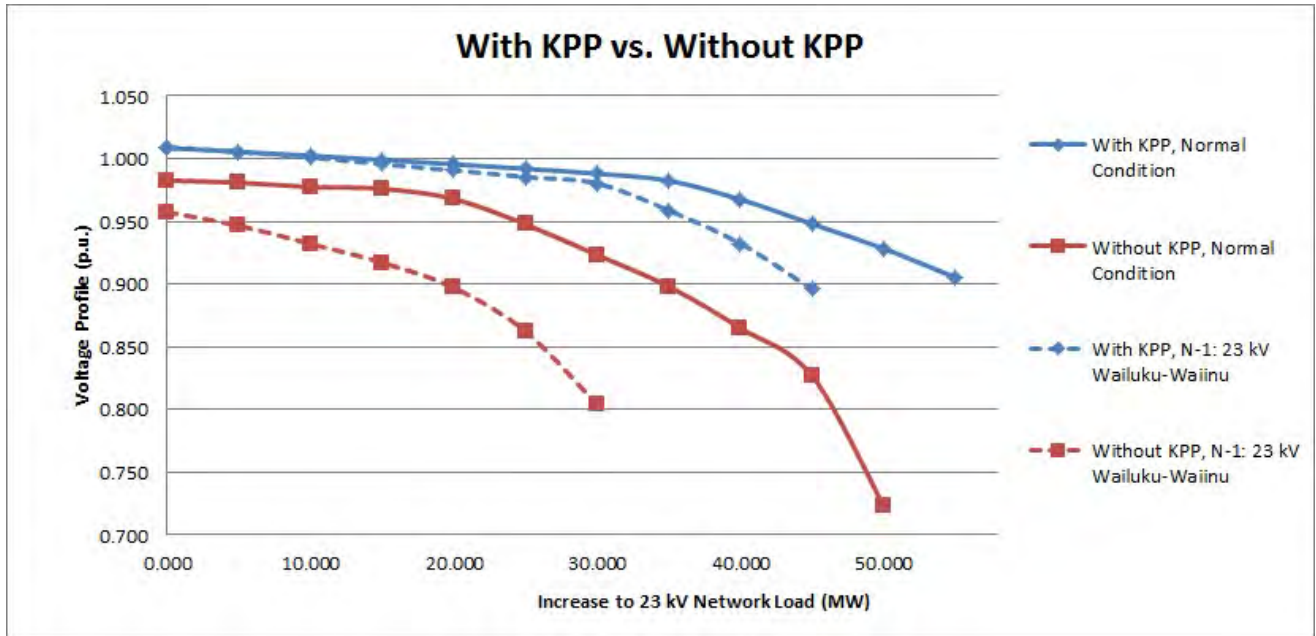


Figure 20: P-V characteristics of existing system with and without KPP for losing 23 kV Wailuku-Waiinu Line.

P-V characteristic comparison of Alternative 1 - Alternative 5:

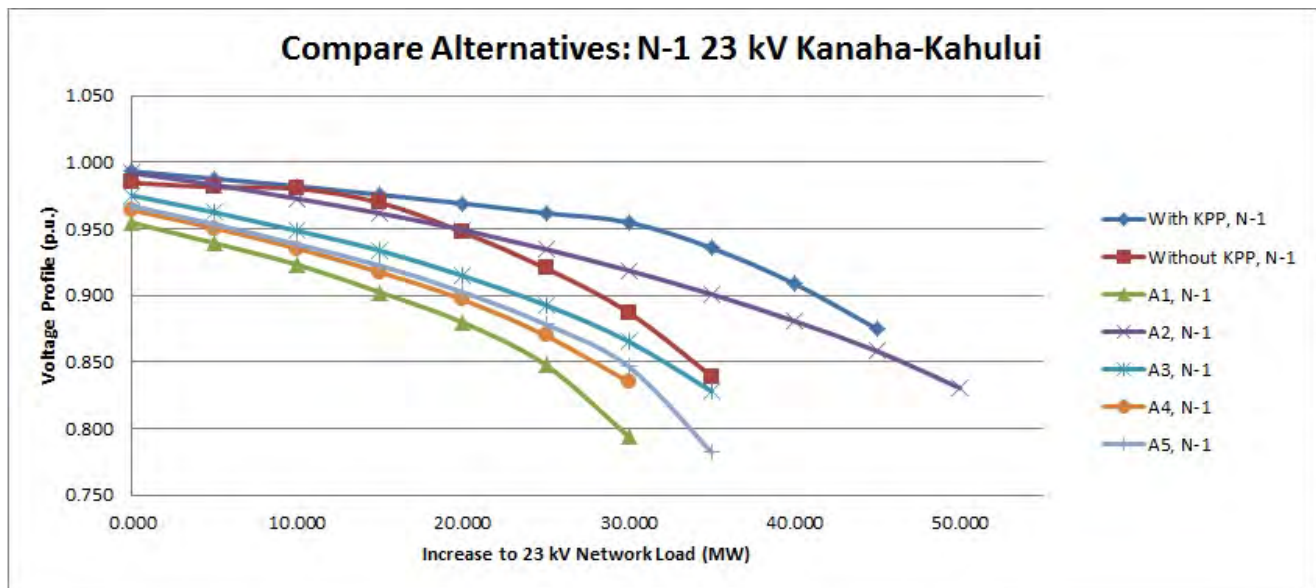


Figure 21: Comparison of P-V characteristics of transmission Alternatives for losing the 23 kV Kanaha-Kahului Line.

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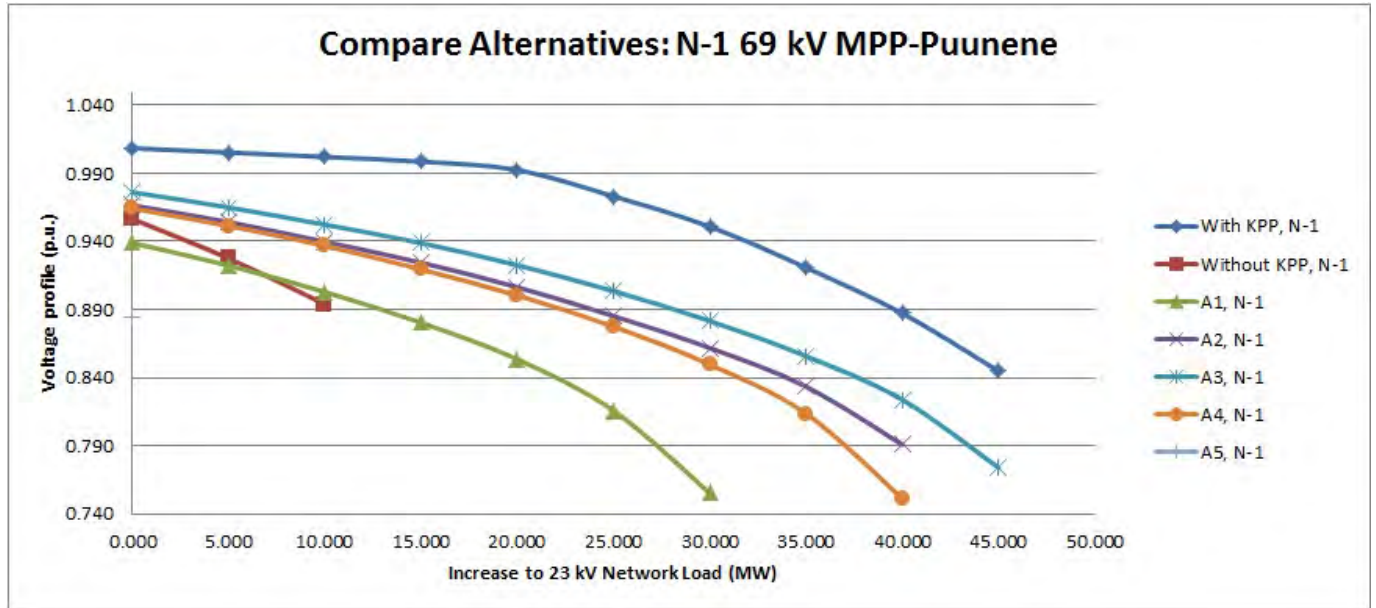


Figure 22: Comparison of P-V characteristics of transmission Alternatives for losing the 69 kV MPP-Puunene Line.

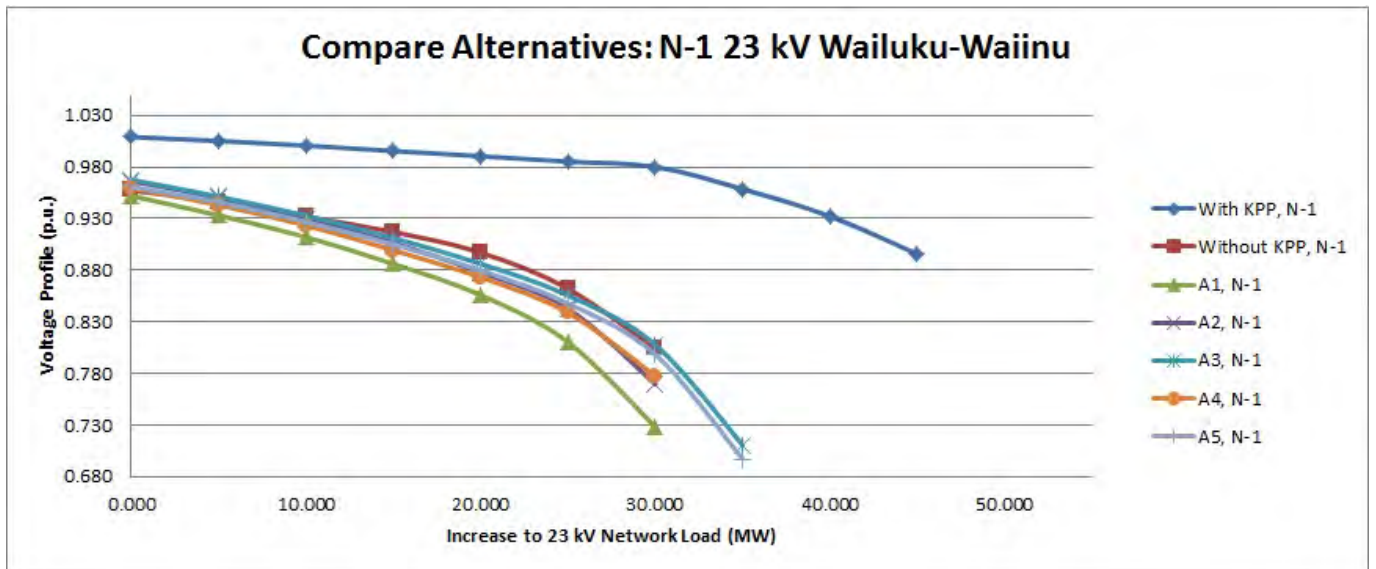


Figure 23; Comparison of P-V characteristics of transmission Alternatives for losing the 23 kV Wailuku-Waiinu Line.

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P-V characteristic comparison of Combination 1- Combination 7:

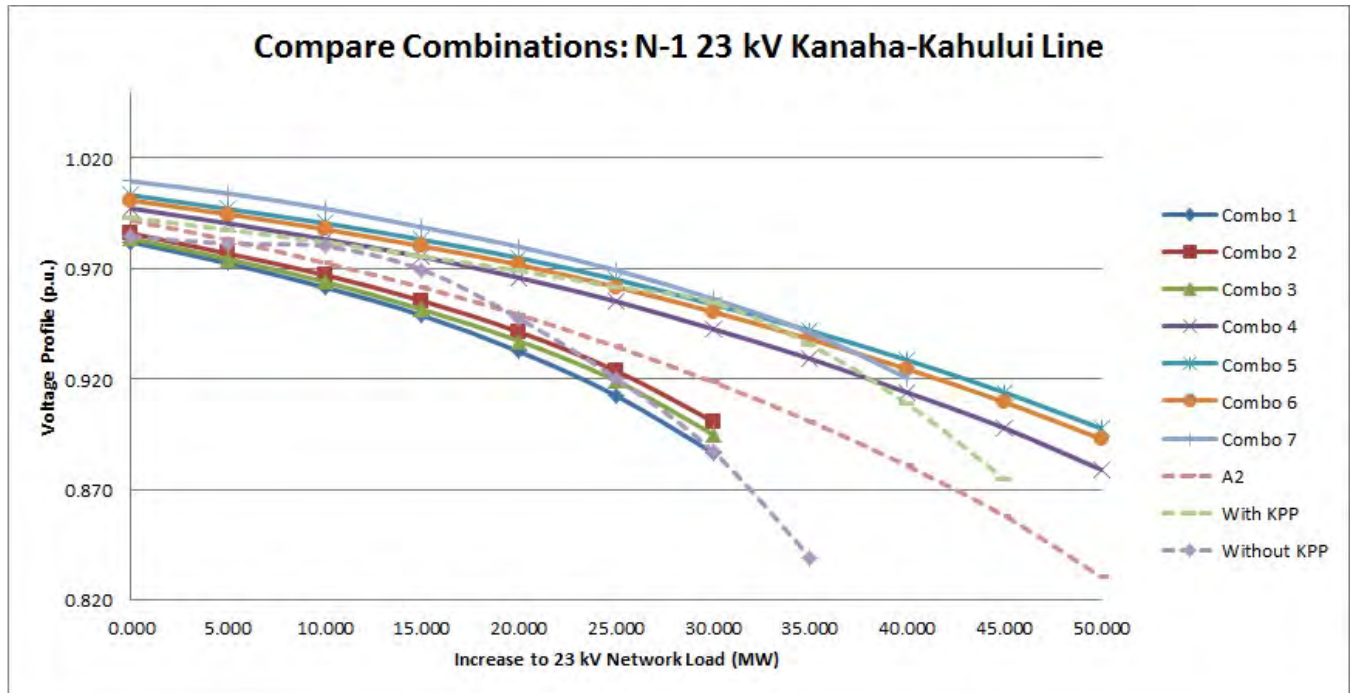


Figure 24; Comparison of P-V characteristics of transmission Combinations for losing the 23 kV Kanaha-Kahului Line.

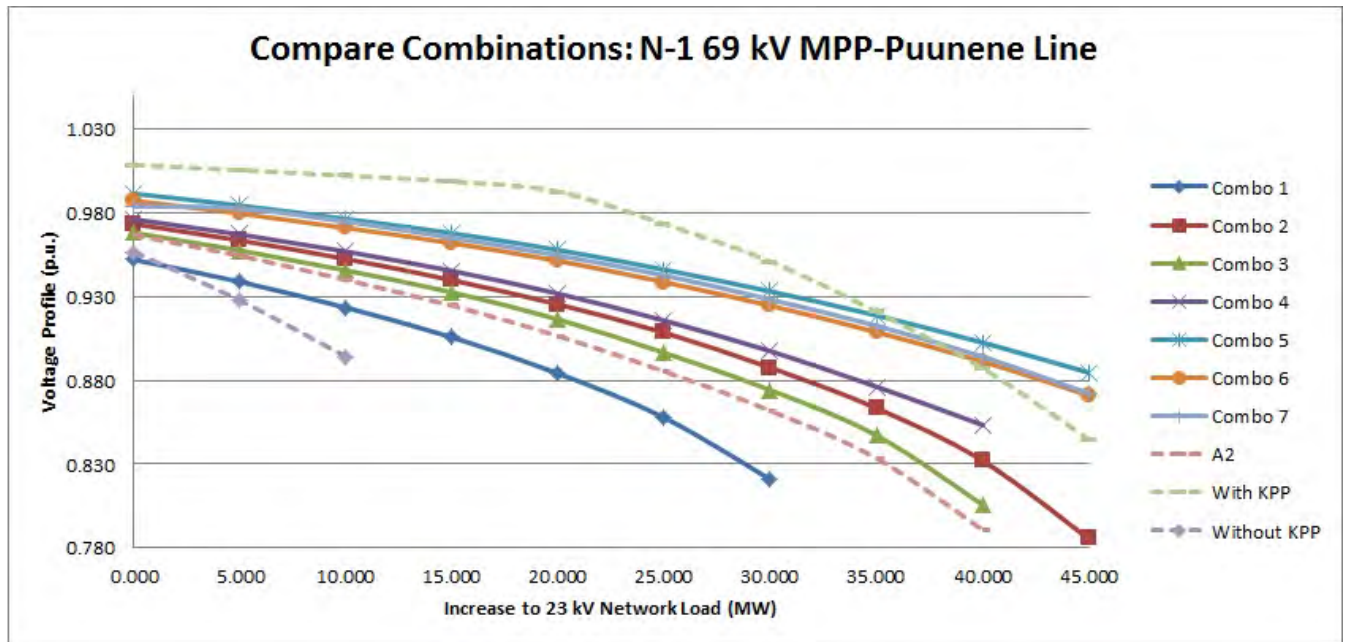


Figure 25 Comparison of P-V characteristics of transmission Combinations for losing the 69 kV MPP-Puunene Line.

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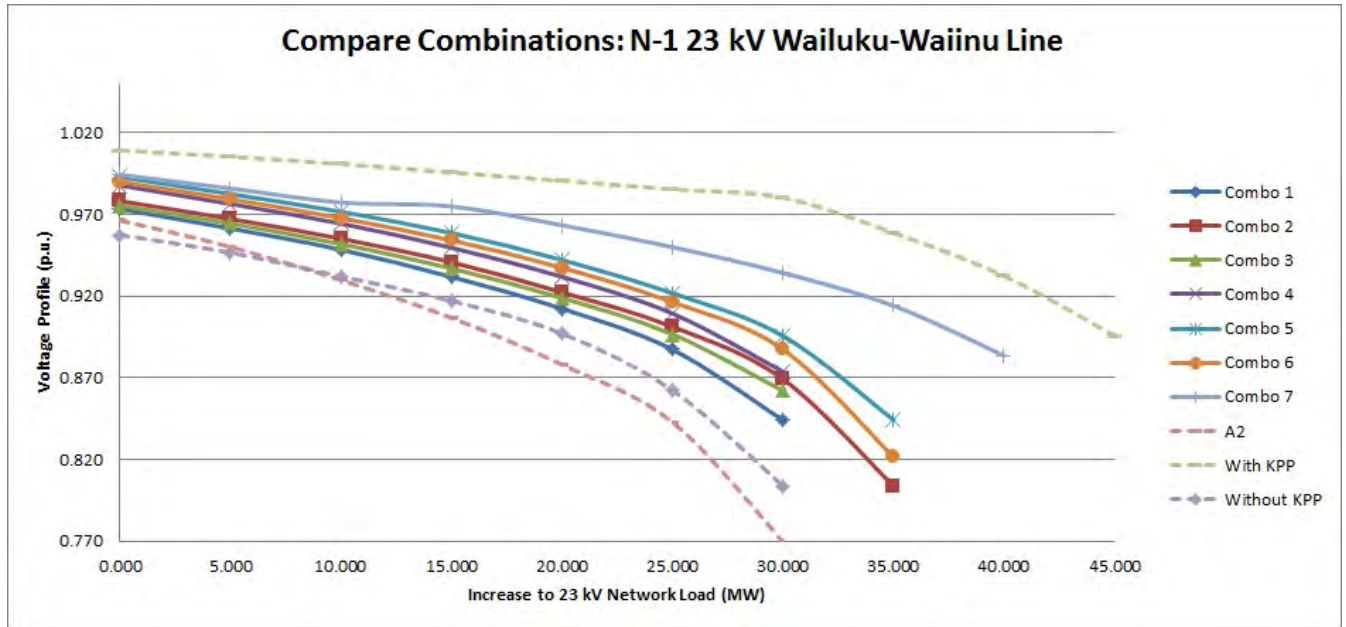


Figure 26: Comparison of P-V characteristics of transmission Combinations for losing the 23 kV Wailuku-Waiinu Line.

Synchronous Condenser Option:

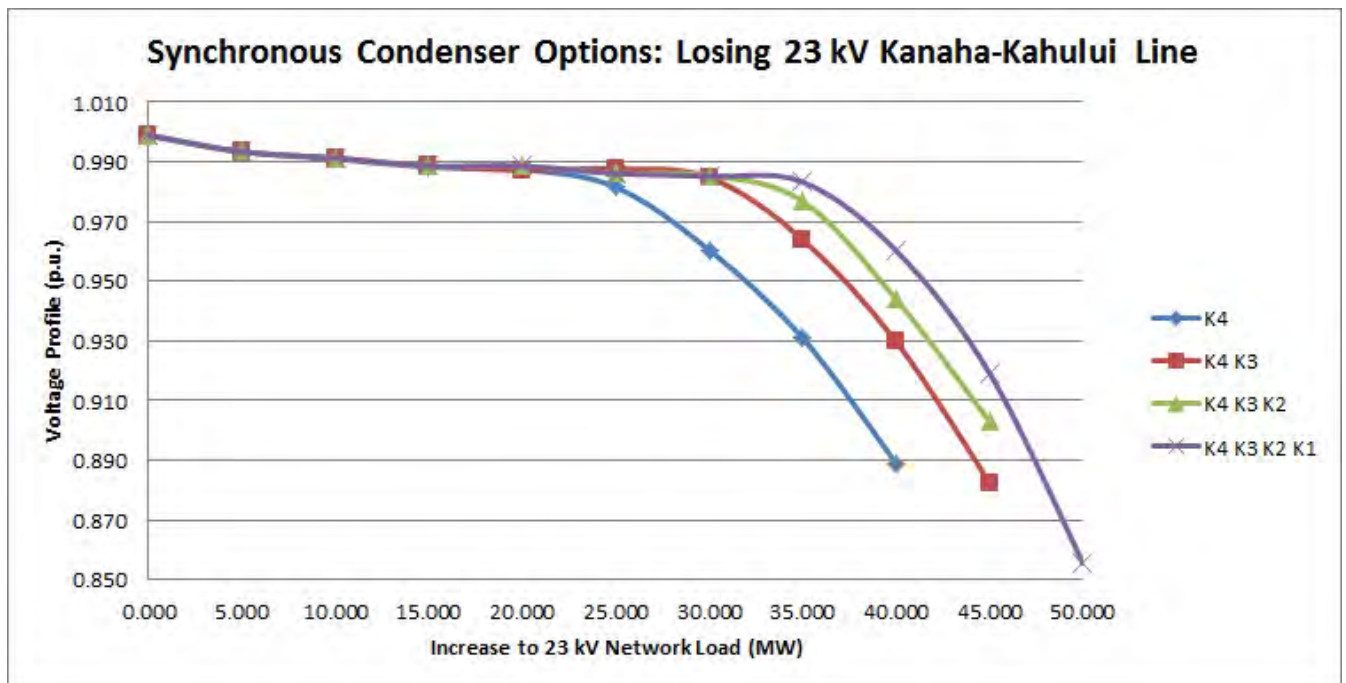


Figure 27: Comparison of P-V characteristics of synchronous condenser options for losing the 23 kV Kanaha-Kahului Line.

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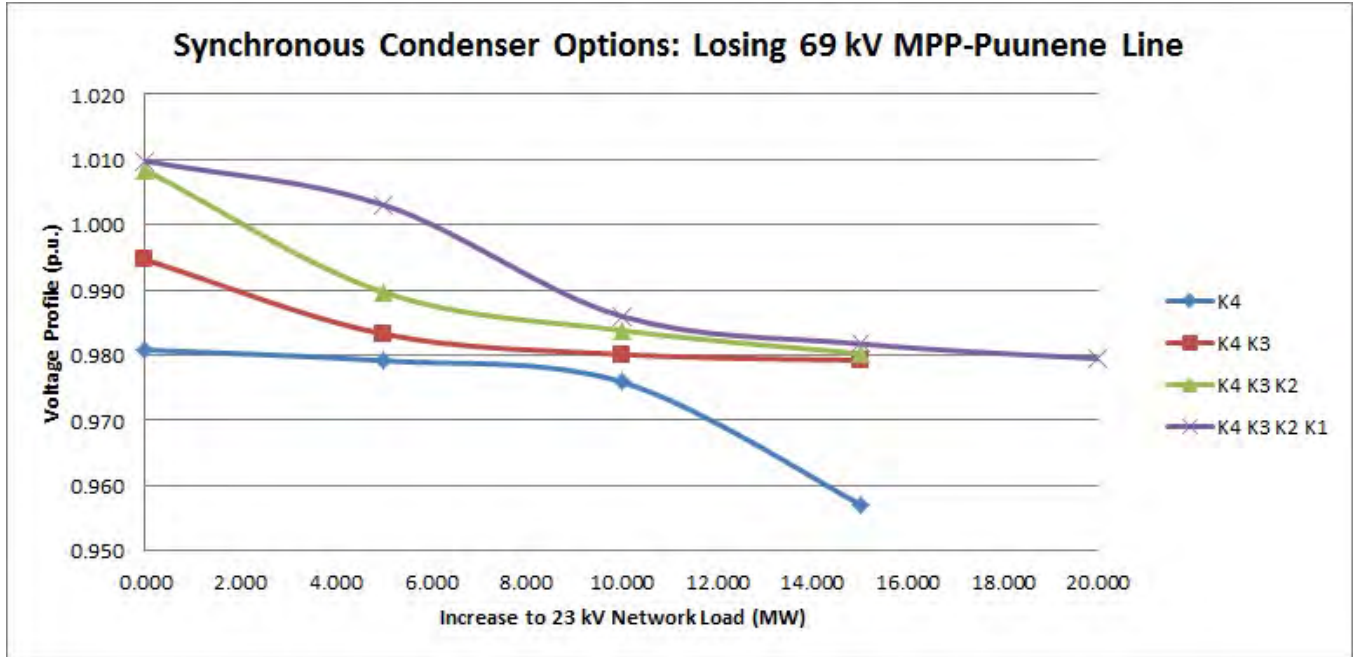


Figure 28: Comparison of P-V characteristics of synchronous condenser options for losing the 69 kV MPP-Puunene Line.

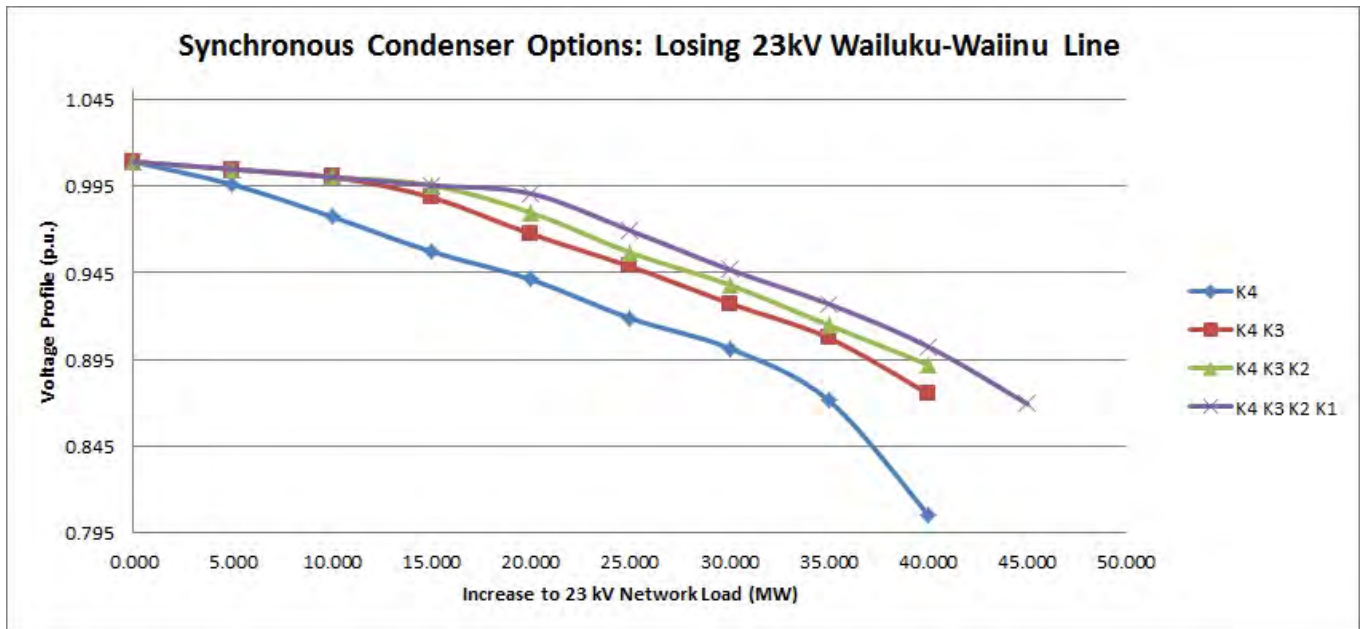


Figure 29: Comparison of P-V characteristics of synchronous condenser options for losing the 23 kV Wailuku-Waiinu Line.

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### New Firm Generation on 23 kV Network Option:

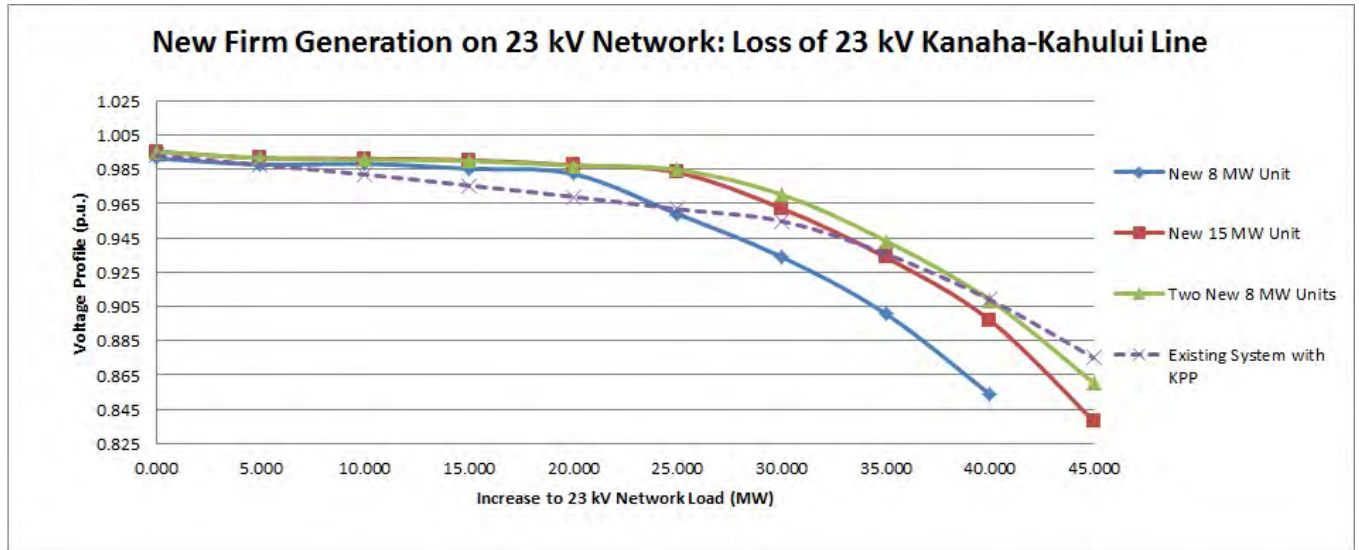


Figure 30: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 23 kV Kanaha-Kahului Line.

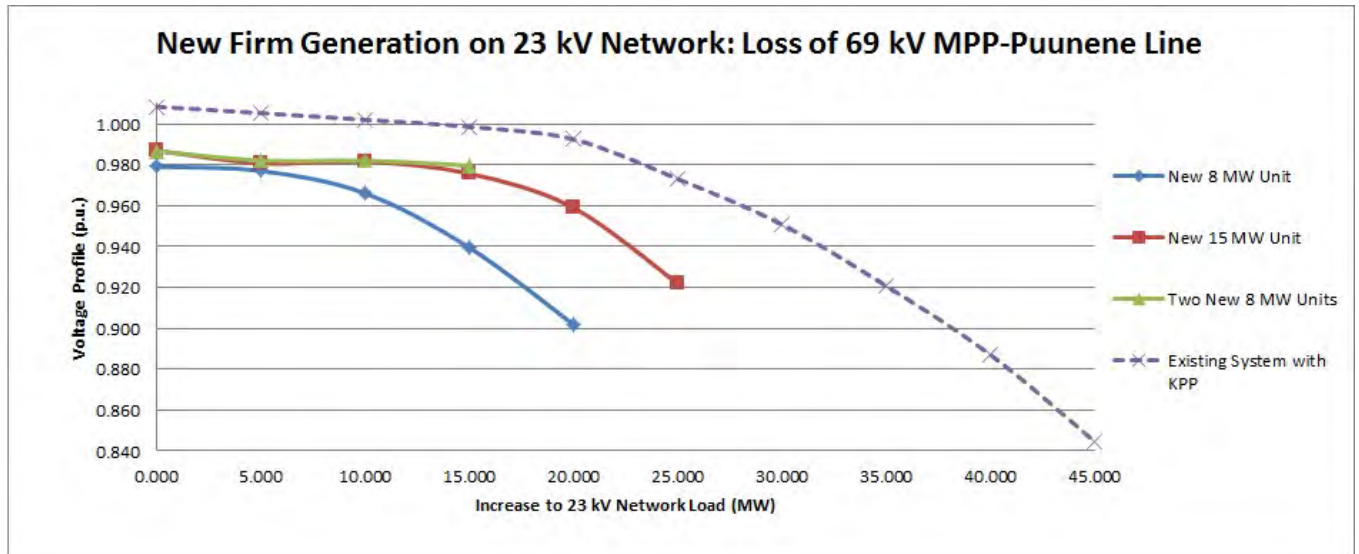


Figure 31: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 69 kV MPP-Puunene Line.

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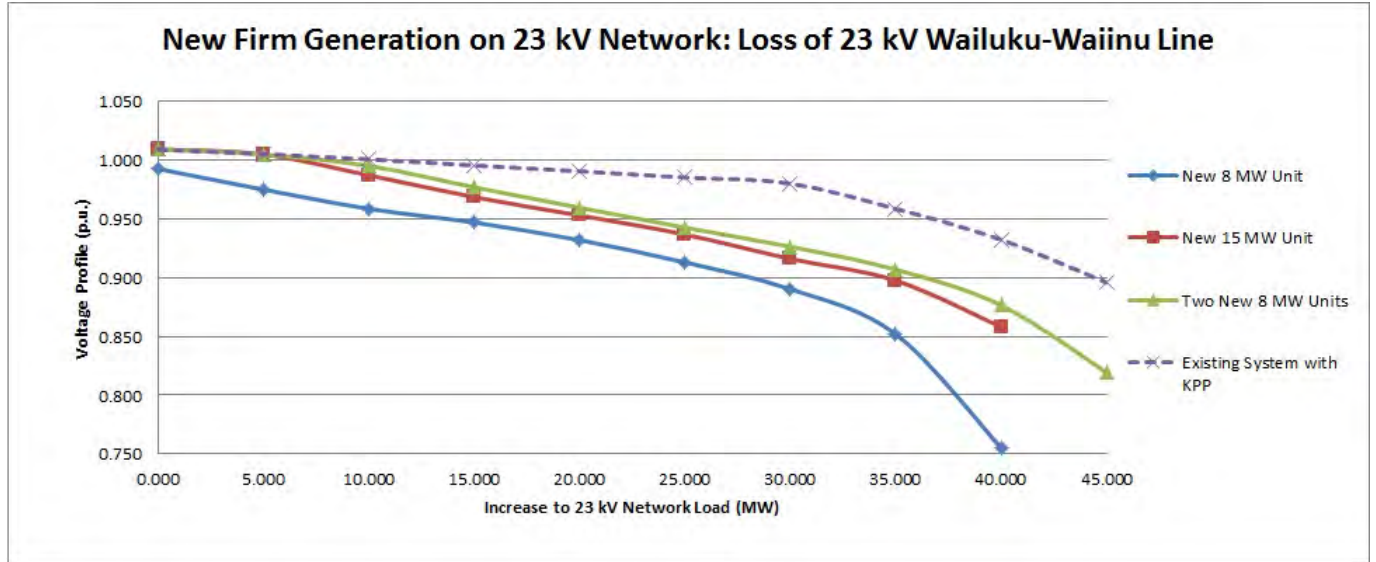


Figure 32: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 23 kV Wailuku-Waiinu Line.

## New Firm Generation on the 69 kV Network Option:

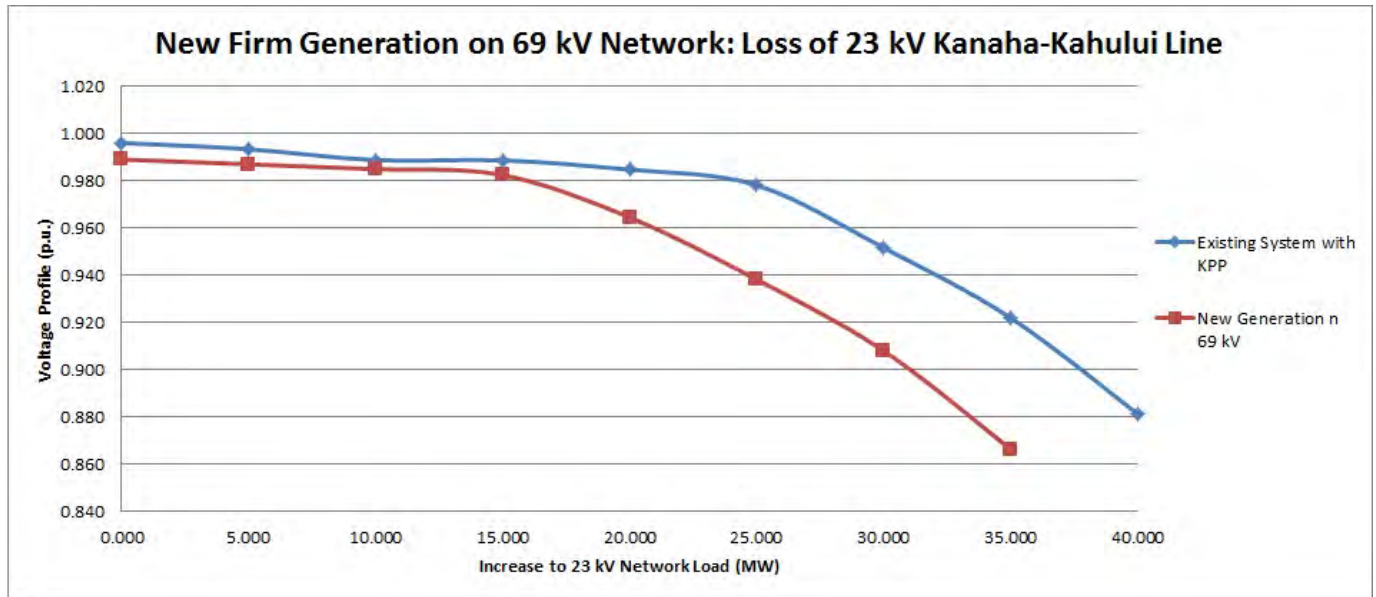


Figure 33: Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 23 kV Kanaha-Kahului Line.

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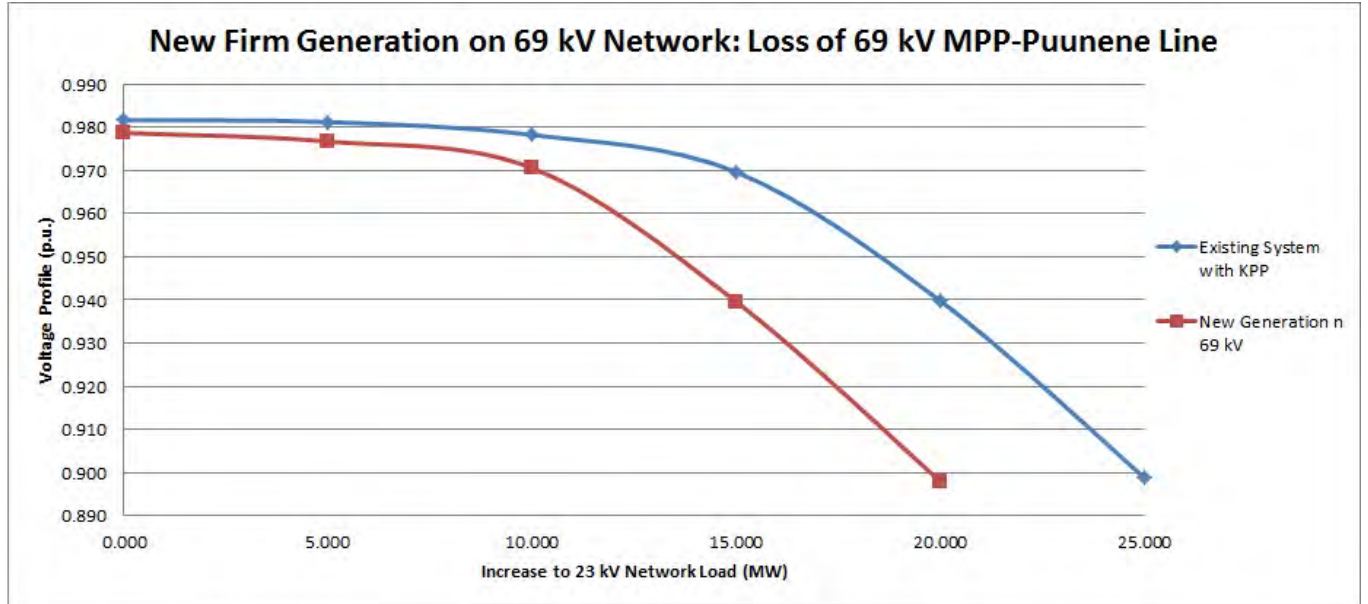


Figure 34: Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 69 kV MPP-Puunene Line.

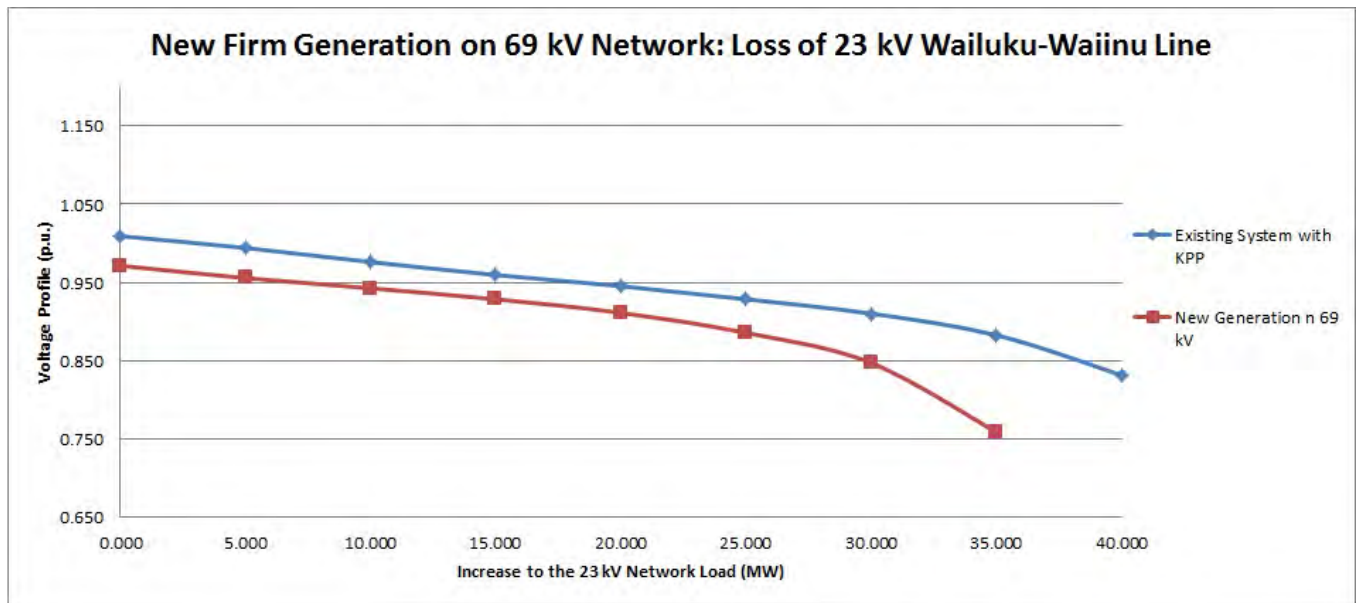


Figure 35; Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 23 kV Wailuku-Waiinu Line.



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BESS Option:

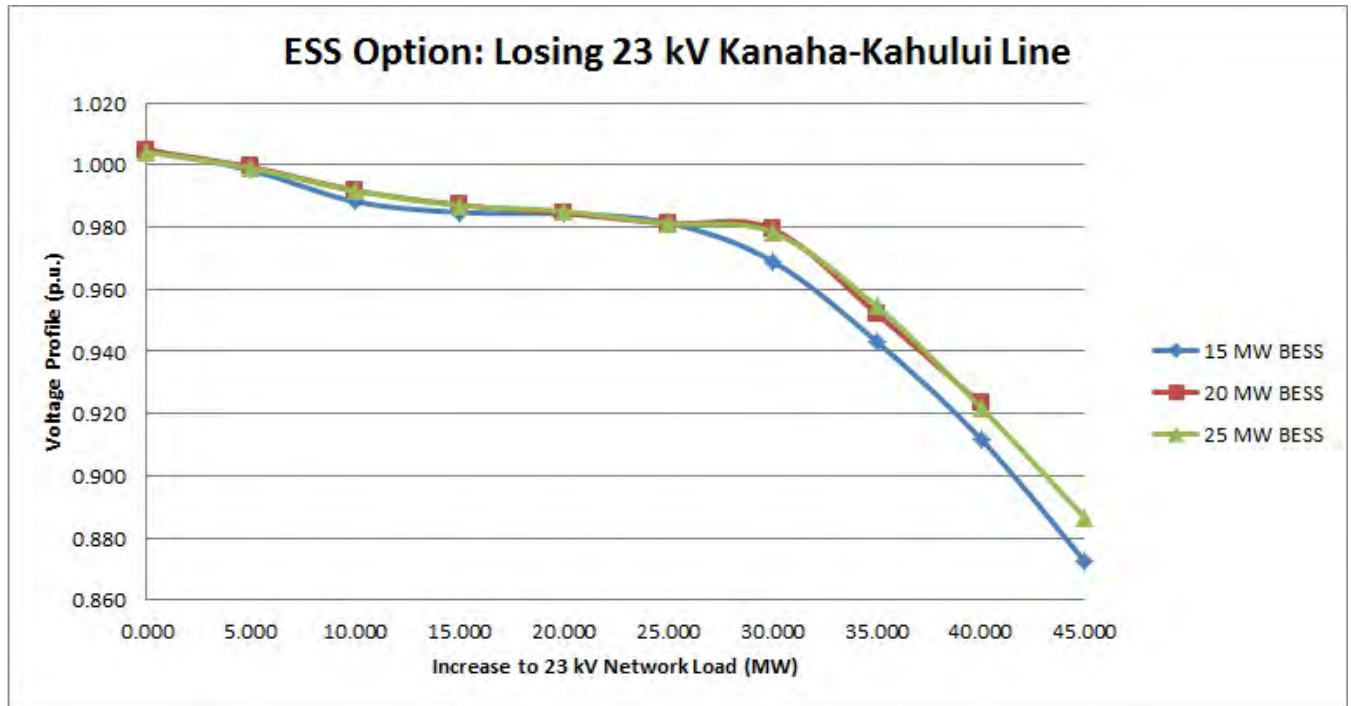


Figure 36: Comparison of P-V characteristics of various BESS options for losing the 23 kV Kanaha-Kahului Line.

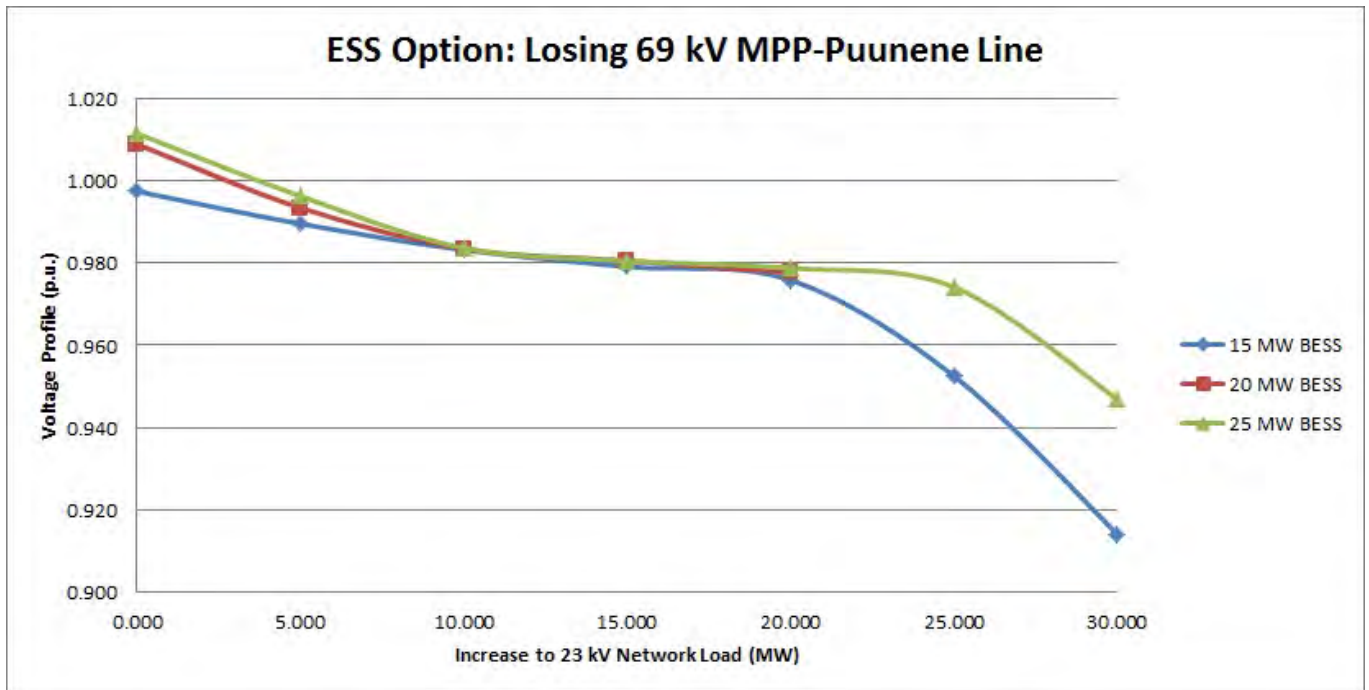


Figure 37 Comparison of P-V characteristics of various BESS options for losing the 69 kV MPP-Puunene Line.

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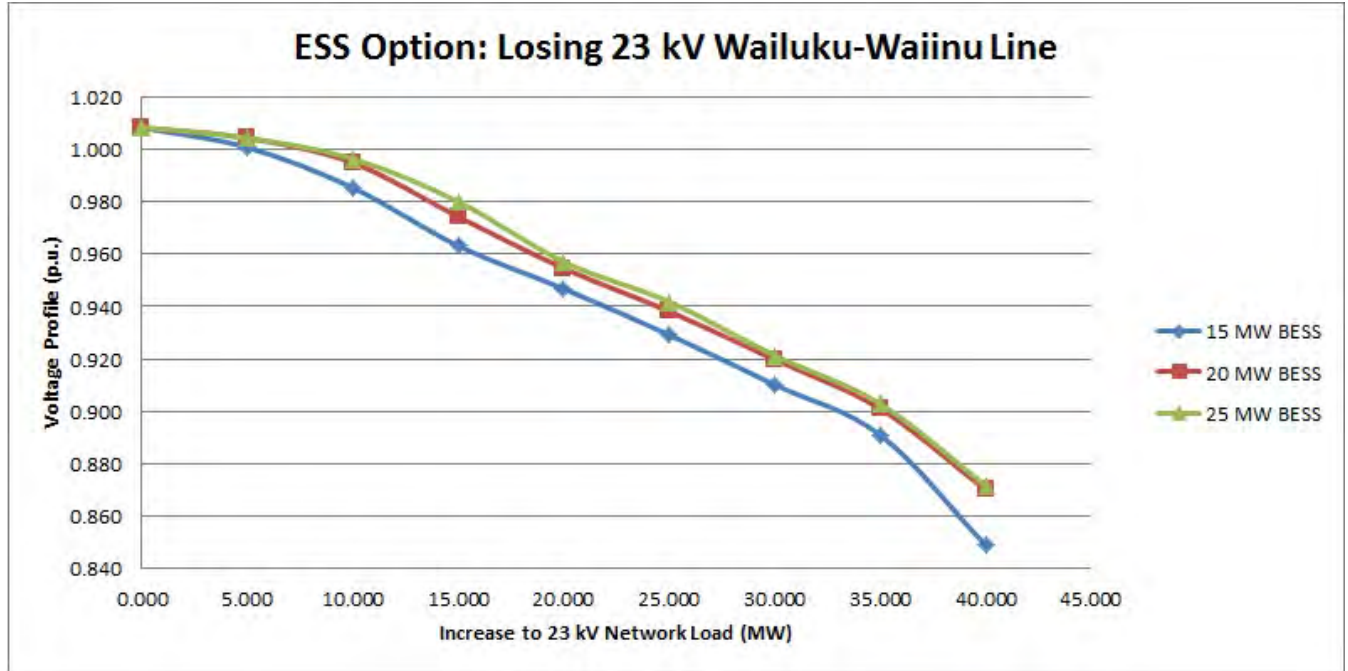


Figure 38: Comparison of P-V characteristics of various BESS options for losing the 23 kV Wailuku-Waiinu Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### System load above 170 MW:

The longest period of time that the Maui system has historically been observed to have remained 170 MW and above within the last year is 7 hours, which occurred on September 23, 2013.

| <b>September 23, 2013</b> |                  |
|---------------------------|------------------|
| Hour                      | System Load (MW) |
| 1                         | 120.2            |
| 2                         | 114.3            |
| 3                         | 109.6            |
| 4                         | 108              |
| 5                         | 114.7            |
| 6                         | 121.1            |
| 7                         | 133.4            |
| 8                         | 147.4            |
| 9                         | 158.1            |
| 10                        | 165.2            |
| 11                        | 165.4            |
| 12                        | 164.5            |
| 13                        | 163.7            |
| 14                        | 167.2            |
| 15                        | 169.3            |
| 16                        | 170.5            |
| 17                        | 174              |
| 18                        | 177.1            |
| 19                        | 178.8            |
| 20                        | 186.1            |
| 21                        | 183.1            |
| 22                        | 170.2            |
| 23                        | 152.6            |
| 24                        | 133.7            |



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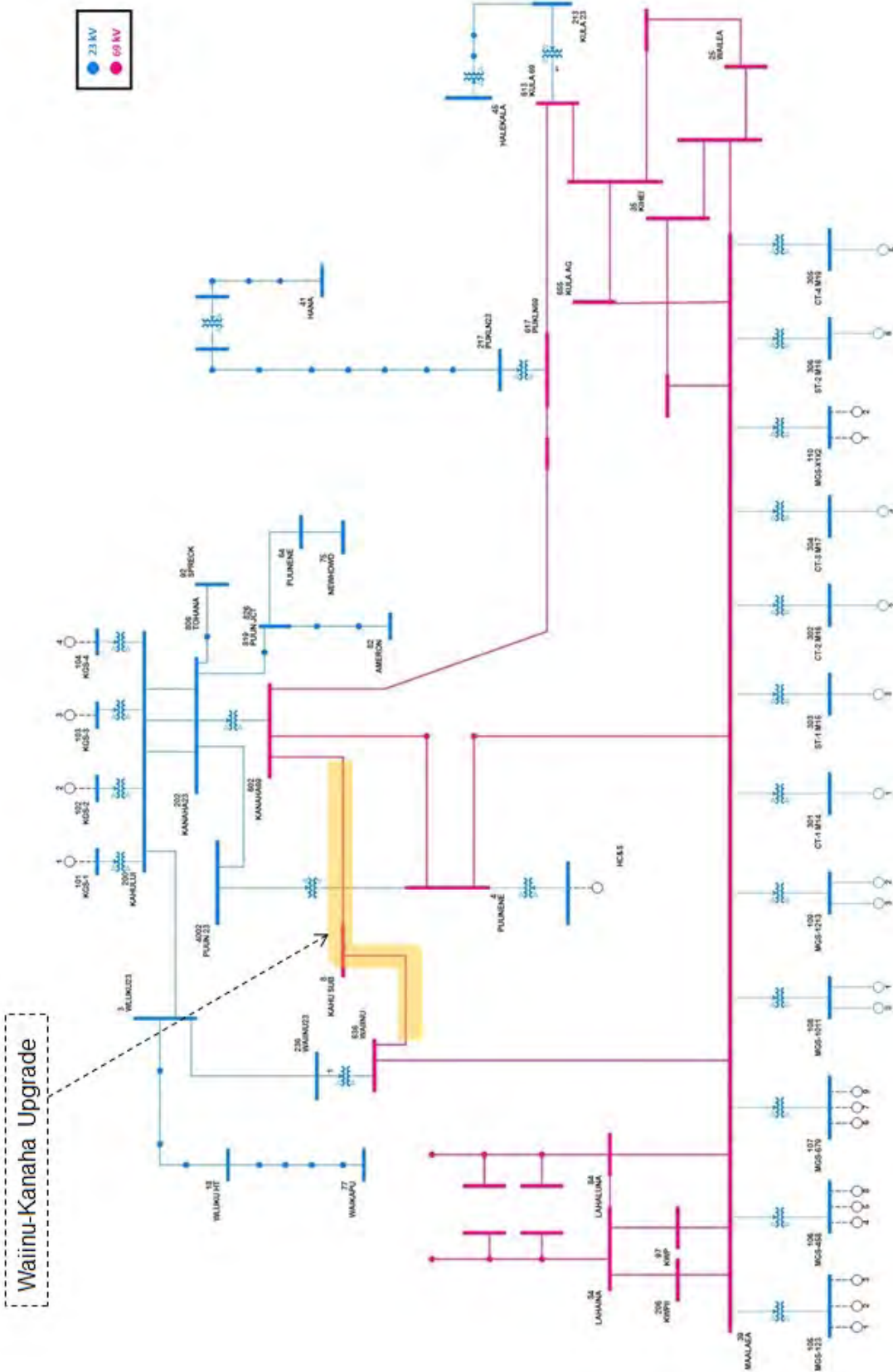


Figure 40: Single line diagram of the existing Maui 23 kV and 69 kV network with Waiinu-Kanaha Upgrade project implemented.

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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**Table 2: Maui System Peak Forecast.**

| <b>Maui Electric Company, Ltd.<br/>(Maui Division)<br/>SYSTEM PEAK FORECAST</b> |             |
|---|-------------|
| Year  | System Load |
| 2013  | 194.5       |
| 2014  | 197.9       |
| 2015  | 199.7       |
| 2016  | 202.1       |
| 2017  | 208.2       |
| 2018  | 214.4       |
| 2019  | 218.3       |
| 2020  | 220.0       |
| 2021  | 221.9       |
| 2022  | 222.6       |
| 2023  | 223.3       |
| 2024  | 223.0       |
| 2025  | 223.3       |
| 2026  | 222.1       |
| 2027  | 220.4       |
| 2028  | 217.1       |
| 2029  | 214.8       |
| 2030  | 210.8       |

# Kahului Power Plant Retirement – Comprehensive Assessment

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## Appendix C – Short Circuit Analysis

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HECO Transmission Planning Division

Document Title: Kahului Power Plant Retirement – Comprehensive Assessment

Reference: TPD 2014-22

## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

# Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

**Prepared For**  
**Transmission Planning Division**

**Prepared by:**

Transmission Planning Division


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## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

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## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

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### **Revision History**

| <b>Date</b>    | <b>Revision Number</b> | <b>Change Description</b> |
|----------------|------------------------|---------------------------|
| August 1, 2014 | Original               | Original                  |
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## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

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### Executive Summary

Maui Electric Company (Maui Electric) announced the retirement of Kahului Power Plant (KPP) in the year 2019. Transmission Planning Division (TPD) performed a study to determine the effect of the KPP retirement on the short circuit current at various buses in the Maui transmission system.

The study results show that the retirement of KPP 3 & 4 leads to reduced fault current on the 69 KV and 23 KV transmission systems. The change in fault current could be as much as 5000 amperes. Such a large change in fault current may affect the relay operation and the reliable operation of the transmission system. Therefore, it is necessary to re-evaluate the effect of reduced fault current on the Maui system.

The study also shows that the non-transmission alternatives evaluated to address the impact of the retirement of KPP leads to increased fault current on the 69 KV transmission system. The increase in fault current could be as much as 5000 amperes.

### Background

Maui Electric announced the retirement of Kahului Power Plant (KPP) in the year 2014. Transmission Planning Division (TPD) has performed a study to determine the effect of the KPP retirement on the short circuit current at various buses in the Maui transmission system. The results of this study are presented in this report.

TPD has also evaluated the effect of KPP retirement on the transmission line overloading, transformer overloading, bus voltage violations, voltage stability, and transient stability of the Maui electrical system. The results of those studies are presented in separate reports.

Figure 1 shows the interaction of Maui 23 KV transmission system near KPP and the rest of the 69 KV transmission system. The 23 KV transmission system near KPP is shown as an orange cloud. KPP is part of this 23 KV transmission system. After KPP retirement, this 23 KV transmission system depends solely on 69 KV transmission system for supply of generation to meet the load. The three substations where this 69 KV – 23 KV transformation takes place are – Waiinu, Puunene, and Kanaha.

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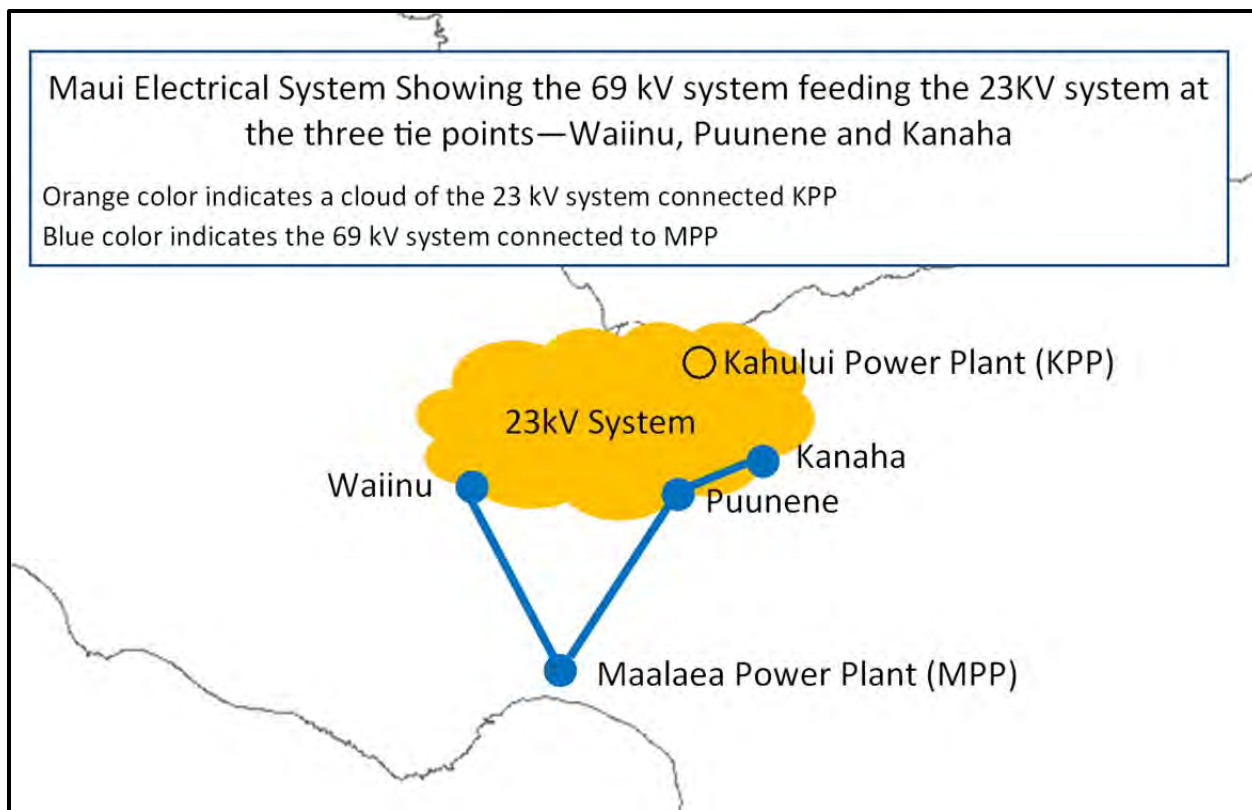


Figure 1 – Maui electrical system showing 69 KV transmission system feeding 23 KV transmission system at three tie points – Waiinu, Puunene, and Kanaha

As part of the KPP retirement study by TPD, PSSE<sup>1</sup> scenarios Case 0 – 5 were created. These scenarios represent the base case and various alternatives considered to alleviate the transmission limitations due to the retirement of KPP. The alternatives considered include transmission alternative, where new transmission upgrades are recommended, and non-transmission alternatives, where no new transmission upgrades are included. The 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiiu and MPP-Puunene is the transmission alternative. These non-transmission alternatives are – a) diesel generators (DG), b) battery (BESS) and c) synchronous condensers. These PSSE scenarios are given in Table 1. The study has also evaluated the effect of KPP retirement on the short circuit current under N-1 conditions. A list of N-1 contingencies are given in Table 2.

**Table 1 – PSSE Models used in the Short Circuit Study**

|        | Scenario Name                          | Scenario Description   |
|--------|--|--|
| Case 0 | Case 0 – 2014 Base Case                | 2014 peak case with HC&S and KPP 3 & 4 on line.  |
| Case 1 | 2019 Base Case plus KPP 3&4 Retirement | 2019 peak case; KPP retired, HC&S retired--retired generation picked up at Maalaea Power Plant |

<sup>1</sup> Power System Simulator for Engineering

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| Scenario Name   | Scenario Description  |
|---|---|
| Case 2<br>Case 1 plus transmission Upgrades                   | Case 1 plus the following transmission upgrades <ul style="list-style-type: none"> <li>• 23 KV Waiinu – Kanaha upgraded to 69 KV</li> <li>• Reconductor MPP – Waiinu and MPP – Puunene from 336 AAC to 556 AAC</li> </ul> |
| Case 3<br>Case 1 plus diesel generators (DG) on 23 KV system. | Case 1 plus diesel generator (DG) on 23 KV system   |
| Case 4<br>Case 1 plus battery (BESS) on 23 KV system          | Case 1 plus battery (BESS) on 23 KV system  |
| Case 5<br>Case 1 plus synchronous condenser                   | Case 1 plus synchronous condenser on 23 KV system   |

**Table 2 – List of contingencies included in the short circuit study**

| Contingency Name         | Contingency Description                             |
|--------------------------|---|
| None                     | Cases 0 – 5 plus no line outage                     |
| MPP – Waiinu 69 KV line  | Cases 0 – 5 plus outage of MPP – Waiinu 69 KV line  |
| MPP – Puunene 69 KV line | Cases 0 – 5 plus outage of MPP – Puunene 69 KV line |

The topic of short circuit current was evaluated in a recent study by EPS<sup>2</sup>. The study determined that even for very high renewable wind and solar penetration levels considered in the study, there is sufficient short circuit ratio available for proper operation of the inverter based technologies such as solar and wind generators.

### Methodology

PSSE was used to calculate short circuit current. 3-phase fault was applied at each bus in the Maui transmission system. The short circuit currents from PSSE were tabulated.

Post processing of the short circuit current included calculating the percent change in short circuit current in Cases 1 – 5 compared to Case 0.

### Assumptions

- The study is a follow-up of the other studies by TPD on KPP retirement. The assumptions are consistent with the assumptions in the other studies performed by TPD on KPP retirement (thermal analysis, voltage stability analysis, transient stability analysis).
- This study is not a High PV/wind penetration study. This topic has been addressed in a study by EPS referenced in the Background section of this report.
- This study solely focuses on the effect of KPP retirement on the short circuit current at the critical buses in the Maui transmission system.

<sup>2</sup> “Maui Electric Company, Ltd. Curtailment Reduction Plan Impact Study” Dated June 30, 2014

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### Results and Analysis

The results of the fault current calculations are given in Appendix A of the report. This table contains the percent change in fault current at substations that are 23 KV and larger compared to Case 0 (base case). The changes in fault currents greater than 5% are highlighted with different colors. The green color highlight indicates that the fault current has decreased 5% and larger with respect to the Case 0. The red color highlight indicates that the fault current has increased 5% and larger with respect to the Case 0 with KPP 3 & 4 in service.

There are several generation dispatches in Cases 1 – 5 with respect to Case 0. These generation dispatches cause either the increase in fault current (generation addition) or decrease in fault current (generation retirement). In general, the KPP 3 & 4 retirement, HC&S retirement lead to decreased fault currents and dispatched units at Maalaea Power Plant (MPP) causes an increase in fault currents. These increase and decrease in fault currents are marked as red and green in Table A.1.

A comparison of the fault current for non-transmission alternatives (Case 3, Case 4, and Case5) shows that the changes in fault current are very similar to each other and are also very similar to the Case 0. This is due to the location of the non-transmission alternatives on the 23 KV transmission system that replaces the retired KPP3 & 4 generators. However, if the non-transmission alternatives are located on the 69 KV transmission system, we expect to notice drastic change in fault current.

**Fault Current Due to KPWII Wind Generator** – This study shows that addition of KPWII causes substantial increase in fault current. This is due to the fact that PSSE models KPWII wind generator as synchronous condenser. The substantial increase in fault current is contrary to the fact that inverter based technologies do not contribute significantly to the fault current. PSSE calculations are acceptable for planning studies. However, further adjustments to the fault current will be needed for accurate fault current calculations.

Table 3 shows the changes in short circuit fault current at Maui substations 23 KV and larger for Cases 1 & 2. Only changes greater than 5% have been reported. Whereas the increase in fault current due to KPWII addition is intuitive, the increase in fault current in Case 2 is counterintuitive because the changes in the fault currents are due to many different factors – KPP 3 & 4 retirement, HC&S retirement, KPWII addition, Maalaea 679 on-line, Maalaea 1213 on-line, and various 23 KV and 69 KV transmission upgrades with change in topology. Therefore, the association of increase and decrease in short circuit current to one factor is next to impossible. To establish such an association, we made several runs to quantify the change in short circuit current due to various transmission upgrades and KPP retirements. The results from these simulations have been discussed below.

#### **Table 3 Fault Current at buses that show change by 5 % and larger (Cases 0, 1, and 2)**

*(Green highlights show that the fault current has decreased 5% or larger with respect to Case 0, and red highlights show that the fault current has increased 5% or larger with respect to Case 0)*

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| Bus   | Name       | KV    | 3PH   | Case0  |          | Case1 (Delta %) |         |         | Bus   | Case2 (Delta %) |          |         |
|-------|------------|-------|-------|--------|----------|-----------------|---------|---------|-------|-----------------|----------|---------|
|       |            |       |       | MVA    | Amp      | NoCont          | Cont1   | Cont2   |       | NoCont          | Cont1    | Cont2   |
| Col 1 | Col 2      | Col 3 | Col 4 | Col 5  | Col 6    | Col 7           | Col 8   | Col 9   | Col 1 | Col 11          | Col 12   | Col 13  |
| 4     | PUUNENE    | 69.00 | 3PH   | 641.23 | 5,365.40 | 21.65           | 22.00   | 42.69   |       | 7.15            | 23.67    | (14.06) |
| 23    | PUUKOL B   | 69.00 | 3PH   | 373.99 | 3,129.30 | 0.72            | (0.35)  | (1.52)  |       | 0.79            | 0.17     | (1.02)  |
| 401   | PUUNENEA   | 69.00 | 3PH   | 612.53 | 5,125.30 | 20.61           | 21.07   | 41.70   |       | 2.12            | 23.43    | (22.62) |
| 402   | PUUNENEB   | 69.00 | 3PH   | 646.62 | 5,410.50 | 20.02           | 20.17   | 41.65   |       | 7.60            | 20.79    | (11.24) |
| 602   | KANAHA69   | 69.00 | 3PH   | 597.10 | 4,996.20 | 20.00           | 20.53   | 41.08   |       | (1.37)          | 22.75    | (27.10) |
| 636   | WAIINU     | 69.00 | 3PH   | 529.15 | 4,427.60 | 4.90            | 16.58   | 2.92    |       | (18.33)         | (367.82) | (8.25)  |
| 2060  | KWP1134    | 34.50 | 3PH   | 224.70 | 3,760.40 | (13.03)         | (13.78) | (14.62) |       | (13.01)         | (13.47)  | (14.32) |
| 2061  | KWP11_CLT1 | 34.50 | 3PH   | 223.00 | 3,731.90 | (13.22)         | (13.97) | (14.81) |       | (13.20)         | (13.66)  | (14.51) |
| 136   | WAIINU B   | 12.47 | 3PH   | 88.57  | 4,100.80 | 1.05            | 26.53   | 3.49    |       | (2.15)          | (89.74)  | 0.48    |

### Effect of Transmission Upgrades on Fault Currents

To determine the effect of transmission upgrades on the fault currents, we compared the results of Case 2 (with transmission upgrade) with Case 1 (no transmission upgrade). The change in short circuit current is given in Table 4.

The results show that short circuit current increases. Due to transmission upgrades and change in transmission topology, the equivalent impedances (Thevenin Equivalence) is reduced. The reduction in equivalent impedance gives rise to increased fault current contributions.

**Table 4 – 5% or larger change in Short Circuit Current due transmission upgrades**

*(Case1 is without transmission upgrade and Case2 is with transmission upgrade)*

| Bus | Name     | KV    | 3PH | Case1  |          | Case2 (delta %) |         |         |
|-----|----------|-------|-----|--------|----------|-----------------|---------|---------|
|     |          |       |     | MVA    | Amp      | NoCont          | Cont1   | Cont2   |
| 4   | PUUNENE  | 69.00 | 3PH | 502.43 | 4,204.00 | (18.50)         | 2.14    | (99.03) |
| 401 | PUUNENEA | 69.00 | 3PH | 486.31 | 4,069.10 | (23.29)         | (23.29) | (23.29) |
| 402 | PUUNENEB | 69.00 | 3PH | 517.14 | 4,327.10 | (15.53)         | (15.53) | (15.53) |
| 602 | KANAHA69 | 69.00 | 3PH | 477.67 | 3,996.90 | (26.72)         | (26.72) | (26.72) |
| 617 | PUKLN69  | 69.00 | 3PH | 398.10 | 3,331.00 | (8.87)          | (8.87)  | (8.87)  |
| 636 | WAIINU   | 69.00 | 3PH | 503.22 | 4,210.60 | (24.42)         | (24.42) | (24.42) |
| 3   | WLUKU23  | 23.00 | 3PH | 189.28 | 4,751.30 | 5.03            | 5.03    | 5.03    |
| 40  | ONEHEE   | 23.00 | 3PH | 158.97 | 3,990.40 | 42.65           | 42.65   | 42.65   |
| 236 | WAIINU23 | 23.00 | 3PH | 209.12 | 5,249.50 | 12.78           | 12.78   | 12.78   |
| 840 | TO-ONEE  | 23.00 | 3PH | 196.50 | 4,932.70 | 48.37           | 48.37   | 48.37   |

### Effect of KPP Retirement on 69 KV and 23 KV transmission systems

To determine the effect of KPP retirement on the short circuit current, we created Case 1a from Case 1 by not retiring KPP 3 & 4. Table 5 shows the change in the fault current 5% or larger due to the retirement of KPP 3 & 4. We observe that the change in fault current varies from few amperes to as much as 5000 amperes (Kahului 23 KV substation). Such a large change in fault

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current may affect the relay operation and thus the reliability of the system. Therefore, it is necessary to review and update the current relay settings after the KPP 3 & 4 retirements.

**Table 5 – 5% or larger change in Short Circuit Current due to the retirement of KPP 3 & 4**

*(Case1 is without KPP 3 & 4 and Case1a is with KPP 3 & 4)*

| Bus  | Name     | KV    | 3PH | Case1a   |          | Case1 (delta %) |       |       |
|------|----------|-------|-----|----------|----------|-----------------|-------|-------|
|      |          |       |     | MVA      | Amp      | NoCont          | Cont1 | Cont2 |
| 4    | PUUNENE  | 69.00 | 3PH | 574.73   | 4,809.00 | 12.58           | 12.56 | 22.84 |
| 25   | WAILEA   | 69.00 | 3PH | 520.99   | 4,359.30 | 4.54            | 3.27  | 5.09  |
| 39   | MAALAEA  | 69.00 | 3PH | 1,118.21 | 9,356.50 | 8.05            | 4.76  | 4.94  |
| 83   | KEALAHOU | 69.00 | 3PH | 546.78   | 4,575.10 | 5.76            | 4.54  | 8.44  |
| 401  | PUUNENEA | 69.00 | 3PH | 555.94   | 4,651.80 | 12.53           | 12.64 | 22.83 |
| 402  | PUUNENEB | 69.00 | 3PH | 587.46   | 4,915.50 | 11.97           | 11.71 | 22.25 |
| 602  | KANAHA69 | 69.00 | 3PH | 546.07   | 4,569.20 | 12.53           | 12.72 | 22.84 |
| 613  | KULA 69  | 69.00 | 3PH | 477.68   | 3,996.90 | 5.89            | 5.08  | 10.26 |
| 617  | PUKLN69  | 69.00 | 3PH | 430.39   | 3,601.30 | 7.51            | 7.39  | 15.61 |
| 636  | WAIINU   | 69.00 | 3PH | 542.07   | 4,535.70 | 7.17            | 17.70 | 5.89  |
| 655  | KULA AG  | 69.00 | 3PH | 545.31   | 4,562.90 | 5.59            | 4.32  | 7.84  |
| 1203 | AWFTAP69 | 69.00 | 3PH | 514.11   | 4,301.80 | 4.56            | 3.34  | 5.33  |
| 3    | WLUKU23  | 23.00 | 3PH | 252.35   | 6,334.50 | 24.99           | 34.46 | 35.83 |
| 5    | MAUI PIN | 23.00 | 3PH | 261.97   | 6,576.00 | 26.27           | 35.01 | 36.75 |
| 7    | WAI WELL | 23.00 | 3PH | 148.96   | 3,739.20 | 16.74           | 27.39 | 25.57 |
| 8    | KAHU SUB | 23.00 | 3PH | 273.78   | 6,872.50 | 27.04           | 35.60 | 37.57 |
| 18   | WLUKU HT | 23.00 | 3PH | 146.35   | 3,673.80 | 16.64           | 27.53 | 25.52 |
| 22   | WS PUMP  | 23.00 | 3PH | 136.64   | 3,429.90 | 15.84           | 26.98 | 24.53 |
| 30   | MOKUHAU  | 23.00 | 3PH | 161.99   | 4,066.40 | 17.92           | 28.51 | 27.12 |
| 33   | WS MILL  | 23.00 | 3PH | 236.00   | 5,924.10 | 23.78           | 33.46 | 34.39 |
| 40   | ONEHEE   | 23.00 | 3PH | 203.03   | 5,096.50 | 21.70           | 31.54 | 31.84 |
| 43   | WAIEHU   | 23.00 | 3PH | 111.30   | 2,793.80 | 13.27           | 24.19 | 20.89 |
| 48   | MAUIBLOC | 23.00 | 3PH | 79.03    | 1,983.90 | 10.35           | 22.62 | 17.25 |
| 64   | PUUNENE  | 23.00 | 3PH | 118.20   | 2,967.10 | 16.07           | 25.73 | 25.07 |
| 73   | KUAU     | 23.00 | 3PH | 89.29    | 2,241.50 | 12.52           | 21.54 | 20.06 |
| 75   | NEWHDWD  | 23.00 | 3PH | 94.25    | 2,365.90 | 13.45           | 23.26 | 21.86 |
| 77   | WAIKAPU  | 23.00 | 3PH | 78.16    | 1,961.90 | 10.26           | 22.53 | 17.12 |
| 82   | AMERON   | 23.00 | 3PH | 94.45    | 2,370.90 | 13.32           | 23.67 | 22.15 |
| 88   | AMERBLDG | 23.00 | 3PH | 97.92    | 2,458.10 | 13.71           | 24.06 | 22.65 |
| 92   | SPRECK   | 23.00 | 3PH | 127.80   | 3,207.90 | 16.66           | 25.52 | 25.27 |
| 93   | PAIAMKA  | 23.00 | 3PH | 99.49    | 2,497.40 | 13.67           | 22.67 | 21.56 |
| 200  | KAHULUI  | 23.00 | 3PH | 381.12   | 9,567.00 | 41.71           | 48.83 | 50.95 |
| 202  | KANAHA23 | 23.00 | 3PH | 384.54   | 9,652.80 | 36.78           | 43.90 | 46.55 |
| 217  | PUKLN23  | 23.00 | 3PH | 94.94    | 2,383.20 | 1.66            | 4.98  | 6.04  |
| 236  | WAIINU23 | 23.00 | 3PH | 272.88   | 6,849.80 | 23.36           | 32.88 | 35.16 |
| 671  | JCT B    | 23.00 | 3PH | 119.30   | 2,994.60 | 14.32           | 25.85 | 22.60 |
| 806  | TOHANA   | 23.00 | 3PH | 190.06   | 4,771.00 | 22.64           | 31.21 | 32.26 |
| 819  | PUUN JCT | 23.00 | 3PH | 207.47   | 5,207.90 | 24.53           | 33.47 | 34.61 |
| 826  |          | 23.00 | 3PH | 171.27   | 4,299.30 | 21.30           | 30.48 | 31.05 |



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| Bus  | Name     | KV    | 3PH | Case1a |          | Case1 (delta %) |       |       |
|------|----------|-------|-----|--------|----------|-----------------|-------|-------|
|      |          |       |     | MVA    | Amp      | NoCont          | Cont1 | Cont2 |
| 827  | CONC TAP | 23.00 | 3PH | 100.86 | 2,531.90 | 14.04           | 24.39 | 23.07 |
| 838  |          | 23.00 | 3PH | 80.26  | 2,014.80 | 10.48           | 22.75 | 17.44 |
| 840  | TO-ONEE  | 23.00 | 3PH | 266.07 | 6,678.90 | 26.15           | 34.91 | 36.71 |
| 848  | JCT C    | 23.00 | 3PH | 69.07  | 1,733.90 | 10.49           | 20.46 | 18.10 |
| 858  | PUUOHALA | 23.00 | 3PH | 207.59 | 5,211.00 | 21.58           | 31.59 | 31.71 |
| 892  | BALWNPK  | 23.00 | 3PH | 110.35 | 2,770.10 | 14.83           | 23.75 | 23.00 |
| 893  | PAIAMKA  | 23.00 | 3PH | 101.26 | 2,541.90 | 13.84           | 22.80 | 21.75 |
| 4002 | PUUN 23  | 23.00 | 3PH | 304.23 | 7,637.00 | 25.40           | 32.33 | 35.77 |

### Conclusions

The study results shows that the retirement of KPP 3 & 4 leads to reduced fault current on the 69 KV and 23 KV transmission systems. The change in fault current could be as much as 5000 amperes. Such a large change in fault current may affect the relay operation and the reliable operation of the transmission system. Therefore, it is necessary to re-evaluate the effect of reduced fault current on the Maui system.

The study also shows that the non-transmission alternatives evaluated to address the impact of the retirement of KPP leads to increased fault current on the 69 KV transmission system. The increase in fault current could be as much as 5000 amperes.

# Appendix A

**Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

**Table A.1 – Change in 3-phase fault current with respect to Case 0**

**Notes:**

- Delta % is defined as percent change with respect to Case 0
- Green highlighted cells indicate that the fault current has decreased by 5% with respect to Case 0.
- Red highlighted cells indicate that the fault current has increased by 5% with respect to Case 0.
- Case 0 – 5 are defined in table below
- Contingencies are defined as below.

**Table A.1 – Change in short circuit current with respect to Case 0**

| Bus | Name      | KV    | 3P H | Case0    |          |       | Case1 (Delta %) |         |         | Case2 (Delta %) |       |       | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
|-----|-----------|-------|------|----------|----------|-------|-----------------|---------|---------|-----------------|-------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--|--|--|--|--|
|     |           |       |      | MVA      | Amp      | Col 6 | NoCont          | Cont t1 | Cont t2 | Col 7           | Col 8 | Col 9 | Col 10          | Col 11 | Col 12 | Col 13          | Col 14 | Col 15 | Col 16          | Col 17 | Col 18 | NoCont | Cont 1 | Cont 2 | Col 19 | Col 20 | Col 21 | Col 22 | NoCont | Cont 1 | Cont 2 | Col 23 | Col 24 | Col 25 |  |  |  |  |  |
| 4   | PUUNEN E  | 69.00 | 3P H | 641.23   | 5,365.40 | Col 6 | 21.6            | 22.00   | 42.69   | 7.15            | 23.67 | 14.06 | 12.36           | 12.54  | 25.76  | 9.75            | 9.52   | 17.45  | 6.94            | 7.46   | 20.89  |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 23  | PUUKOL B  | 69.00 | 3P H | 373.99   | 3,129.30 | Col 6 | 0.72            | 0.35    | 1.52    | 0.79            | 0.17  | 2.10  | 0.18            | 0.32   | 0.90   | 1.62            | 2.36   | 1.20   | (2.90)          | (2.57) | (3.83) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 25  | WAILEA    | 69.00 | 3P H | 525.46   | 4,396.80 | Col 6 | 5.35            | 4.42    | 6.57    | 5.04            | 5.07  | 5.15  | 3.63            | 4.00   | 4.13   | 4.91            | 5.88   | 5.14   | (0.37)          | (0.29) | (0.28) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 29  | NAPILI A  | 69.00 | 3P H | 313.68   | 2,624.70 | Col 6 | 0.61            | 0.28    | 1.27    | 0.67            | 0.15  | 0.85  | 0.15            | 0.28   | 0.75   | 1.36            | 1.98   | 1.01   | (2.41)          | (2.14) | (3.19) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 34  | LAHAINA   | 69.00 | 3P H | 563.77   | 4,717.20 | Col 6 | 0.99            | 0.63    | 2.43    | 1.09            | 0.14  | 1.66  | 0.20            | 0.42   | 1.43   | 2.37            | 3.46   | 1.72   | (4.52)          | (4.00) | (5.93) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 35  | KIHEI     | 69.00 | 3P H | 611.07   | 5,113.10 | Col 6 | 7.12            | 5.76    | 6.10    | 7.10            | 6.54  | 6.14  | 5.67            | 5.96   | 5.01   | 7.42            | 8.49   | 7.07   | 1.02            | 1.64   | 0.55   |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 39  | MAALAE A  | 69.00 | 3P H | 1,070.73 | 8,959.20 | Col 6 | 3.97            | 0.81    | 2.67    | 4.19            | 2.32  | 5.15  | 2.56            | 2.97   | 0.59   | 6.62            | 8.59   | 5.32   | (6.88)          | (5.76) | (9.62) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 50  | MAHINA A  | 69.00 | 3P H | 352.17   | 2,946.80 | Col 6 | 0.65            | 0.34    | 5.15    | 0.72            | 0.14  | 0.98  | 0.15            | 0.29   | 0.86   | 1.51            | 2.21   | 1.11   | (2.73)          | (2.43) | (3.61) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 83  | KEALAHOU  | 69.00 | 3P H | 548.56   | 4,590.00 | Col 6 | 6.07            | 5.18    | 11.51   | 4.71            | 6.00  | 5.21  | 3.20            | 3.55   | 5.67   | 4.09            | 4.97   | 5.12   | (1.26)          | (0.58) | (1.25) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 84  | LAHALUN A | 69.00 | 3P H | 549.06   | 4,594.20 | Col 6 | 1.05            | 0.53    | 8.18    | 1.15            | 0.22  | 1.54  | 0.29            | 0.50   | 1.31   | 2.40            | 3.48   | 1.77   | (4.31)          | (3.80) | (5.69) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |
| 97  | KWP       | 69.00 | 3P H | 639.70   | 5,352.70 | Col 6 | 2.12            | 0.33    | 1.64    | 2.24            | 1.20  | 0.78  | 1.22            | 1.46   | 0.58   | 3.61            | 4.81   | 2.89   | (4.06)          | (3.49) | (5.62) |        |        |        |        |        |        |        |        |        |        |        |        |        |  |  |  |  |  |

Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name       | KV | 3P H | Case0  |          |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |
|-----|------------|----|------|--------|----------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|
|     |            |    |      | MVA    | Amp      | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |
| 206 | KWP11      | 69 | 3P H | 623.76 | 5,219.20 | Col 6 | 7               | 0.7    | 2.6    | 4.6             | 0.6    | 1.7    | 3.8             | 1.4    | 3.5    | 0.81            | 2.06   | 0.05   | 7.2             | 6.6    | 8.8    |
| 223 | PUUKOLA    | 69 | 3P H | 417.02 | 3,489.40 | Col 6 | 7               | 0.71   | 0.4    | 1.7             | 0.79   | 0.10   | 1.2             | 0.28   | 0.8    | 1.72            | 2.54   | 1.25   | 3.3             | 2.9    | 4.3    |
| 250 | MAHINA B   | 69 | 3P H | 347.19 | 2,905.10 | Col 6 | 7               | 0.60   | 0.3    | 1.4             | 0.66   | 0.09   | 1.0             | 0.23   | 0.9    | 1.43            | 2.12   | 1.04   | 2.7             | 2.4    | 3.6    |
| 401 | PUUNEN EA  | 69 | 3P H | 612.53 | 5,125.30 | Col 6 | 7               | 20.6   | 21.41  | 2.12            | 23.4   | 3      | 22.62           | 3      | 0      | 8.37            | 8.03   | 16.1   | 5.79            | 6.27   | 19.5   |
| 402 | PUUNEN EB  | 69 | 3P H | 646.62 | 5,410.50 | Col 6 | 7               | 20.0   | 20.17  | 7.60            | 20.7   | 9      | 11.24           | 4      | 8      | 9.15            | 9.10   | 16.8   | 5.87            | 6.45   | 20.2   |
| 602 | KANAHA 69  | 69 | 3P H | 597.10 | 4,996.20 | Col 6 | 7               | 20.0   | 20.53  | 1.3             | 22.7   | 5      | 27.10           | 4      | 9      | 7.53            | 7.13   | 15.2   | 5.08            | 5.53   | 18.6   |
| 613 | KULA 69    | 69 | 3P H | 483.51 | 4,045.70 | Col 6 | 7               | 7.03   | 6.5    | 4.36            | 7.33   | 4      | 3.9             | 3.89   | 7.91   | 3.84            | 4.47   | 5.81   | 0.3             | 0.26   | 3.94   |
| 617 | PUK169     | 69 | 3P H | 446.42 | 3,735.40 | Col 6 | 7               | 10.8   | 11.27  | 2.92            | 12.0   | 5      | 4.0             | 5.65   | 14.4   | 4.41            | 4.54   | 9.11   | 1.58            | 2.19   | 10.4   |
| 623 | PUUKA 69   | 69 | 3P H | 417.02 | 3,489.40 | Col 6 | 7               | 0.71   | 0.4    | 0.79            | 0.10   | 1.2    | 0.8             | 0.28   | 0.8    | 1.72            | 2.54   | 1.25   | 3.3             | 2.9    | 4.3    |
| 629 | NAP11B     | 69 | 3P H | 305.60 | 2,559.60 | Col 6 | 7               | 0.54   | 0.3    | 0.61            | 0.09   | 0.7    | 0.8             | 0.22   | 0.7    | 1.28            | 1.88   | 0.93   | 2.3             | 2.1    | 3.1    |
| 636 | WAI10U     | 69 | 3P H | 529.15 | 4,427.60 | Col 6 | 7               | 4.90   | 16.58  | 18.33           | 367.82 | 5      | 8.2             | 0.28   | 0.8    | 0.63            | 8.0    | 9      | 4.5             | 5.3    | 4.8    |
| 650 | MAHINA B   | 69 | 3P H | 347.19 | 2,905.10 | Col 6 | 7               | 0.60   | 0.3    | 0.66            | 0.09   | 1.0    | 1.0             | 0.23   | 0.9    | 1.43            | 2.12   | 1.04   | 2.7             | 2.4    | 3.6    |
| 655 | KULA AG    | 69 | 3P H | 545.65 | 4,565.60 | Col 6 | 7               | 5.64   | 4.7    | 4.53            | 5.50   | 3      | 5.0             | 3.32   | 5.00   | 3.97            | 4.87   | 4.79   | 1.4             | 0.8    | 0.61   |
| 823 | PUUKB 69   | 69 | 3P H | 400.00 | 3,347.00 | Col 6 | 7               | 0.75   | 0.3    | 0.83            | 0.16   | 1.1    | 1.1             | 0.34   | 0.7    | 1.72            | 2.51   | 1.27   | 3.1             | 2.7    | 4.1    |
| 850 | MAHINA A   | 69 | 3P H | 365.90 | 3,061.60 | Col 6 | 7               | 0.68   | 0.3    | 0.75            | 0.14   | 2.0    | 2.0             | 0.30   | 0.9    | 1.56            | 2.29   | 1.15   | 2.8             | 2.5    | 3.7    |
| 120 | AWFTAP 3   | 69 | 3P H | 517.52 | 4,330.30 | Col 6 | 7               | 5.18   | 4.3    | 4.79            | 4.96   | 7      | 5.0             | 3.77   | 4.13   | 4.57            | 5.53   | 4.94   | 0.5             | 0.11   | 0.32   |
| 971 | KWP34      | 50 | 3P H | 333.59 | 5,582.50 | Col 6 | 7               | 0.76   | 0.0    | 0.81            | 0.32   | 8      | 0.5             | 0.55   | 0.7    | 1.52            | 2.09   | 1.21   | 1.8             | 1.5    | 2.5    |
| 206 | KWP134     | 50 | 3P H | 224.70 | 3,760.40 | Col 6 | 7               | 13.03  | 13.78  | 13.01           | 13.47  | 32     | 14.32           | 13.19  | 06     | 12.31           | 82     | 65     | 15.17           | 14.98  | 15.86  |
| 206 | KWP11_CL 1 | 50 | 3P H | 223.90 | 3,731.90 | Col 6 | 7               | 13.22  | 13.13  | 13.20           | 13.66  | 51     | 14.51           | 13.39  | 26     | 12.51           | 02     | 86     | 15.36           | 15.18  | 16.06  |
| 120 | AUWAHI 34  | 50 | 3P H | 199.13 | 3,332.30 | Col 6 | 7               | 0.32   | 1.2    | 0.03            | 1.12   | 5      | 1.6             | 0.84   | 1.99   | 0.14            | 1.25   | 2.00   | 1.2             | 0.1    | 1.05   |



**Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

| Bus | Name    | KV    | 3P H | Case0  |          |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |
|-----|---------|-------|------|--------|----------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|
|     |         |       |      | MVA    | Amp      | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |
| 42  | KEANAE  | 23.00 | 3P H | 16.6   | 416.90   | Col 6 | 3.31            | 7      | 3.4    | 5.4             | 1.22   | 2.69   | 1.97            | 2.76   | 2.37   | 1.46            | 0.97   | 2.00   | 2.35            | 2.54   | 2.47   |
| 43  | WAIHU   | 23.00 | 3P H | 107.62 | 2,701.50 | Col 6 | 10.3            | 1      | 20.08  | 19.54           | 11.9   | 4.95   | 3.3             | 3.7    | 0.3    | 9.1             | 16.33  | 9.8    | 7.3             | 11.93  | 7.1    |
| 48  | MAUBLO  | 23.00 | 3P H | 77.3   | 1,942.80 | Col 6 | 8.45            | 19     | 19.16  | 16.81           | 8.86   | 3.32   | 2.0             | 1.7    | 0.92   | 5.8             | 12.9   | 6.4    | 4.8             | 8.6    | 4.5    |
| 61  | HOSMER  | 23.00 | 3P H | 33.2   | 834.00   | Col 6 | 1.46            | 9      | 3.3    | 6.4             | 0.66   | 1.99   | 0.86            | 1.22   | 3.32   | 0.76            | 0.69   | 1.76   | 0.79            | 1.18   | 3.25   |
| 64  | PUUNEN  | 23.00 | 3P H | 113.75 | 2,855.30 | Col 6 | 12.7            | 21     | 21.24  | 24.15           | 11.9   | 12.7   | 3.8             | 3.8    | 0.28   | 11.1            | 16.79  | 11.1   | 8.8             | 12.36  | 8.1    |
| 73  | KUAU    | 23.00 | 3P H | 86.6   | 2,175.90 | Col 6 | 9.89            | 18     | 19.31  | 19.36           | 9.20   | 10.0   | 2.9             | 2.4    | 0.68   | 8.3             | 12.3   | 8.8    | 6.6             | 9.3    | 6.1    |
| 74  | HUELO   | 23.00 | 3P H | 21.8   | 547.90   | Col 6 | 4.62            | 4      | 4.8    | 7.1             | 1.83   | 3.94   | 2.83            | 3.81   | 3.24   | 2.12            | 1.39   | 2.77   | 3.39            | 3.62   | 3.50   |
| 75  | NEWHD   | 23.00 | 3P H | 91.4   | 2,295.70 | Col 6 | 10.8            | 19     | 19.21  | 21.4            | 9.59   | 10.5   | 2.9             | 2.6    | 0.90   | 8.6             | 13.45  | 9.1    | 6.8             | 9.8    | 6.3    |
| 77  | WAIKAPU | 23.00 | 3P H | 76.5   | 1,921.80 | Col 6 | 8.38            | 19     | 19.16  | 16.70           | 8.77   | 3.27   | 1.9             | 1.6    | 0.94   | 5.8             | 11.2   | 6.3    | 4.7             | 8.5    | 4.4    |
| 82  | AMERON  | 23.00 | 3P H | 91.8   | 2,305.40 | Col 6 | 10.8            | 20     | 20.55  | 21.85           | 9.19   | 10.2   | 2.7             | 2.3    | 1.21   | 8.0             | 12.99  | 8.6    | 6.4             | 9.5    | 5.8    |
| 88  | AMERBL  | 23.00 | 3P H | 95.1   | 2,387.10 | Col 6 | 11.1            | 20     | 22.22  | 22.31           | 9.52   | 10.5   | 2.8             | 2.5    | 1.14   | 8.4             | 13.3   | 8.9    | 6.7             | 9.8    | 6.1    |
| 92  | SPRECK  | 23.00 | 3P H | 122.42 | 3,073.00 | Col 6 | 13.0            | 21     | 23.11  | 23.94           | 12.8   | 13.4   | 4.3             | 4.4    | 0.3    | 12.1            | 18.43  | 13.1   | 9.7             | 13.28  | 9.1    |
| 93  | PAIAMKA | 23.00 | 3P H | 96.2   | 2,415.70 | Col 6 | 10.7            | 19     | 19.20  | 20.69           | 10.1   | 11.0   | 3.3             | 3.0    | 0.42   | 9.4             | 14.0   | 9.9    | 7.4             | 10.6   | 6.9    |
| 145 | SUMMIT  | 23.00 | 3P H | 29.0   | 727.80   | Col 6 | 1.64            | 3      | 3.2    | 5.6             | 0.81   | 2.04   | 1.02            | 1.39   | 3.10   | 0.88            | 0.80   | 1.75   | 0.96            | 1.38   | 3.04   |
| 200 | KAHULUI | 23.00 | 3P H | 323.69 | 8,125.30 | Col 6 | 31.3            | 37     | 37.81  | 44.81           | 33.9   | 31.9   | 18.75           | 21.12  | 12.05  | 63.88           | 78.73  | 64.73  | 43.78           | 52.66  | 41.60  |
| 202 | KANAHA  | 23.00 | 3P H | 338.88 | 8,506.60 | Col 6 | 28.2            | 34     | 34.39  | 42.81           | 29.9   | 28.4   | 13.73           | 16.20  | 6.2    | 45.82           | 58.78  | 45.09  | 33.11           | 40.90  | 29.25  |
| 213 | KULA 23 | 23.00 | 3P H | 46.7   | 1,172.00 | Col 6 | 1.87            | 5      | 4.7    | 9.4             | 1.03   | 2.71   | 1.24            | 1.58   | 4.77   | 1.16            | 1.12   | 2.53   | 1.07            | 1.47   | 4.62   |
| 217 | PUKLN23 | 23.00 | 3P H | 96.7   | 2,427.80 | Col 6 | 3.46            | 9      | 7.7    | 14.81           | 0.94   | 5.08   | 1.93            | 2.37   | 9.19   | 1.61            | 1.45   | 4.64   | 1.47            | 2.61   | 8.44   |
| 236 | WAINU2  | 23.00 | 3P H | 254.25 | 6,382.20 | Col 6 | 17.7            | 25     | 25.79  | 32.20           | 28.2   | 7.61   | 7.0             | 9.3    | 3.4    | 20.30           | 31.41  | 20.28  | 16.12           | 23.51  | 15.51  |
| 671 | JCT B   | 23.00 | 3P H | 115.19 | 2,891.50 | Col 6 | 11.2            | 21     | 21.62  | 27.27           | 12.8   | 5.25   | 3.4             | 4.0    | 0.3    | 9.7             | 17.6   | 10.54  | 7.8             | 12.79  | 7.5    |



Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name         | KV    | 3P H | Case0  |       |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |         |        |        |    |
|-----|--------------|-------|------|--------|-------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|---------|--------|--------|----|
|     |              |       |      | MVA    | Amp   | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont | Con t1 | Con t2 |    |
| 303 | ST-1 M15     | 13.80 | 3P H | 312.06 | 13,05 | Col 6 | 7               | 8      | 9      | 10              | 11     | 12     | 13              | 14     | 15     | 16              | 17     | 18     | 19              | 20     | 21     | 22      | 23     | 24     | 25 |
| 304 | CT-3 M17     | 13.80 | 3P H | 405.57 | 16,96 | Col 6 | 6               | 4      | 9      | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09    | 0.09   | 0.09   |    |
| 305 | CT-4 M19     | 13.80 | 3P H | 405.57 | 16,96 | Col 6 | 6               | 4      | 9      | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09            | 0.09   | 0.09   | 0.09    | 0.09   | 0.09   |    |
| 306 | ST-2 M18     | 13.80 | 3P H | 297.95 | 12,46 | Col 6 | 6               | 9      | 2      | 0.34            | 0.34   | 0.34   | 0.34            | 0.34   | 0.34   | 0.34            | 0.34   | 0.34   | 0.34            | 0.34   | 0.34   | 0.34    | 0.34   | 0.34   |    |
| 804 | HC&S TG4     | 13.80 | 3P H | 416.99 | 17,44 | Col 6 | 6               | 9      | 2      | 0.58            | 0.58   | 0.58   | 0.58            | 0.58   | 0.58   | 0.58            | 0.58   | 0.58   | 0.58            | 0.58   | 0.58   | 0.58    | 0.58   | 0.58   |    |
| 120 | BURIED_ TERT | 13.80 | 3P H | 126.96 | 5,311 | Col 6 | 5               | 3      | 7      | 0.02            | 0.02   | 0.02   | 0.02            | 0.02   | 0.02   | 0.02            | 0.02   | 0.02   | 0.02            | 0.02   | 0.02   | 0.02    | 0.02   | 0.02   |    |
| 13  | KULA 12      | 12.47 | 3P H | 77.44  | 3,585 | Col 6 | 5               | 5      | 5      | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15    | 0.15   | 0.15   |    |
| 98  | KAUHIKO A    | 12.47 | 3P H | 32.80  | 1,518 | Col 6 | 3               | 3      | 8      | 0.19            | 0.19   | 0.19   | 0.19            | 0.19   | 0.19   | 0.19            | 0.19   | 0.19   | 0.19            | 0.19   | 0.19   | 0.19    | 0.19   | 0.19   |    |
| 112 | MAKA 12      | 12.47 | 3P H | 35.56  | 1,646 | Col 6 | 4               | 4      | 31     | 0.37            | 0.37   | 0.37   | 0.37            | 0.37   | 0.37   | 0.37            | 0.37   | 0.37   | 0.37            | 0.37   | 0.37   | 0.37    | 0.37   | 0.37   |    |
| 123 | PUUKB 12     | 12.47 | 3P H | 78.28  | 3,624 | Col 6 | 10              | 8      | 3      | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15            | 0.15   | 0.15   | 0.15    | 0.15   | 0.15   |    |
| 125 | WALEA A      | 12.47 | 3P H | 93.37  | 4,321 | Col 6 | 7               | 2      | 2      | 1.07            | 1.07   | 1.07   | 1.07            | 1.07   | 1.07   | 1.07            | 1.07   | 1.07   | 1.07            | 1.07   | 1.07   | 1.07    | 1.07   | 1.07   |    |
| 129 | NAPILA 2     | 12.47 | 3P H | 72.43  | 3,353 | Col 6 | 9               | 9      | 1      | 0.13            | 0.13   | 0.13   | 0.13            | 0.13   | 0.13   | 0.13            | 0.13   | 0.13   | 0.13            | 0.13   | 0.13   | 0.13    | 0.13   | 0.13   |    |
| 134 | LAHAINA 1    | 12.47 | 3P H | 89.27  | 4,133 | Col 6 | 6               | 6      | 5      | 0.10            | 0.10   | 0.10   | 0.10            | 0.10   | 0.10   | 0.10            | 0.10   | 0.10   | 0.10            | 0.10   | 0.10   | 0.10    | 0.10   | 0.10   |    |
| 135 | KIHEI A      | 12.47 | 3P H | 84.63  | 3,918 | Col 6 | 3               | 6      | 2      | 1.14            | 1.14   | 1.14   | 1.14            | 1.14   | 1.14   | 1.14            | 1.14   | 1.14   | 1.14            | 1.14   | 1.14   | 1.14    | 1.14   | 1.14   |    |
| 136 | WAINU B      | 12.47 | 3P H | 88.57  | 4,100 | Col 6 | 7               | 5      | 9      | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27    | 0.27   | 0.27   |    |
| 139 | MAALA A      | 12.47 | 3P H | 91.98  | 4,258 | Col 6 | 8               | 2      | 2      | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27            | 0.27   | 0.27   | 0.27    | 0.27   | 0.27   |    |
| 150 | MAHINA 12    | 12.47 | 3P H | 77.80  | 3,601 | Col 6 | 9               | 9      | 4      | 0.04            | 0.04   | 0.04   | 0.04            | 0.04   | 0.04   | 0.04            | 0.04   | 0.04   | 0.04            | 0.04   | 0.04   | 0.04    | 0.04   | 0.04   |    |
| 155 | KULA AG      | 12.47 | 3P H | 45.01  | 2,084 | Col 6 | 1               | 9      | 1      | 0.87            | 0.87   | 0.87   | 0.87            | 0.87   | 0.87   | 0.87            | 0.87   | 0.87   | 0.87            | 0.87   | 0.87   | 0.87    | 0.87   | 0.87   |    |
| 175 | NEWHD WD     | 12.47 | 3P H | 40.21  | 1,861 | Col 6 | 1               | 13     | 07     | 5.81            | 5.81   | 5.81   | 5.81            | 5.81   | 5.81   | 5.81            | 5.81   | 5.81   | 5.81            | 5.81   | 5.81   | 5.81    | 5.81   | 5.81   |    |
| 177 | WAIKAP 2     | 12.47 | 3P H | 37.46  | 1,734 | Col 6 | 6               | 78     | 31     | 5.00            | 5.00   | 5.00   | 5.00            | 5.00   | 5.00   | 5.00            | 5.00   | 5.00   | 5.00            | 5.00   | 5.00   | 5.00    | 5.00   | 5.00   |    |



Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name      | KV    | 3P H | Case0 |          |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |       |
|-----|-----------|-------|------|-------|----------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-------|
|     |           |       |      | MVA   | Amp      | Col 6 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |       |
| 203 | KANAH A   | 12.47 | 3P H | 96.3  | 4,462.60 | Col 6 | 4.47            | 10.24  | 8.07   | 24.07           | 0.58   | 6.58   | 5.9             | 2.05   | 2.60   | 12.19           | 1.35   | 0.91   | 6.63            | 1.64   | 2.92   | 10.82 |
| 204 | KANAH B   | 12.47 | 3P H | 86.9  | 4,025.90 | Col 6 | 4.10            | 10.23  | 10.04  | 23.04           | 6.14   | 6.14   | 6.1             | 1.85   | 3.04   | 11.63           | 1.20   | 0.76   | 5.66            | 1.55   | 3.45   | 10.39 |
| 205 | KANAH C   | 12.47 | 3P H | 95.6  | 4,430.40 | Col 6 | 4.36            | 10.23  | 14.69  | 23.69           | 5.84   | 5.84   | 6.6             | 1.98   | 2.53   | 12.00           | 1.30   | 0.87   | 6.51            | 1.60   | 2.87   | 10.66 |
| 216 | HAIKU 2   | 12.47 | 3P H | 28.3  | 1,311.20 | Col 6 | 4.43            | 6.6    | 9.0    | 9.0             | 5.62   | 5.62   | 0.9             | 3.51   | 4.03   | 4.53            | 3.24   | 2.98   | 4.02            | 3.65   | 3.96   | 5.04  |
| 225 | WAILEA B  | 12.47 | 3P H | 91.9  | 4,255.00 | Col 6 | 1.02            | 1.3    | 2.8    | 3               | 1.15   | 1.15   | 0.9             | 0.67   | 0.97   | 1.45            | 0.84   | 1.11   | 1.30            | 0.07   | 0.42   | 0.93  |
| 234 | LAHAINA 2 | 12.47 | 3P H | 91.7  | 4,246.10 | Col 6 | 0.12            | 0.1    | 0.4    | 0.5             | 0.0    | 0.0    | 0.3             | 0.04   | 0.07   | 0.3             | 0.38   | 0.57   | 0.28            | 0.6    | 0.6    | 0.92  |
| 235 | KIHEI B   | 12.47 | 3P H | 86.0  | 3,981.80 | Col 6 | 1.18            | 1.2    | 1.6    | 6               | 1.21   | 1.21   | 1.0             | 0.94   | 1.13   | 1.27            | 1.16   | 1.38   | 1.36            | 0.32   | 0.56   | 0.74  |
| 325 | WAILEA C  | 12.47 | 3P H | 93.0  | 4,306.10 | Col 6 | 1.10            | 1.4    | 2.3    | 1               | 1.23   | 1.23   | 1.0             | 0.73   | 1.03   | 1.52            | 0.90   | 1.17   | 1.36            | 0.10   | 0.46   | 0.98  |
| 335 | KIHEI C   | 12.47 | 3P H | 83.8  | 3,881.30 | Col 6 | 1.18            | 1.3    | 1.6    | 7               | 1.21   | 1.21   | 1.0             | 0.94   | 1.12   | 1.28            | 1.15   | 1.37   | 1.36            | 0.33   | 0.57   | 0.75  |
| 336 | WAINU C   | 12.47 | 3P H | 88.6  | 4,101.90 | Col 6 | 1.03            | 26.32  | 3.4    | 3.4             | 89.87  | 89.87  | 0.4             | 0.02   | 15.96  | 0.15            | 0.0    | 10.97  | 0.1             | 0.4    | 12.44  | 0.14  |
| 405 | WILUKU C  | 12.47 | 3P H | 76.8  | 3,558.20 | Col 6 | 7.44            | 27.17  | 17     | 17              | 3.63   | 3.63   | 10              | 2.2    | 0.75   | 1.07            | 5.4    | 13.07  | 5.94            | 4.3    | 9.0    | 4.09  |
| 415 | WILUKU D  | 12.47 | 3P H | 63.8  | 2,956.70 | Col 6 | 6.39            | 26.16  | 16     | 16              | 2.90   | 2.90   | 9.3             | 1.8    | 1.45   | 1.43            | 4.2    | 11.4   | 4.7             | 3.4    | 7.7    | 3.17  |
| 425 | WAILEA D  | 12.47 | 3P H | 84.3  | 3,906.70 | Col 6 | 0.73            | 1.0    | 3.0    | 5               | 0.84   | 0.84   | 0.6             | 0.43   | 0.72   | 1.19            | 0.58   | 0.83   | 1.02            | 0.0    | 0.27   | 0.77  |
| 435 | KIHEI D   | 12.47 | 3P H | 89.6  | 4,149.20 | Col 6 | 1.21            | 1.3    | 1.6    | 7               | 1.23   | 1.23   | 1.0             | 0.96   | 1.15   | 1.29            | 1.19   | 1.42   | 1.39            | 0.32   | 0.56   | 0.73  |
| 443 | WAIEHUJ 2 | 12.47 | 3P H | 55.1  | 2,553.60 | Col 6 | 5.90            | 27.61  | 15     | 20              | 2.38   | 2.38   | 8.5             | 1.5    | 2.46   | 2.35            | 3.5    | 10.17  | 3.9             | 2.8    | 6.9    | 2.63  |
| 511 | MPINE     | 12.47 | 3P H | 59.8  | 2,769.80 | Col 6 | 7.20            | 26.18  | 18     | 18              | #N/A   | #N/A   | #N/A            | 0.8    | 1.94   | 3.43            | 3.1    | 9.3    | 3.5             | 2.4    | 6.8    | 2.03  |
| 534 | LAHAINA 5 | 12.47 | 3P H | 99.4  | 4,603.20 | Col 6 | 0.08            | 0.2    | 0.5    | 4               | 0.0    | 0.0    | 0.4             | 0.0    | 0.03   | 0.9             | 0.36   | 0.57   | 0.26            | 0.7    | 0.6    | 1.02  |
| 723 | PUUKA 12  | 12.47 | 3P H | 91.0  | 4,215.40 | Col 6 | 0.05            | 0.2    | 0.5    | 1               | 0.0    | 0.0    | 0.3             | 0.0    | 0.02   | 0.8             | 0.32   | 0.51   | 0.22            | 0.7    | 0.6    | 0.92  |
| 729 | NAPILB12  | 12.47 | 3P H | 74.3  | 3,443.80 | Col 6 | 0.11            | 0.1    | 0.3    | 5               | 0.0    | 0.0    | 0.2             | 0.05   | 0.08   | 0.7             | 0.32   | 0.48   | 0.24            | 0.5    | 0.4    | 0.72  |
| 750 | MAHINB 12 | 12.47 | 3P H | 79.1  | 3,664.20 | Col 6 | 0.09            | 0.1    | 0.4    | 0               | 0.11   | 0.11   | 0.2             | 0.02   | 0.06   | 0.2             | 0.32   | 0.48   | 0.23            | 0.5    | 0.5    | 0.72  |

Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name      | KV  | 3P H | Case0 |           |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |      |      |      |      |      |      |
|-----|-----------|-----|------|-------|-----------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|------|------|------|------|------|------|
|     |           |     |      | MVA   | Amp       | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |      |      |      |      |      |      |
| 803 | KAHULU 3  | 12  | 3P H | 62.0  | 2,871.2   | Col 6 | 7               | 6.14   | 26     | 17              | 27     | 26.9   | 4               | 76     | 1.8    | 2.07            | 2.90   | 1.13   | 0.96            | 4.33   | 3.8    | 8    | 3.4  | 6.3  | 5    | 7    |      |
| 817 | PUKUNA    | 12  | 3P H | 93.9  | 4,348.70  | Col 5 | 3               | 3.03   | 7.1    | 16              | 4.15   | 2      | 43              | 1.3    | 1.93   | 7.99            | 1.46   | 1.93   | 7.99            | 1.13   | 0.96   | 4.33 | 1.01 | 1.57 | 7.82 | 7.82 |      |
| 834 | LAHAINA 4 | 12  | 3P H | 92.0  | 4,261.60  | Col 5 | 5               | 0.08   | 0.1    | 0.4             | 0.0    | 7      | 6               | 0.0    | 0.04   | 0.6             | 0.00   | 0.04   | 0.6             | 0.34   | 0.54   | 0.25 | 0.7  | 0.6  | 0.9  | 4    |      |
| 917 | PUKUNA B  | 12  | 3P H | 87.2  | 4,040.00  | Col 5 | 6               | 2.88   | 7.0    | 15              | 4.01   | 5      | 5               | 1.2    | 1.85   | 7.87            | 1.39   | 1.85   | 7.87            | 1.06   | 0.88   | 4.23 | 1.00 | 1.55 | 7.17 | 7.17 |      |
| 101 | KGS-1     | 11  | 3P H | 84.6  | 4,250.50  | Col 5 | 1               | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | 254    | 269    | 256  | 96   | 107  | 102  | 102  | 51   |
| 102 | KGS-2     | 11  | 3P H | 72.4  | 3,635.30  | Col 5 | 30              | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | 317    | 333    | 318  | 109  | 120  | 115  | 115  | 26   |
| 103 | KGS-3     | 11  | 3P H | 79    | 5,963.50  | Col 5 | 50              | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | 128    | 142    | 132  | 108  | 122  | 115  | 115  | 99   |
| 104 | KGS-4     | 11  | 3P H | 270   | 13,590.74 | Col 5 | 74              | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | 5.7    | 3.9    | 1.0  | 12   | 15   | 12   | 12   | 62   |
| 164 | PUUNENE   | 7.2 | 3P H | 6.15  | 493.10    | Col 5 | 0               | 2.09   | 11     | 6.7             | 0.99   | 1      | 1               | 1.7    | 0.04   | 1.78            | 2.98   | 0.04   | 1.78            | 2.98   | 0.2    | 1.9  | 0.0  | 0.3  | 1.1  | 0.10 | 0.10 |
| 108 | MGS-1011  | 6.9 | 3P H | 386   | 32,360.77 | Col 5 | 0               | 0.07   | 1.7    | 2.3             | 0.6    | 7      | 3               | 1.2    | 0.24   | 0.9             | 5      | 0.09   | 0.9             | 5      | 0.61   | 1.09 | 0.33 | 1.0  | 1.2  | 1.9  | 4    |
| 109 | MGS-1213  | 6.9 | 3P H | 309   | 25,850.02 | Col 5 | 0               | 24     | 27     | 27              | 25     | 85     | 67              | 26     | 24     | 25              | 26     | 24     | 25              | 26     | 26     | 27   | 26   | 26   | 27   | 27   | 59   |
| 192 | SPRECKA   | 4.6 | 3P H | 37.0  | 4,649.40  | Col 5 | 4               | 5.08   | 23     | 17              | 5.4    | 6      | 6               | 5.4    | 3.68   | 2.23            | 4.09   | 1.0    | 2.23            | 4.09   | 2.4    | 5.8  | 2.5  | 1.9  | 4.0  | 1.5  | 2    |
| 45  | HALEKAL A | 4.1 | 3P H | 7.08  | 982.40    | Col 5 | 6               | 2.06   | 2.2    | 1.7             | 2.01   | 2      | 2               | 1.3    | 1.26   | 1.96            | 2.05   | 1.50   | 1.96            | 2.05   | 1.26   | 1.15 | 1.66 | 1.58 | 2.07 | 2.15 |      |
| 105 | MGS-123   | 4.1 | 3P H | 90.2  | 12,520.30 | Col 5 | 3               | 0.28   | 0.0    | 0.2             | 0.14   | 5      | 5               | 0.1    | 0.30   | 0.23            | 0.6    | 0.19   | 0.23            | 0.6    | 0.53   | 0.72 | 0.44 | 0.5  | 0.4  | 0.7  | 3    |
| 106 | MGS-458   | 4.1 | 3P H | 267   | 37,050.00 | Col 5 | 6               | 0.1    | 2.1    | 2.5             | 0.9    | 3      | 1               | 1.3    | 0.00   | 0.9             | 3      | 4.1    | 4.6             | 4.3    | 4.7    | 4.8  | 4.1  | 4.8  | 4.1  | 4.8  | 7    |
| 107 | MGS-679   | 4.1 | 3P H | 193   | 26,880.71 | Col 5 | 6               | 36     | 38     | 38              | 37     | 88     | 70              | 37     | 36     | 37              | 38     | 36     | 37              | 38     | 20.4   | 20.6 | 20.2 | 37   | 37   | 38   | 30   |
| 110 | MGS-X1X2  | 4.1 | 3P H | 91.9  | 12,760.90 | Col 5 | 9               | 0.29   | 0.0    | 0.2             | 0.14   | 5      | 5               | 0.1    | 0.31   | 0.14            | 0.6    | 0.20   | 0.23            | 0.6    | 0.55   | 0.74 | 0.45 | 0.5  | 0.4  | 0.7  | 4    |
| 173 | KUAU A    | 4.1 | 3P H | 12.4  | 1,730.70  | Col 5 | 7               | 4.02   | 22     | 14              | 1.79   | 3      | 3               | 2.5    | 0.73   | 1.79            | 5.43   | 1.20   | 4.10            | 5.43   | 0.63   | 0.70 | 0.70 | 0.59 | 1.6  | 1.03 |      |
| 403 | WILUKA A  | 4.1 | 3P H | 27.4  | 3,812.00  | Col 5 | 7               | 3.71   | 19     | 9.1             | 0.82   | 6      | 6               | 5.3    | 3.44   | 0.82            | 1.89   | 0.6    | 2.95            | 1.89   | 1.8    | 4.8  | 2.0  | 1.6  | 3.2  | 1.3  |      |
| 404 | WILUKA B  | 4.1 | 3P H | 27.5  | 3,819.20  | Col 5 | 2               | 3.61   | 19     | 9.8             | 0.76   | 5      | 5               | 5.2    | 3.36   | 0.76            | 1.86   | 0.6    | 3.88            | 1.86   | 1.8    | 5.3  | 2.0  | 1.6  | 3.7  | 1.3  |      |

Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name            | KV  | 3P H | Case0 |        |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |      |      |     |    |
|-----|-----------------|-----|------|-------|--------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|------|------|-----|----|
|     |                 |     |      | MVA   | Amp    | Col 6 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |      |      |     |    |
| 407 | WAI WELL        | 4.1 | 3P H | 26.3  | 3,655. | 3.66  | 7               | 8      | 9      | 10              | 2.67   | 0.76   | 5.2             | 0.4    | 4.21   | 2.68            | 1.6    | 19     | 20              | 21     | 1.4    | 3.6  | 1.1  | 9   |    |
| 418 | WLUKU HT        | 4.1 | 3P H | 47.6  | 6,607. | 5.35  | 7               | 8      | 9      | 10              | 5.08   | 1.37   | 7.7             | 1.2    | 2.28   | 2.62            | 2.8    | 19     | 20              | 21     | 2.3    | 6.6  | 2.0  | 9   |    |
| 431 | KAMOLE 4        | 4.1 | 3P H | 13.6  | 1,887. | 4.84  | 7               | 8      | 9      | 10              | 2.72   | 5.45   | 1.8             | 3.85   | 4.51   | 4.25            | 3.51   | 19     | 20              | 21     | 4.07   | 4.82 | 4.73 | 7   |    |
| 436 | WAINU A         | 4.1 | 3P H | 24.1  | 3,353. | 3.00  | 6               | 7      | 8      | 9               | 3.13   | 1.5    | 5.5             | 0.3    | 4.26   | 2.58            | 1.1    | 19     | 20              | 21     | 1.2    | 3.2  | 0.8  | 7   |    |
| 440 | ONEHEE 4        | 4.1 | 3P H | 24.2  | 3,362. | 3.49  | 16              | 17     | 18     | 19              | 12.7   | 14.9   | 14.             | 0.4    | 4.13   | 3.53            | 0.8    | 19     | 20              | 21     | 0.7    | 3.2  | 0.3  | 4   |    |
| 493 | PAIAMKA 1       | 4.1 | 3P H | 33.8  | 4,703. | 6.02  | 23              | 24     | 25     | 26              | 3.92   | 4.94   | 5.6             | 0.42   | 3.01   | 5.43            | 0.7    | 19     | 20              | 21     | 0.3    | 3.0  | 0.10 | 6   |    |
| 844 | KAHUL 4         | 4.1 | 3P H | 38.2  | 5,301. | 5.33  | 63              | 64     | 65     | 66              | 14.9   | 14.8   | 16.             | 0.2    | 2.88   | 3.85            | 1.3    | 19     | 20              | 21     | 1.0    | 4.6  | 0.6  | 4   |    |
| 845 | KAHUL 5         | 4.1 | 3P H | 38.2  | 5,305. | 5.28  | 50              | 51     | 52     | 53              | 14.9   | 14.8   | 16.             | 0.2    | 3.46   | 4.43            | 1.3    | 19     | 20              | 21     | 1.0    | 4.6  | 0.6  | 4   |    |
| 846 | KAHUL 6         | 4.1 | 3P H | 38.2  | 5,301. | 4.71  | 58              | 59     | 60     | 61              | 14.9   | 14.9   | 16.             | 0.8    | 2.88   | 3.85            | 1.3    | 19     | 20              | 21     | 1.0    | 4.6  | 0.6  | 5   |    |
| 141 | HANA 1          | 2.4 | 3P H | 7.29  | 1,754. | 1.08  | 3               | 4      | 5      | 6               | 0.34   | 0.57   | 0.2             | 0.60   | 1.08   | 2.21            | 0.48   | 19     | 20              | 21     | 0.63   | 0.76 | 1.32 | 7   |    |
| 142 | KEANAE          | 2.4 | 3P H | 4.96  | 1,193. | 0.54  | 6               | 7      | 8      | 9               | 0.22   | 0.06   | 0.1             | 0.32   | 0.73   | 1.91            | 0.33   | 19     | 20              | 21     | 0.23   | 0.34 | 0.90 | 7   |    |
| 161 | HOSMER          | 2.4 | 3P H | 5.16  | 1,241. | 0.66  | 6               | 7      | 8      | 9               | 0.0    | 0.49   | 0.0             | 0.23   | 0.61   | 0.44            | 0.07   | 19     | 20              | 21     | 0.40   | 0.80 | 0.64 | 7   |    |
| 174 | HUELO 1         | 2.4 | 3P H | 2.84  | 684.0  | 0.01  | 1               | 2      | 3      | 4               | 0.0    | 0.4    | -               | 0.0    | 0.31   | 0.37            | 0.07   | 19     | 20              | 21     | 0.1    | 0.1  | 0.1  | 5   |    |
| 209 | KAILUA A        | 2.4 | 3P H | 2.58  | 620.4  | 0.0   | 5               | 6      | 7      | 8               | 0.0    | 0.4    | 0.0             | 0.0    | 0.29   | 0.34            | 0.06   | 19     | 20              | 21     | 0.2    | 0.1  | 0.1  | 8   |    |
| 241 | HANA 2          | 2.4 | 3P H | 8.78  | 2,112. | 1.36  | 2               | 3      | 4      | 5               | 0.36   | 0.84   | 0.2             | 0.72   | 1.26   | 2.35            | 0.54   | 19     | 20              | 21     | 0.83   | 0.97 | 1.54 | 7   |    |
| 422 | WSCO PMP        | 2.4 | 3P H | 48.7  | 11,72  | 5.75  | 15              | 16     | 17     | 18              | 6.18   | 2.25   | 8.2             | 1.3    | 0.4    | 1.27            | 3.8    | 19     | 20              | 21     | 3.2    | 5.7  | 2.9  | 8   |    |
| 430 | MOKU PMP        | 2.4 | 3P H | 26.2  | 6,319. | 3.66  | 13              | 14     | 15     | 16              | 3.29   | 0.75   | 5.2             | 0.4    | 1.13   | 2.03            | 1.6    | 19     | 20              | 21     | 1.5    | 3.0  | 1.2  | 0   |    |
| 920 | AUWAHI 31_SIEM1 | 0.6 | 3P H | 84.8  | 70,97  | 2.4   | 0.2             | 0.3    | 0.4    | 0.5             | 2.6    | 0.6    | 0.5             | 2.7    | 0.8    | 1.10            | 2.7    | 19     | 20              | 21     | 2.9    | 1.0  | 0.88 | 7   |    |
| 920 | AUWAHI 32_SIEM2 | 0.6 | 3P H | 84.4  | 70,68  | 2.4   | 0.3             | 0.4    | 0.5    | 0.6             | 2.6    | 0.6    | 0.5             | 2.7    | 0.8    | 1.09            | 2.7    | 19     | 20              | 21     | 3.0    | 1.0  | 0.87 | 9   |    |
| 920 | KWPHI_G EN1     | 0.6 | 3P H | 146.  | 122.9  | 23.   | 23.             | 24.    | 25.    | 26.             | 23.    | 23.    | 24.             | 23.    | 23.    | 24.             | 23.    | 22.    | 19              | 20     | 21     | 24.  | 24.  | 25. | 15 |

**Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

| Bus Col | Name Col 2 | KV Col 3 | 3P H Col 4 | Case0     |            |              | Case1 (Delta %) |              |        | Case2 (Delta %) |               |        | Case3 (Delta %) |                |               | Case4 (Delta %) |        |                | Case5 (Delta %) |        |                |               |
|---------|------------|----------|------------|-----------|------------|--------------|-----------------|--------------|--------|-----------------|---------------|--------|-----------------|----------------|---------------|-----------------|--------|----------------|-----------------|--------|----------------|---------------|
|         |            |          |            | MVA Col 5 | Amp Col 6  | Con t1 Col 7 | NoC ont Col 8   | Con t2 Col 9 | Col 10 | NoC ont Col 11  | Con t1 Col 12 | Col 13 | Col 14          | NoC ont Col 15 | Con t1 Col 16 | Col 17          | Col 18 | NoC ont Col 19 | Con t1 Col 20   | Col 21 | NoC ont Col 22 | Con t1 Col 23 |
| 90971   | KWPI_1     | 0.58     | 3P H       | 240.25    | 241.235.90 | 0.50         | 0.50            | 0.52         | 0.53   | 0.53            | 0.53          | 0.29   | 0.37            | 0.2            | 0.98          | 1.34            | 0.79   | 1.1            | 0.9             | 1.1    | 0.9            | 1.5           |
| 44      | DET 03     | 0.48     | 3P H       | 15.93     | 19.163.20  | 1.72         | 2.51            | 3.2          | 0.93   | 1.85            | 0.9           | 1.17   | 1.58            | 2.33           | 0.98          | 0.88            | 1.56   | 1.20           | 1.65            | 2.39   |                |               |
| 127     | CONCRET E  | 0.48     | 3P H       | 23.01     | 27.680.60  | 3.87         | 12.95           | 3            | 2.06   | 3.13            | 3.8           | 0.5    | 0.88            | 2.49           | 1.8           | 4.1             | 1.8    | 1.6            | 2.8             | 1.2    |                |               |
| 148     | MAUBLO C   | 0.48     | 3P H       | 10.72     | 12.888.90  | 2.53         | 13.53           | 0            | 1.56   | 0               | 3.4           | 0.06   | 2.11            | 2.56           | 0.3           | 2.5             | 0.5    | 0.4            | 1.4             | 0.1    |                |               |
| 182     | AMERON     | 0.48     | 3P H       | 26.63     | 32.029.00  | 4.34         | 13.42           | 10.64        | 2.59   | 3.68            | 4.4           | 0.7    | 0.65            | 2.38           | 2.2           | 4.7             | 2.3    | 1.9            | 3.2             | 1.5    |                |               |
| 188     | AMERBL DG  | 0.48     | 3P H       | 3.66      | 4.401.50   | 1.83         | 11.10           | 4            | 0.4    | 0.66            | 1.3           | 0.12   | 1.90            | 3.05           | 0.03          | 1.6             | 0.18   | 0.1            | 0.8             | 0.29   |                |               |
| 501     | AUX K1     | 0.48     | 3P H       | 13.90     | 16.715.70  | #N/          | #N/             | #N/          | #N/    | #N/             | #N/           | #N/    | #N/             | #N/            | 12.60         | 15.77           | 13.31  | 8.6            | 12.34           | 10.98  |                |               |
| 502     | AUX K2     | 0.48     | 3P H       | 10.40     | 12.511.40  | #N/          | #N/             | #N/          | #N/    | #N/             | #N/           | #N/    | #N/             | #N/            | 11.67         | 15.03           | 12.56  | 8.6            | 12.24           | 10.94  |                |               |
| 503     | AUX K3     | 0.48     | 3P H       | 10.76     | 12.939.80  | #N/          | #N/             | #N/          | #N/    | #N/             | #N/           | 5.0    | 5.2             | 4.0            | 5.0           | 8.2             | 6.1    | 5.7            | 9.6             | 8.3    |                |               |
| 504     | AUX K4     | 0.48     | 3P H       | 11.88     | 14.287.90  | #N/          | #N/             | #N/          | #N/    | #N/             | #N/           | 0.1    | 3.42            | 3.84           | 0.39          | 0.50            | 1.76   | 0.8            | 1.2             | 0.7    |                |               |
| 2062    | KWPII-BESS | 0.48     | 3P H       | 139.62    | 167.939.00 | 8.4          | 8.8             | 9.3          | 8.4    | 8.7             | 9.2           | 8.5    | 8.5             | 9.0            | 8.0           | 7.7             | 8.2    | 9.6            | 9.5             | 10.10  |                |               |
| 12033   | XP_BESS    | 0.48     | 3P H       | 101.47    | 122.047.80 | 0.2          | 0.9             | 2.4          | 0.5    | 0.63            | 1.0           | 0.6    | 0.43            | 1.64           | 0.4           | 0.52            | 1.45   | 1.1            | 0.0             | 1.23   |                |               |

# Kahului Power Plant Retirement: Transmission System Steady State Analysis

Prepared for  
Maui Electric Company, Ltd.

Prepared by  
Hawaiian Electric Company, Inc  
System Planning Department  
Transmission Planning Division

June 12, 2014


Reference # TPD2014-23

## KPP Retirement Steady State Analysis

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## Kahului Power Plant Retirement: Transmission System Steady State Analysis

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## KPP Retirement Steady State Analysis

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## Introduction

Kahului Power Plant (KPP) is scheduled to be decommissioned in 2019. The Maui transmission system consists of a 23kV system and a 69kV system. KPP serves majority of the load on the 23kV system.

Figure 1 identifies the power plants, substations, and transmission lines associated with the KPP retirement. With the retirement of KPP, all of the load on the 23kV system will need to be served from the 69kV system. The Maui transmission system utilizes three 69/23kV tie transformers to interconnect the 69kV system and the 23kV system. These 69/23kV transformers are located at Waiinu Substation, Puunene Substation, and Kanaha Substation.

This study was conducted to identify the transmission system impacts with the retirement of KPP and analyze various solutions necessary to provide safe reliable power to the customers.

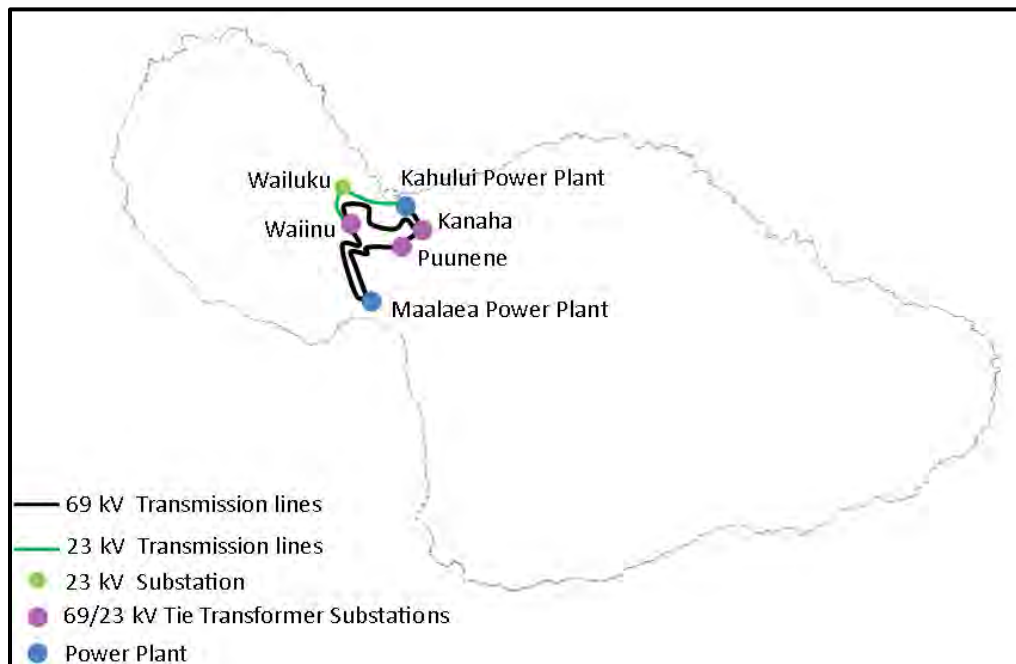


Figure 1: Key central Maui transmission components

## Assumptions

The “23kV system” referred in this document consists of the substations within central Maui—Wailuku, Kanaha, Kahului Sub 8, and substations fed by these major substations. Hana is being fed from Pukalani and the distance from the central substations to Haleakala and Kula do not have the same effect from the rest of the 23kV system; therefore, they are not included in the reference to the “23kV system.”

This study only evaluates the impact to the system from a steady state point; stability analysis will also need to be conducted.

## KPP Retirement Steady State Analysis

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### Model Assumptions

To model the Maui transmission system, we used actual 2013 historical load data to create a benchmark case. From the benchmark case, the following planned transmission system changes were implemented to create the cases for the interested years of study:

- 2014—KPP units K1 and K2 deactivated
- 2014—HC&S Offline
- 2015—Kaonoulu Substation
- 2019—All KPP units decommissioned
- 2019—Waiinu 69/23kV tie transformer enabled to auto-adjust

After the changes are implemented, the cases are uniformly scaled to the forecasted system gross loads.

### Load Assumptions

The gross peak and minimum with DSM/NEM/SIA/FIT load forecast used in this study is based on the May 2014 Adopted Maui Electric Sales and Peak Forecasts. This study focused on the 2014 with a load forecast of 197.9 MW and 2019 with a load forecast of 218.3 MW to represent the current system and the system after the retirement of KPP, respectively. Refer to Appendix A for the entire 2014-2030 load forecasts.

### Generation Assumptions

Currently, MECO operates two power plants—Kahului Power Plant (KPP) and Maalaea Power Plant (MPP). In addition, the following renewable generation serves the Maui load:

- HC&S—12 MW biomass
- KWP I—30 MW wind farm
- KWP II—21 MW wind farm
- Auwahi—21 MW wind farm
- Makila Hydro—0.5 MW hydro

The system also has two 1 MW units in Hana Substation for emergencies. Appendix B provides an overview of the current Maui system generation.

### Thermal Overloads

The amount of power that can flow through the transmission system components, such as conductors and transformers, is limited by its characteristics. Too much current flowing through the conductors and transformers will cause damage due to overheating. Under scenarios with no contingencies, the transmission equipment is evaluated using the normal rating (Rating A). For N-1 contingencies, the system is evaluated with emergency ratings (Rating B). See Appendix C for a single line diagram overview of the central Maui system showing line ratings.

### Voltage Violations

The MECO criteria for transmission planning states that under any operating condition, voltages for any bus shall have a maximum of +5% and a minimum of -10% of the nominal voltage. The per unit (pu) values are shown in Table 1.

Table 1: MECO Voltage Criteria for Transmission Planning

| Criteria                | Normal Conditions | Emergency Conditions |
|-------------------------|-------------------|----------------------|
| Over voltage violation  | > 1.05 pu         | > 1.05 pu            |
| Under voltage violation | < 0.90 pu         | < 0.90 pu            |

This report refers to “low voltages”, which meet the planning criteria by being above 0.90 pu but are of concern as these voltages can be an under voltage violation in the future. Maintaining voltages within the criteria provides customers with good power quality; so there are no damages to customer equipment. Furthermore, if voltages fall too far below 0.9 pu, the system may not be able to recover and a voltage collapse will occur.

### Steady State Analysis

To assess the impact on the transmission system with the retirement of KPP, the cases were subjected to N-1 contingencies. An N-1 contingency occurs when there is an outage of one transmission system component, while all others are in service. The following two contingencies are evaluated, as these contingencies are crucial paths that transfer power from the 69kV system to the 23kV system:

- Contingency 1: Loss of 69kV MPP-Waiinu
- Contingency 2: Loss of 69kV MPP-Puunene

The steady state analysis will identify any thermal overloads or voltage violations that can occur during these contingencies. To see the effects of retiring KPP, analysis was conducted with a case modeling the current system in 2014 and a case with the current system in 2019. Thermal and voltage violations occurred in the 2019 case if no upgrades to the system were made. The following are solutions considered to address the thermal and voltage violations:

- 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiinu and MPP-Puunene from 336AAC to 556AAC
- 25MW Battery Energy Storage System (BESS)
- 40MW Distributed Generation (DG)
- Synchronous condensers from retiring KPP units

Table 2 shows the case assumptions used when analyzing the impacts KPP retiring and the solutions considered. The amount of demand response (DR) needed would need to be similar to the generation provided by the BESS or DG to reduce the load on the 23kV system.

## KPP Retirement Steady State Analysis

Table 2: KPP Retirement Steady State Case Assumptions

| Case | Solution                                      | Description   |
|------|---|---|
| 0    | ---   | <ul style="list-style-type: none"> <li>• 2014 peak</li> <li>• Load Forecast = 197.9MW</li> </ul>  |
| 1    | ---   | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> </ul>   |
| 2    | Transmission Upgrades                         | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 23kV Waiinu-Kanaha upgrade to 69kV</li> <li>• MPP-Waiinu reconducted from 336 to 556</li> <li>• MPP-Puunene reconducted from 336 to 556</li> <li>• Remove FDR C from KPP-Kanaha 23kV</li> </ul> |
| 3    | 25 MW BESS                                    | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 25MW BESS interconnected at KPP</li> </ul>  |
| 4    | 40 MW DG                                      | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• 40MW DG interconnected at KPP</li> </ul>  |
| 5    | KPP Units converted to synchronous condensers | <ul style="list-style-type: none"> <li>• 2019 peak</li> <li>• Load Forecast = 218.3MW</li> <li>• HC&amp;S offline</li> <li>• KPP offline</li> <li>• Kaonoulu Substation in service</li> <li>• Waiinu 69/23kV tie transformer auto-adjust enabled</li> <li>• KPP units converted to synchronous condensers</li> </ul>  |

## Results

Currently with KPP online (2014), there are no thermal or voltage violations under normal or N-1 contingency events. The 23kV system is less dependent on the 69kV system because KPP is serving the load on the 23kV system. This reduces the loading on the 69/23kV tie transformers.

For the 2019 case, under normal conditions, if no system upgrades are made, the Waiinu 69/23kV tie transformer was heavily loaded at 92% of the normal rating. When subjected to an N-1 contingency, the loss of MPP-Waiinu showed overloads on the Puunene and Kanaha 69/23kV tie transformers, overloading on the MPP-Puunene 69kV line, as well as under voltage violations for the 23kV system and the Waiinu 69kV bus.

Figure 2 is a magnified excerpt of the 69kV system and identifies the violations of the system under the loss of MPP-Waiinu contingency.

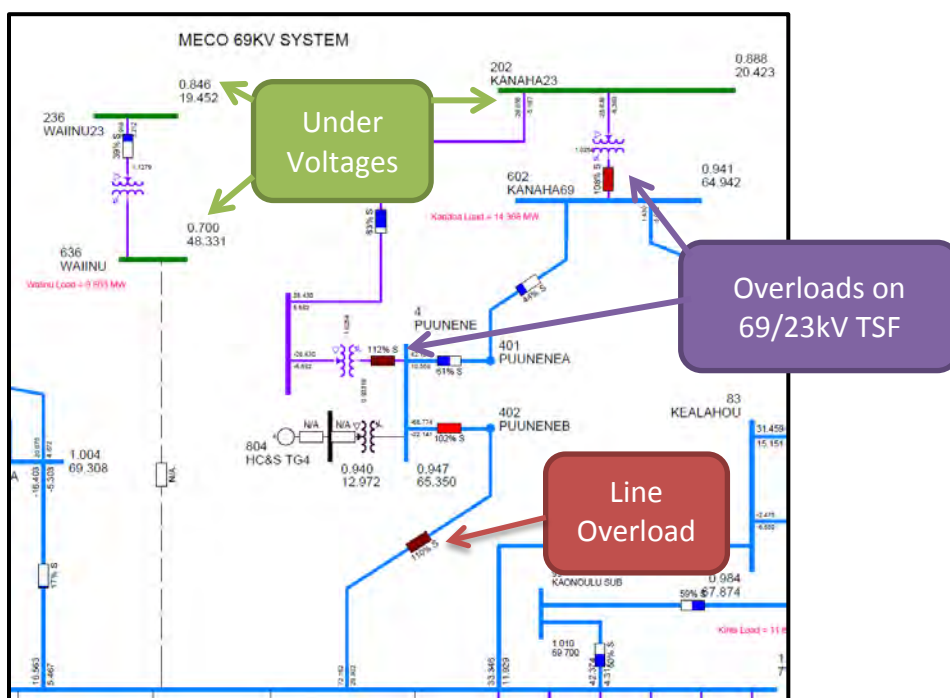


Figure 2: 69kV system current conditions for 2019 under N-1 contingency, loss of MPP-Waiinu

# KPP Retirement Steady State Analysis

Figure 3 shows the PSSE results for the 69kV and 23kV system in a single line diagram.

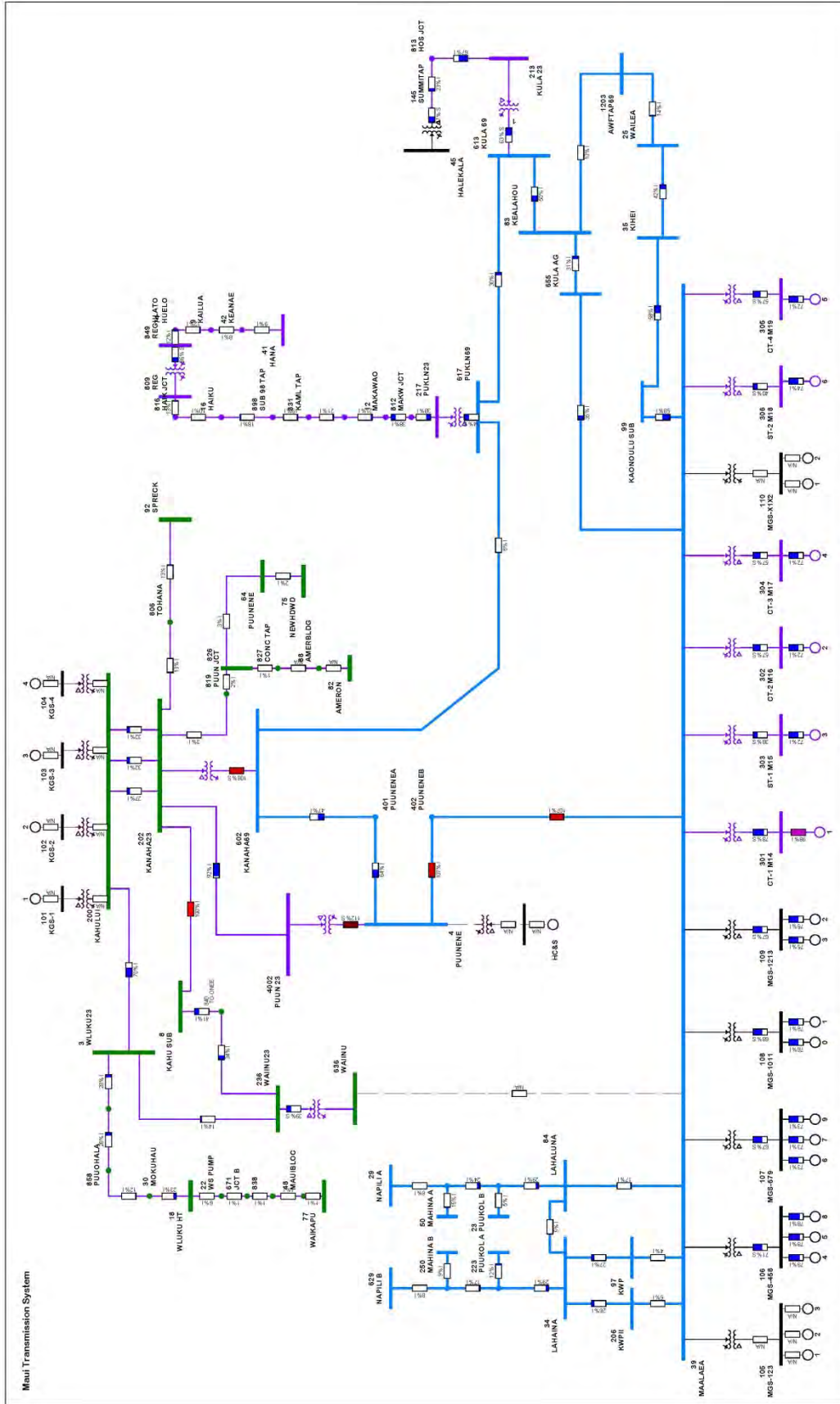


Figure 3: Maui transmission system in 2019 without upgrades under N-1 contingency, loss of MPP-Waiinu

For the loss of MPP-Puunene, the Waiinu 69/23kV tie transformer is overloaded and low voltages occur at Puunene, Kanaha, and Pukalani 69kV Substations. Although the low voltages are within the MECO criteria for transmission planning, the voltages are boarding the 0.90 pu voltage criteria.

Figure 4 shows the overloading of the Waiinu 69/23kV transformer and these low voltage buses with the loss of MPP-Puunene.

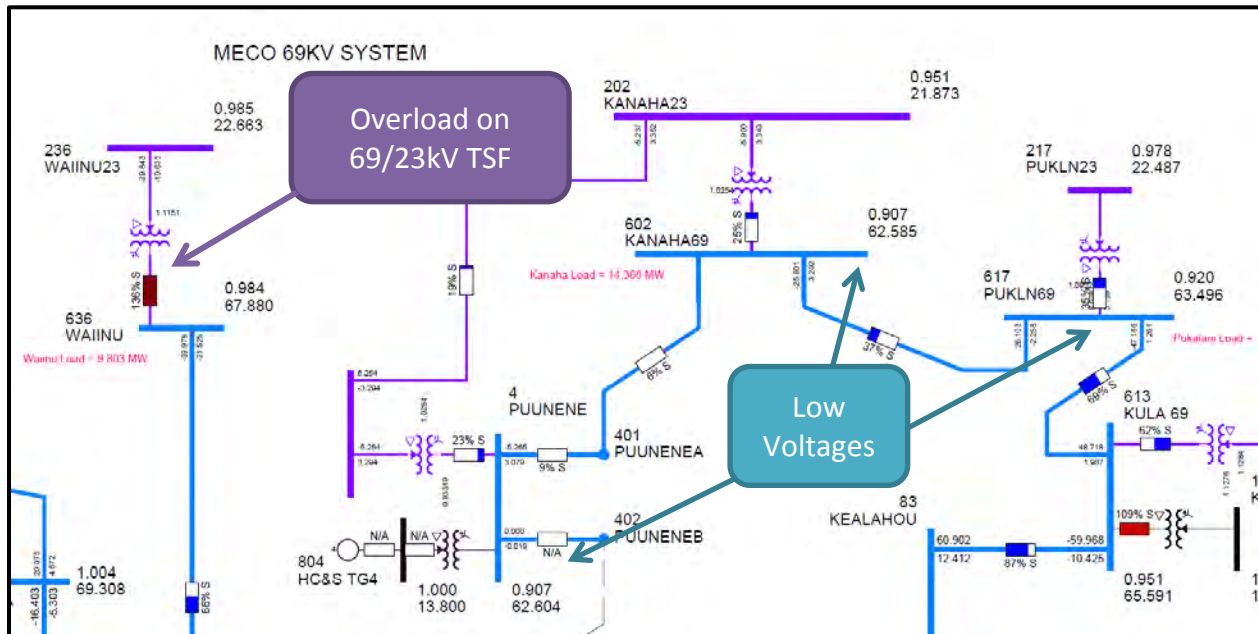


Figure 4: 69kV system with no system upgrades in 2019 under N-1 contingency, loss of MPP-Puunene

If no upgrades are made to the system, thermal and voltage violations occur. To eliminate the violations, a transmission and various non-transmission options were considered as possible solutions. From the 2019 case, the various solutions were modeled and studied to view the impacts to the system. These solutions are explained in detail in the following paragraphs.

### Waiinu-Kanaha Transmission Upgrade

The transmission recommendation is to upgrade the current 23kV Waiinu-Kanaha line to 69kV and reconductor MPP-Waiinu and MPP-Puunene from 336AAC to 556AAC. In addition, with the upgrade of the Waiinu-Kanaha line, feeder C from KPP-Kanaha will need to be removed. Along with the Waiinu-Kanaha 23kV upgrade, the Kahului Sub 8, which is located along the Waiinu-Kanaha 23kV line, will also be upgraded to 69kV. By upgrading the 23kV Waiinu-Kanaha line to 69kV, the loads on the 23kV system will be switched to the 69kV system. This will reduce the loading on the tie transformers.

## KPP Retirement Steady State Analysis

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With these transmission upgrades, the 2019 system will have no thermal or voltage violations under normal or N-1 contingency events. Figure 5 shows the system in 2019 with the transmission upgrades under N-1 contingency. By relocating more loads on the 69kV system, there is less dependency on the tie transformers and transmission lines that provide support to the 23kV system.



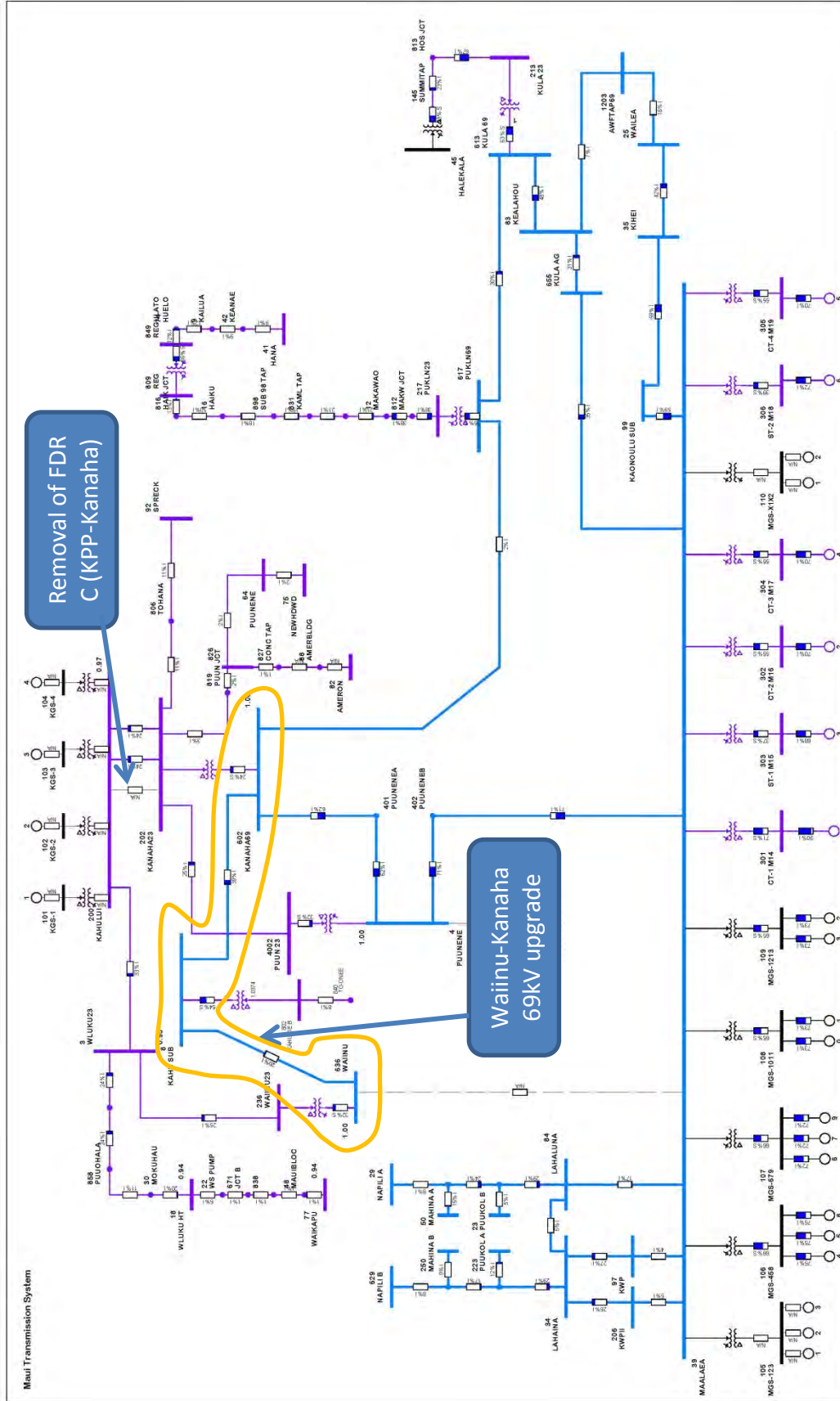


Figure 5: Maui system in 2019 with Transmission Upgrades under N-1 contingency, loss of MPP-Waiinu

## KPP Retirement Steady State Analysis

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### 25MW Battery Energy Storage System (BESS)

The first non-transmission alternative (NTA) considered was the addition of a 25MW BESS interconnected to the 23kV system; this 25MW:30min BESS was addressed in the 2013 Integrated Resource Plan. For modeling purposes, the 25MW BESS was added to the retiring KPP site. However, the BESS will effectively provide the same support if added anywhere on the 23kV system. The BESS has the ability to respond to system disturbances immediately but will be limited by the MWh parameters. Due to the voltage and thermal issues seen with an N-1 contingency, the BESS will need to be able to supply the 23kV system during this system condition, which could possibly be for multiple hours. Other control settings, operation and parameters of the BESS are beyond the scope of this study.

A BESS has the capabilities to instantaneously respond to system disturbances depending on the controls of the BESS. Due to the under voltages occurring when the system is subject to the N-1 contingencies, if the system peaks occur from the hours of 10:00 AM to 8:00 PM and the contingency occurs during this peak period the BESS would need to supply power during this time. Therefore, the 25MW BESS should have at least an 8 hour duration (200MWh), to allow line crews to repair the line. The BESS can also be paired with DG—discussed in the next section—to reduce the duration needed.

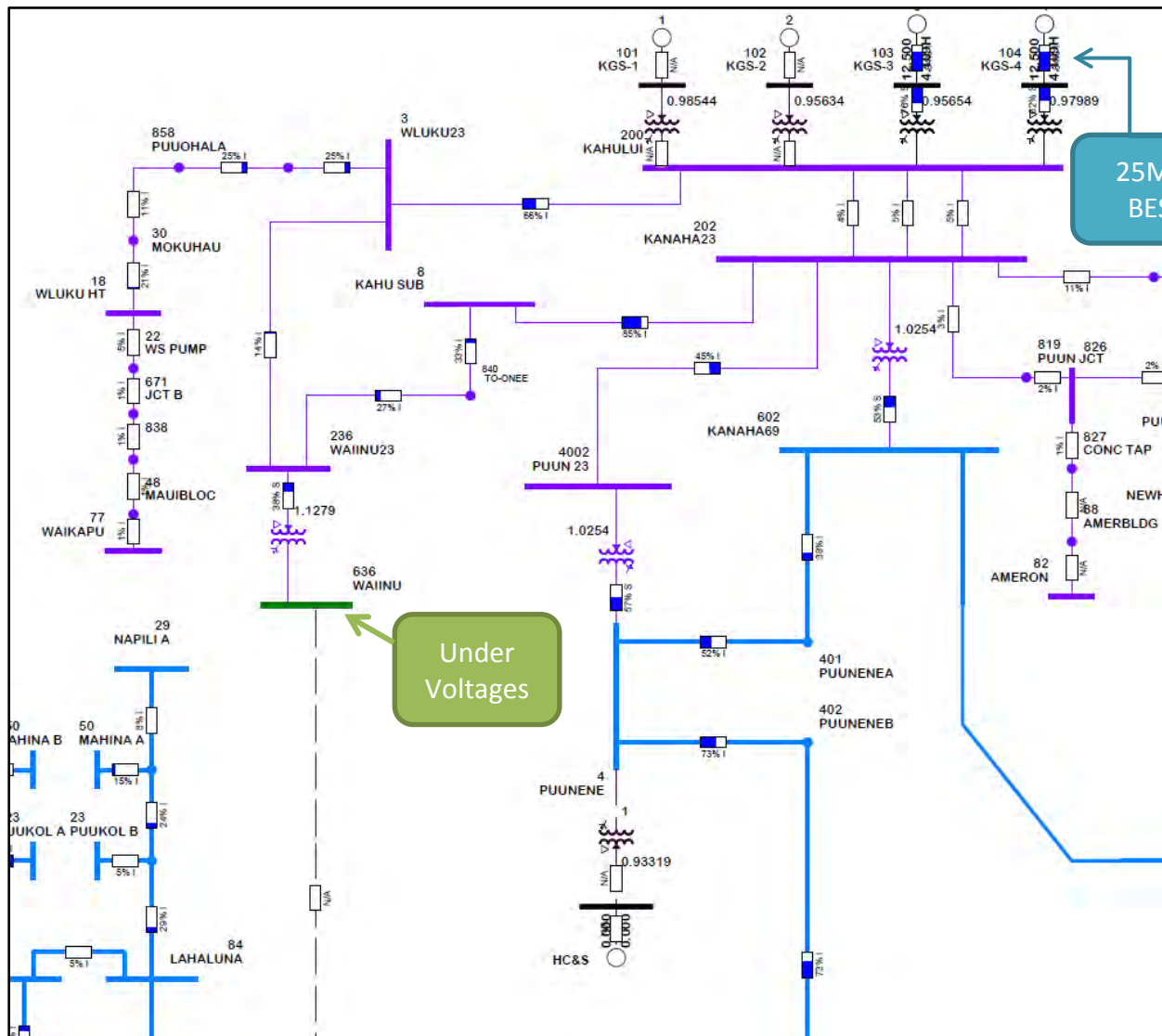


Figure 6: 25MW BESS modeled on the 23kV system improves voltages under N-1 contingency, loss of MPP-Waiinu

With the addition of a 25MW BESS on the 23kV system, when subjected to an N-1 contingency, low voltages occur at the 69kV Waiinu bus. There are no overloads on the 69/23kV tie transformers or the MPP-Puunene line. Furthermore, the low voltages at Waiinu 69kV are due to the control for the Waiinu 69/23kV tie transformer controlling the Waiinu 23kV bus voltage. With capability to control the Waiinu 69/23kV tie transformer tap settings, the Waiinu 69kV bus voltage could be kept within the planning criteria, above 0.90 pu.

#### 40MW Distributed Generation (DG)

Another NTA considered is to have firm DG interconnected into the 23kV system. Having quick starting DG units would minimize the outage seen by the customer. Sizing, fuel, daily operation, and other unit characteristics is beyond the scope of this study, further analysis will need. Adding generation to the 23kV system will help alleviate the loading on the 69/23kV tie

## KPP Retirement Steady State Analysis

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transformers, and the 23kV system dependency on the 69kV system would be eliminated. Furthermore, with the retirement of KPP, the system will be deficient of supply by 40MW, so the addition of 40MW of DG to the system would meet the adequacy of supply requirements.

For modeling purposes, five 8.5MW units were added to the KPP site to total approximately 40MW of DG. The specific characteristics of the units can differ from the 8.5MW units that are modeled as well as the interconnection site on the 23kV system. Further analysis will need to be conducted based on the potential locations and parameters of the units which the system will require for stability. The issue of land zoning and air quality permits will also need to be addressed.

Due to the start-up times required for the DG, customers will experience outages. Fast starting units can have start-up times around 5 minutes. Stability analysis will show if the system can maintain a stability until these DG units can provide power. As mentioned before, a combination of BESS and DG can be used to eliminate the outages customers will experience. The BESS will serve the customers until the DG can start-up and output power.

With the 40MW of DG, no thermal or voltage issues occur during normal conditions and with the loss of MPP-Puunene. However, the loss of MPP-Waiinu resulted in under voltage violations for Waiinu 69KV. Similar to the under voltage violation for the BESS NTA for Waiinu 69kV, if the Waiinu 69/23kV tie transformer controls were adjusted properly, the Waiinu 69kV bus voltage could be kept above 0.9pu. Figure 7 shows the 69kV system, under voltage violation for the 69kV Waiinu bus with the loss of MPP-Waiinu. Figure 8 shows the 23kV system with no thermal or under voltage violations under the MPP-Waiinu contingency.

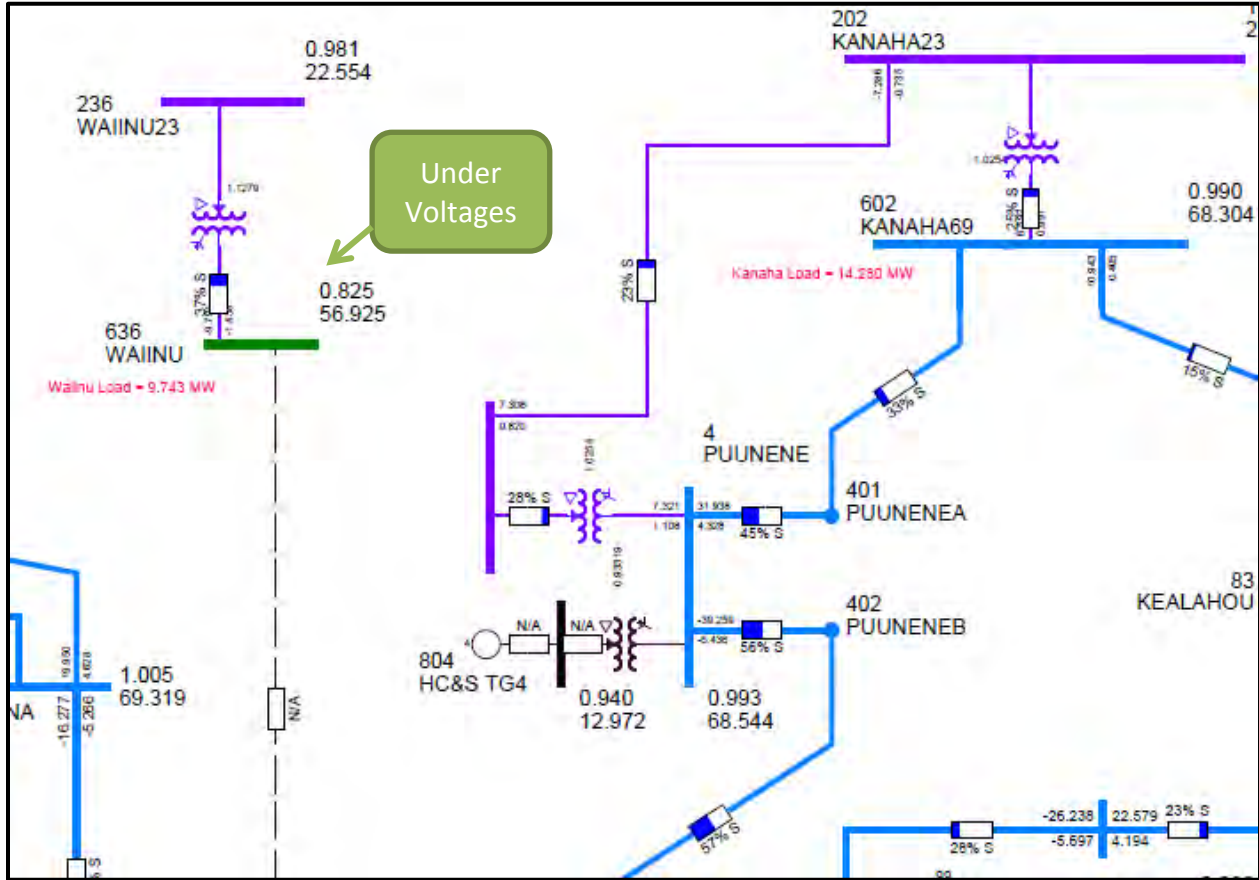


Figure 7: 69kV system with 40MW DG on 23kV system, under N-1 Contingency (loss of MPP-Waiinu) resulting in under voltage violation at Waiinu 69kV bus

# KPP Retirement Steady State Analysis

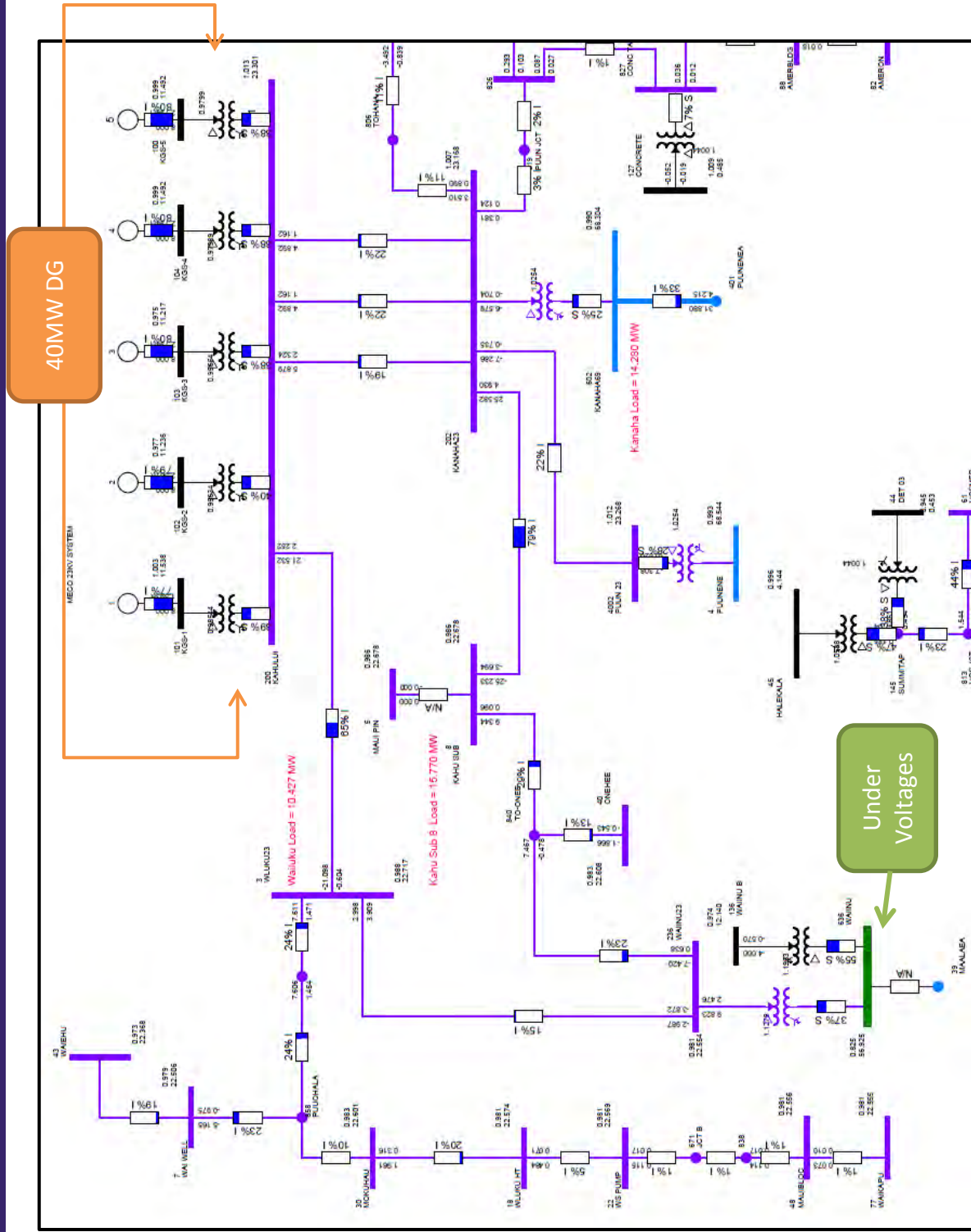


Figure 8: 23kV system with five 8.5MW units for 40MW DG interconnected on 23kV system providing support during N-1 contingency, loss of MPP-Waiinu

## Synchronous Condensers

To provide voltage support, another NTA considered was converting the existing KPP units to synchronous condensers. A synchronous machine operating without a prime mover is a synchronous condenser. Controlling of the field excitation allows a synchronous condenser to either absorb or supply reactive power to the system.

Under normal conditions, because of the transferring of load from MPP to the 23kV system, the Waiinu 69/23kV tie transformer is heavily loaded at 93% of its normal rating. As the load increases on the 23kV system, the Waiinu 69/23kV tie transformer will be overloaded. For the MPP-Waiinu N-1 contingency, although the synchronous condensers help the 23kV system voltages remain within the planning criteria, the Puunene and Kanaha 69/23kV tie transformers are overloaded. In addition, the MPP-Puunene is above 100% of its emergency rating and the Waiinu 69kV bus violated the voltage criteria.

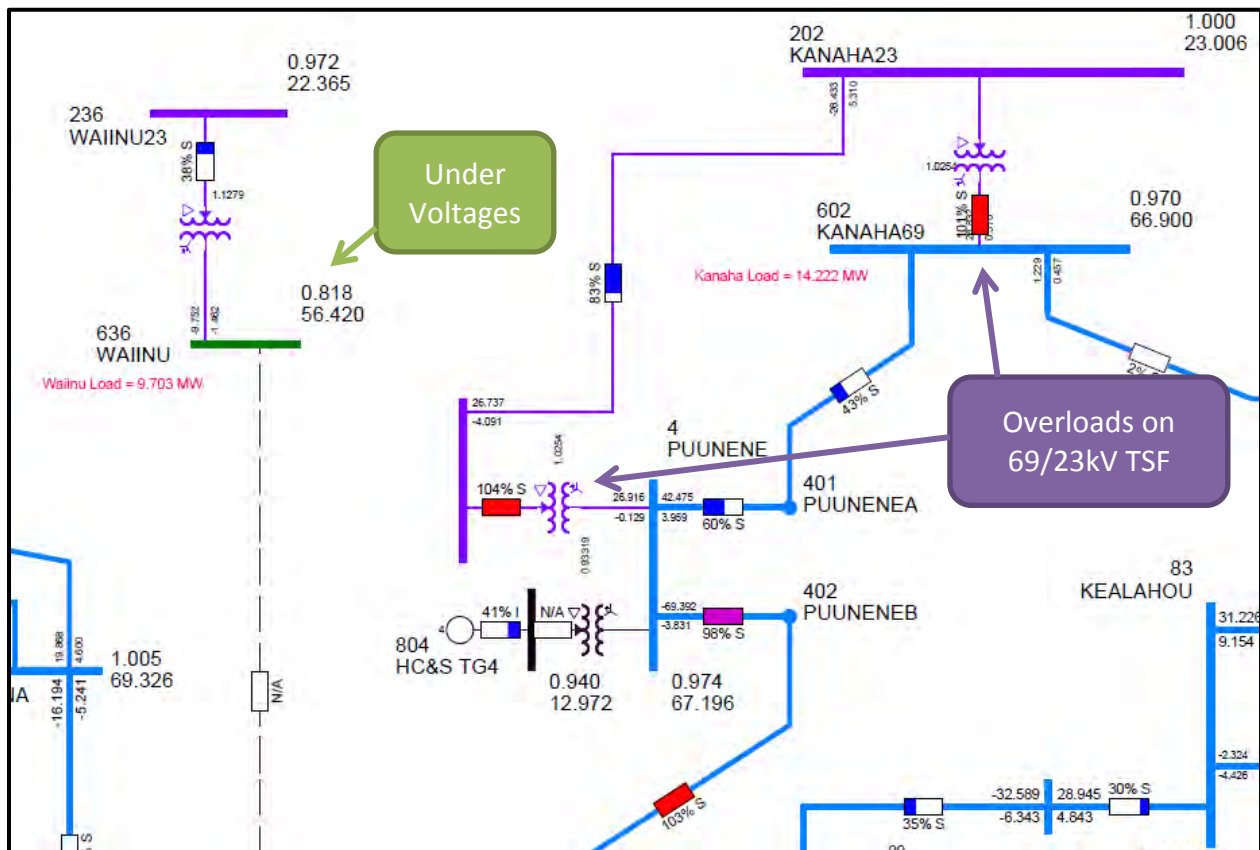


Figure 9: 2019 69kV system with KPP units converted to synchronous condensers subjected to MPP-Waiinu contingency

Due to the overloading issues with using KPP units as synchronous condensers, transmission upgrades will also be needed. The Waiinu 69kV under voltage violation occurs because the transformer taps are being controlled to regulate the 23kV Waiinu bus.

## KPP Retirement Steady State Analysis

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### Summary of Results

To address the under voltage violations and overloads on the transmission system with the retirement of KPP, this steady state analysis considered the following system improvements:

- 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiinu and MPP-Puunene from 336AAC to 556AAC
- 25MW BESS
- 40MW DG
- Synchronous condensers from retiring KPP units

The retirement of KPP impacts the 23kV system greatly. With no upgrades to the transmission system and the retirement of KPP violations to the criteria for transmission planning are eminent.

The transmission upgrades resulted in the system having no thermal or voltage issues for normal or N-1 conditions. While the 25MW BESS and 40MW DG had some under voltage violations and high thermal loadings. The KPP units a synchronous condensers managed the under voltages but thermal overloads occur. Table 3 lists the issues of concerns for the various cases that were used in the study.



Table 3: Summary of Analysis

| Case | Case Description                          | Condition                  | NOTES   |
|------|---|----------------------------|---|
| 0    | 2014 Current System                       | Normal                     | No thermal or voltage violations  |
|      |   | Contingency 1: MPP-Waiinu  | No thermal or voltage violations  |
|      |   | Contingency 2: MPP-Puunene | No thermal or voltage violations  |
| 1    | 2019 No Upgrades                          | Normal                     | Waiinu 69/23kV loaded at 92% of normal rating   |
|      |   | Contingency 1: MPP-Waiinu  | Overloads on MPP-Puunene, Puunene 69/23kV TSF, Kanaha 69/23kV TSF, and under voltages in central Maui 23KV system and Waiinu 69kV bus   |
|      |   | Contingency 2: MPP-Puunene | Overloading on the Waiinu 69/23 kV TSF and low voltages at Puunene, Kanaha and Pukalani 69 subs   |
| 2    | 2019 Transmission Upgrades                | Normal                     | No thermal or voltage violations  |
|      |   | Contingency 1: MPP-Waiinu  | No thermal or voltage violations  |
|      |   | Contingency 2: MPP-Puunene | No thermal or voltage violations  |
| 3    | 2019 25MW BESS                            | Normal                     | No thermal or voltage violations  |
|      |   | Contingency 1: MPP-Waiinu  | Under voltage violation for Waiinu 69kVbus and high loading (97%) on Kanaha-Kahului Sub 8 23kV line (percentages based on emergency ratings)  |
|      |   | Contingency 2: MPP-Puunene | No thermal or voltage violations  |
| 4    | 2019 40MW DG                              | Normal                     | No thermal or voltage violations  |
|      |   | Contingency 1: MPP-Waiinu  | Under voltage violation for Waiinu 69kV bus and Kanaha-Kahului Sub 8 23kV line loading at 79% (percentages based on emergency loadings)   |
|      |   | Contingency 2: MPP-Puunene | No thermal or voltage violations  |
| 5    | 2019 K1, K2, K3, K4 Synchronous Condenser | Normal                     | Waiinu 69/23kV TSF loading at 93% of normal rating and MPP-Puunene 69kV line at 79% of normal rating  |
|      |   | Contingency 1: MPP-Waiinu  | Under voltage violation for Waiinu 69kV bus, overloading on MPP-Puunene 69kV line, and overloading on Puunene 69/23kV TSF and Kanaha 69/23kV TSF; Kanaha-Kahului Sub 8 line loading at 86% and Puunene-kanaha 23kV line loading at 83% (percentages based on emergency ratings) |
|      |   | Contingency 2: MPP-Puunene | Overloading on the Waiinu 69/23 kV TSF  |

## KPP Retirement Steady State Analysis

Along with the results from the steady state simulations that were modeled, other issues should be considered. Table 4 identifies various pros and cons associated with the various solutions. These pros and cons will need to be further assessed.

Table 4: Pros and Cons for solutions evaluated

| Solution                   | Pros   | Cons  |
|----------------------------|--|---|
| Transmission Upgrade       | <ul style="list-style-type: none"> <li>• Does not require large area of land</li> <li>• No zoning, air quality permits required</li> <li>• Product life</li> </ul>                           | <ul style="list-style-type: none"> <li>• Transmission capital investment</li> </ul>   |
| 25MW BESS                  | <ul style="list-style-type: none"> <li>• Prolong need for transmission infrastructure</li> <li>• Instantaneous response (compared to DG)</li> <li>• No emissions (compared to DG)</li> </ul> | <ul style="list-style-type: none"> <li>• Need to acquire land</li> <li>• Product life</li> <li>• Limited run time</li> <li>• Cost</li> </ul>  |
| 40MW DG                    | <ul style="list-style-type: none"> <li>• Prolong need for transmission infrastructure</li> <li>• Contribute to Adequacy of Supply</li> <li>• Renewable generation with biodiesel</li> </ul>  | <ul style="list-style-type: none"> <li>• Need to acquire land</li> <li>• Need to acquire air quality permits</li> <li>• Requires zoning for land (Heavy Industrial)</li> <li>• Noise</li> <li>• Disruption to customers (time required for units to start)</li> </ul> |
| KPP Synchronous Condensers | <ul style="list-style-type: none"> <li>• Use existing machines</li> </ul>  | <ul style="list-style-type: none"> <li>• KPP in Tsunami flood zone</li> <li>• Still require transmission infrastructure upgrades</li> </ul>   |

## Conclusion

A steady state analysis was conducted to identify system impacts of the KPP retirement, and evaluated possible solutions. This analysis identified overloading and under voltage violations on the system. To provide safe and reliable power to customers, the system would need an upgrade, to not violate the MECO criteria for Transmission Planning. A transmission upgrade along with several non-transmission upgrades were evaluated for improving the system during normal and contingency scenarios.

Based on the steady state analysis, the transmission upgrades are recommended to maintain a safe reliable system with the retirement of KPP. The transmission upgrades for the 23kV Waiinu-Kanaha conversion to 69kV with MPP-Waiinu and MPP-Puunene reconductoring had a greater effect on improving the system compared to the other solutions. With the transmission upgrades, there were no thermal or voltage violations during normal or N-1 contingency conditions.

## KPP Retirement Steady State Analysis

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### **Appendix A** Load Forecasts

Based on the May 2014 Maui Adopted Sales and Peak Forecasts

Table A.1: Gross Minimum and Peak System Load Forecast with DSM/NEM/FIT/SIA

| Year  | Min* (MW) | Peak* (MW) |
|---|-----------|------------|
| 2014  | 84.4      | 197.9      |
| 2015  | 86.2      | 199.7      |
| 2016  | 88.1      | 202.1      |
| 2017  | 91.5      | 208.2      |
| 2018  | 94.9      | 214.4      |
| 2019  | 97.3      | 218.3      |
| 2020  | 98.9      | 220.0      |
| 2021  | 100.6     | 221.9      |
| 2022  | 101.9     | 222.6      |
| 2023  | 103.2     | 223.3      |
| 2024  | 104.3     | 223.0      |
| 2025  | 105.9     | 223.3      |
| 2026  | 107.1     | 222.1      |
| 2027  | 108.2     | 220.4      |
| 2028  | 108.9     | 217.1      |
| 2029  | 110.3     | 214.8      |
| 2030  | 111.3     | 210.8      |
| *Gross NEM/FIT/SIA are assumed to be zero ;<br>PV has no impact during early morning or evening hours |           |            |

## KPP Retirement Steady State Analysis

---

### **Appendix B** Generation Overview

Table B.1: Current Maui Electric Generation Overview

| Maui Electric Generation Overview |                         |                    |                    |                      |                              |
|-----------------------------------|-------------------------|--------------------|--------------------|----------------------|------------------------------|
| Maalaea Power Plant               |                         |                    |                    |                      |                              |
| Unit                              | Unit Type               | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation | Ramp Rates<br>(Gross MW/min) |
| MX1                               | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| MX2                               | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M1                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M2                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M3                                | ICE                     | 2.5                | 2.5                | Peaking              | 0.0                          |
| M4                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M5                                | ICE                     | 5.6                | 2.0                | Cycling/Peaking      | 1.0                          |
| M6                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M7                                | ICE                     | 5.6                | 2.0                | Cycling/Peaking      | 1.0                          |
| M8                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M9                                | ICE                     | 5.6                | 2.0                | Cycling              | 1.0                          |
| M10                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M11                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M12                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M13                               | ICE                     | 12.5               | 6.0                | Cycling              | 1.0                          |
| M14                               | CT                      | 58                 | 12.5               | DTCC-Baseload        | 2.0                          |
| M15                               | ST                      |                    | 11.0               | DTCC-Baseload        | DTCC-1.0;<br>STCC-0.5        |
| M16                               | CT                      |                    | 12.5               | DTCC-Baseload        | 2.0                          |
| M17                               | CT                      | 58                 | 14.0               | STCC-Cycling         | 2.0                          |
| M18                               | ST                      |                    | 3.0                | STCC-Baseload        | DTCC-1.0;<br>STCC-0.5        |
| M19                               | CT                      |                    | 14.0               | STCC-Baseload        | 2.0                          |
| TOTAL:                            |                         | 212.1              |                    |                      |                              |
| Kahului Power Plant               |                         |                    |                    |                      |                              |
| K1                                | Boiler/Steam<br>Turbine | 5.0                | 2.50               | Cycling              | 0.10                         |
| K2                                | Boiler/Steam<br>Turbine | 5.0                | 2.50               | Cycling              | 0.10                         |
| K3                                | Boiler/Steam<br>Turbine | 11.5               | 3.50               | Baseload             | 0.10                         |
| K4                                | Boiler/Steam<br>Turbine | 12.5               | 3.50               | Baseload             | 0.10                         |
| TOTAL:                            |                         | 34.0               |                    |                      |                              |

## KPP Retirement Steady State Analysis

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| Hana Substation             |              |                    |                    |                      |  |
|-----------------------------|--------------|--------------------|--------------------|----------------------|--|
| Unit                        | Unit Type    | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation |  |
| H1                          | ICE          | 1.0                | 0.0                | Emergency            |  |
| H2                          | ICE          | 1.0                | 0.0                | Emergency            |  |
| Independent Power Producers |              |                    |                    |                      |  |
| Unit                        | Unit Type    | PMAX<br>(Gross MW) | PMIN<br>(Gross MW) | Mode of<br>Operation |  |
| HC&S                        | Biomass      | 12                 | 8.0                | Baseload             |  |
| Kaheawa I                   | Wind Farm    | 30.0               |                    | As-Available         |  |
| Makila Hydro                | Run-of-river | 0.5                |                    | As-Available         |  |
| Auwahi                      | Wind Farm    | 21.0               |                    | As-Available         |  |
| Kaheawa II                  | Wind Farm    | 21.0               |                    | As-Available         |  |
|                             | TOTAL:       | 72.5               |                    |                      |  |



## **Appendix C**

### Single Line Overview with Line Ratings

# KPP Retirement Steady State Analysis

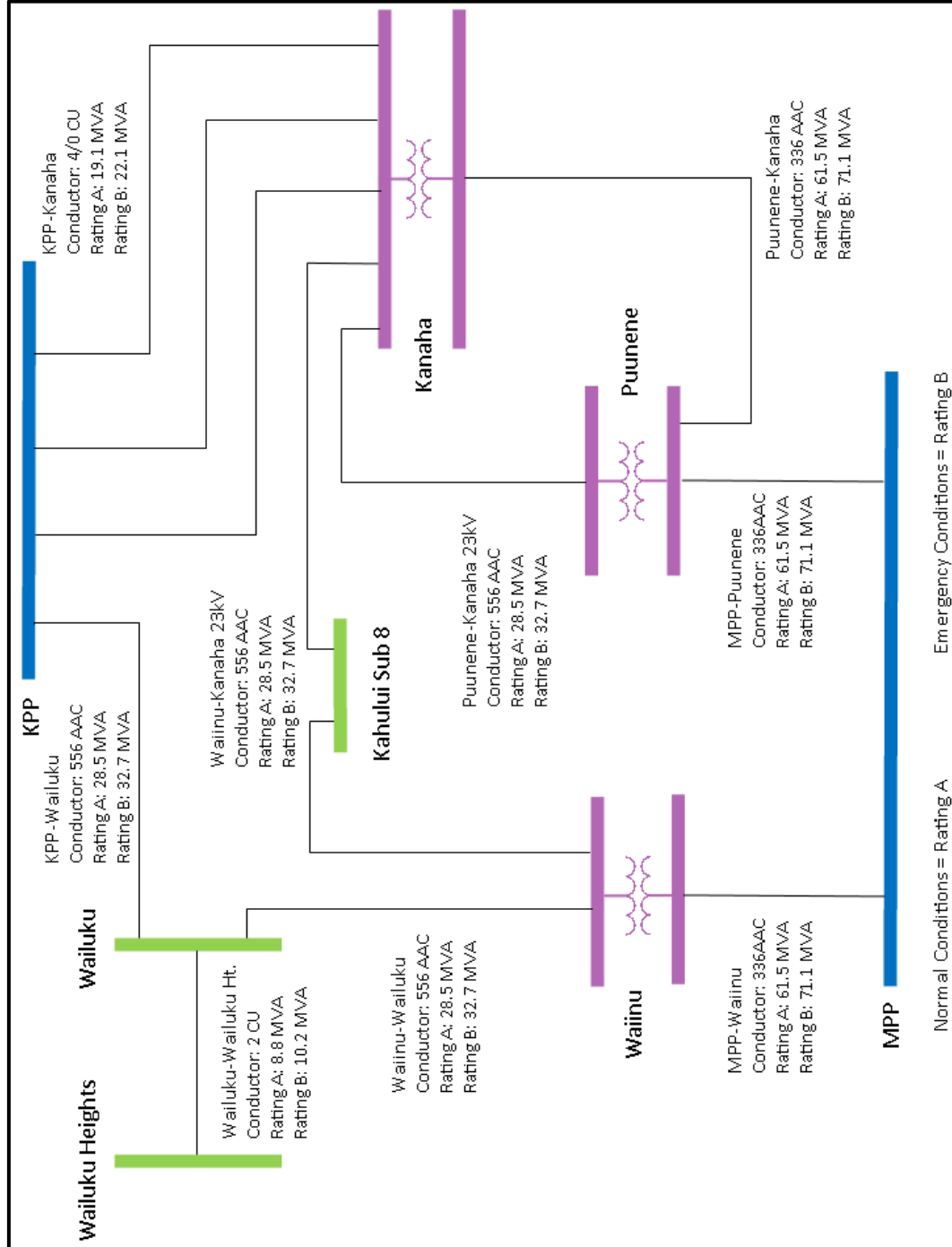


Figure C.1: Overview of Central Maui system showing line ratings

# Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment

Prepared for

**Maui Electric Company, Ltd.**

**Prepared By:**

Hawaiian Electric Company, Inc.  
System Planning Department  
Transmission Planning Division

May 19, 2014

**Reference: TPD 2014-21**

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Executive Summary:

Hawaiian Electric Company's Transmission Planning Division (TPD) has revisited the topic regarding Maui Electric Company's plan to fully decommission Kahului Power Plant (KPP) by the year 2019. TPD has re-examined the various recommended upgrades suggested in previous studies conducted by TPD with the latest updated system models and also considered several non-transmission alternatives. This study addresses the voltage violation and voltage stability issues involved with the retirement of KPP and outlines how each alternative will potentially impact the system. After revisiting the transmission alternatives in the previous study with the latest system models and load forecast, and considering several non-transmission alternatives (NTAs), TPD recommends that proceeding with the Waiinu-Kanaha upgrade project is the most favorable, economical, and engineeringly sound solution to address voltage issues involved with the retirement of KPP, however, thermal limit and system stability issues involved with the retirement of the power plant should be also considered.

### Introduction/Background:

The Maui transmission system consists of a 23 kV network and 69 kV network. KPP has a total capacity of approximately 35 MW and connects into the 23 kV network, and the remainder of Maui's generation connects into the 69 kV network. The two networks are interconnected via 23/69 kV tie transformers located in Waiinu, Kanaha, and Puunene substations. KPP is the only source of generation connected to the 23 kV network. The retirement of the power plant will result in the 23 kV network becoming heavily dependent on power supplied by the 69 kV network via the three tie transformers and induce a diminished limit of power transfer to the 23 kV network, cause voltage sources to be electrically farther from the load center (i.e. the 23 kV network), and remove a reactive power source from the 23 kV network; this potential subjects the 23 kV network to voltage profiles that violate the reliability criteria or are prone to voltage instability in the event suffering a system disturbance. Voltage instability accompanied by a sequence of events (e.g. the loss of a transmission line) will lead to voltage collapse – low, unacceptable voltage profiles in significant parts of the power system – and a possible blackout system event.

TPD performed a study in the past concerning Maui Electric's plan to reduce operation at KPP and its eventual retirement, which analyzed several transmission solutions to address the aforementioned issues. The study recommended upgrading the 23 kV Waiinu to Kanaha transmission line to 69 kV, relocating 23 kV load at Kahului to the 69 kV system, and reconductoring the 69 kV MPP-Puunene and 69 kV MPP-Waiinu transmission lines. TPD has re-examined all recommendations made in the previous study using the latest updated base case models and load forecasts to re-establish the validity of the recommendation. TPD has also examined several non-transmission alternatives, which align with the Public Utilities Commission's (PUC) vision for the company, to be considered as possible solutions to address the issues.

## Kahului Power Plant Retirement: Voltage Stability Assessment

---

This study will identify the system impacts resulting from the retirement of KPP from a voltage stability standpoint, examine various plausible transmission and non-transmission solutions to rectify observed system issues, and recommend the most suitable solution from a transmission stand point.

### Methodology:

TPD used a conventional power-flow program to derive the Power-Voltage (P-V) characteristics of the existing Maui transmission system to determine the system power transfer limits and proximity to a voltage instability event, and the key factors that contribute to its occurrence. The characteristics were compared and contrasted to the P-V characteristics of cases of the existing system with various transmission and non-transmission upgrades to determine the most engineeringly sound solution to avoid violations of the reliability criteria, or even worse, the compromise of system reliability.

### Assumptions:

The following are the assumptions used in this study unless specified otherwise:

- Referencing of the “23 kV network” in this study does not include the 23 kV circuit from Kula to Haleakala due to its electrical distance from the rest of the 23 kV system.
- The Hana 23 kV circuit is fed from Pukalani.
- Kahului Power Plant is retired by 2019.
- Contract with HC&S will expire and HC&S will no longer contribute any generation after year 2014.
- The acceptable “power margin” is between 1.05 - 0.9 per unit (p.u.) voltage per the reliability criteria.
- An N-1 event in this study refers to the loss of a transmission line.
- Existing System refers to the present Maui transmission network and reference of the existing (peak) load is the forecasted peak load of year 2014 which is approximately 200 MW.
- Initial reference point (the y-intercept) in P-V plots is the existing system at peak load.

### Results and Analysis

The P-V characteristics of the various scenarios are derived for the normal condition and N-1 contingency events identified to result in the most severe system issues. These contingencies are:

- Loss of the 69 kV transmission line between Maalaea Power Plant (MPP) and Waiinu substation, which will be referred to as the 69 kV MPP-Waiinu line. This is a critical line that connects MPP to the 23/69 kV tie transformer at Waiinu, supplying power to the heavily loaded Central Maui and Wailuku area. Losing this line will require power to

## Kahului Power Plant Retirement: Voltage Stability Assessment

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travel a greater electrical distance via the 23/69 kV tie transformer at Kanaha and Puunene to serve the Wailuku load.

- Loss of the 69 kV transmission line between MPP and Puunene substation, which will be referred to as the 69 kV MPP-Puunene line. This line powers from MPP to the 23/69 kV tie transformers at Kanaha and Puunene. The loss of this line will require power to travel a greater electrical distance via the 23/69 kV tie transformer at Waiinu to serve the Central Maui load.
- Loss of the 23 kV line between Wailuku substation and Waiinu substation, which will be referred to as the 23 kV Wailuku-Waiinu line. This line serves as an important means of providing power from Waiinu to the Wailuku area. Losing this line will require power to travel a greater electrical distance via Kanaha substation.
- Loss of the 23 kV line between Kanaha substation and Kahului substation, which will be referred to as the 23 kV Kanaha-Kahului line unless specified otherwise.

Figure 1 and Figure 2 show the P-V characteristics of the existing system with and without operation of KPP, respectively, for the normal and most severe N-1 conditions. The initial reference point on the P-V curve is at the point where the curve intercepts the y-axis; it depicts the voltage profile of the 23 kV network on the existing system at peak load level. Moving to the right along the x-axis represents natural growth in load on the 23 kV network. Increases to the load on the 23 kV network result in a decline in voltage profile – continual increase of load on the 23 kV network will inevitably violate the reliability criteria. The end of the P-V curve indicates that the power-flow was unable to solve beyond that point which is indicative of voltage collapse. Thus, as the system approaches the vicinity of voltage collapse, it is subject to voltage instability; the system is typically planned to operate well away from these points. The P-V curve exhibits the limits of power transfer to the 23 kV network.

The limitations of power transfer are dependent on the inherent traits of the system and can be extended or reduced through changes to the system. This aspect can be seen in Figure 1, where an N-1 contingency event shifts the power transfer limit of the normal condition curve to the left – this represents a diminished power transfer limit. It can be seen that the loss of 69 kV MPP-Waiinu line is the most severe out of all the N-1 contingencies due the indication of a steeper decline in voltage profile (curve) and quicker occurrence to voltage collapse (as load increases). It can also be seen that voltage collapse can occur well within the acceptable power margin - a voltage profile that does not violate the reliability criteria isn't necessarily safe of voltage instability/voltage collapse. Thus, the alternatives are evaluated on their capabilities of avoiding violations to the reliability criteria and voltage instability/voltage collapse.

## Kahului Power Plant Retirement: Voltage Stability Assessment

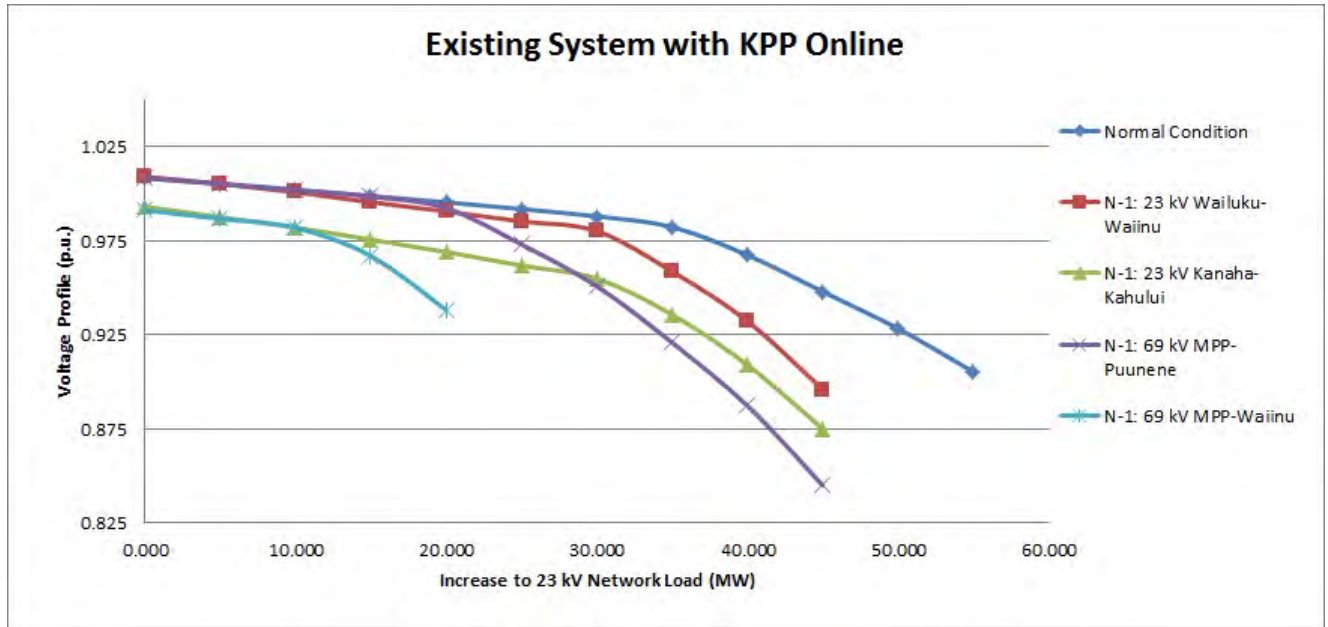


Figure 1: P-V characteristics of existing Maui system with operation of KPP.

As mentioned previously, the power transfer limits can be extended or reduced through changes to the system. A diminished power transfer limit can be expected as a result of the decommissioning of KPP. Without the operation of KPP, the 23 kV network will lose the only source of power generation connected to the 23 kV network and must rely on power supplied by the 69 kV network. This will place an additional burden on the 69 kV transmission lines and 23/69 kV transformers that connect the two networks because the 69 kV network must pick up the demand previously met by KPP.

The system will become vulnerable to voltage instability due to the voltage sources (voltage source for 23 kV network is KPP prior to its decommission; the voltage source will be the generation sources on 69 kV network after KPP retirement) being further away from the load center (i.e. the 23 kV network) and insufficient load reactive compensation on the 23 kV network. This can be seen in Figure 2. It can be observed that with the retirement of KPP, under the N-1 event of losing the 69 kV MPP-Waiinu transmission line, the voltage profile of the 23 kV network is below the sufficient “power margin” and is subjected to voltage collapse at the current 2014 peak load level.

## Kahului Power Plant Retirement: Voltage Stability Assessment

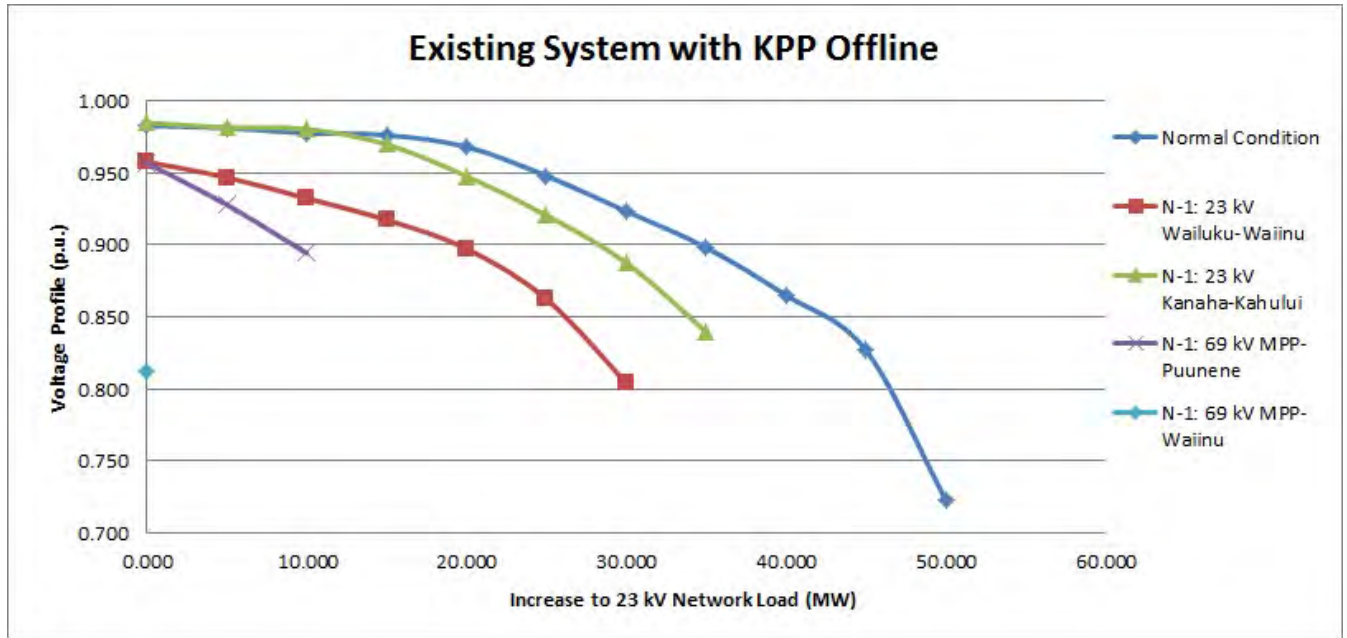


Figure 2: P-V characteristics of existing Maui system without operation of KPP.

Figure 3 compares the P-V characteristics for the normal condition and the most severe N-1 contingency event of the system with and without operation of KPP. It exhibits what changes to the power transfer limit of the 23 kV network is to be expected if KPP is decommissioned without any upgrades to the system.

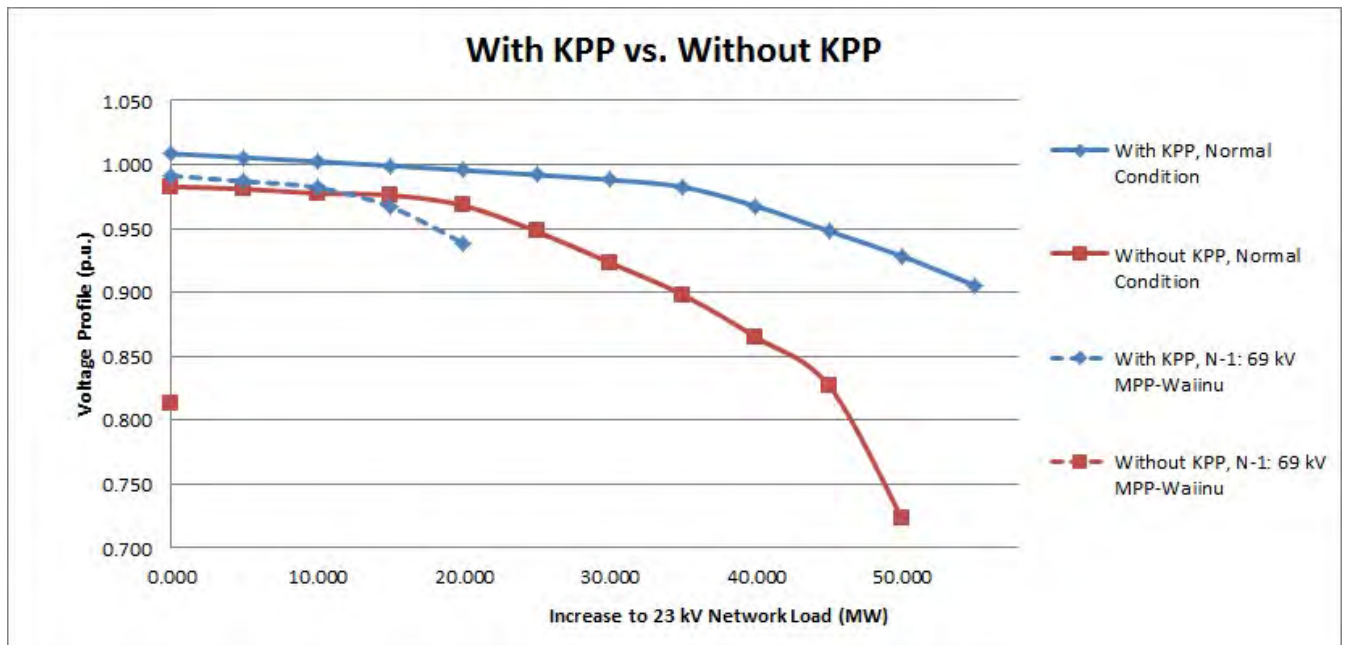


Figure 3: P-V characteristics comparison between system with and without the operation of KPP.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Transmission Solutions

In the past, TPD analyzed several transmission options that would rectify the system's vulnerability to possible voltage instability and voltage collapse events, and avoid any system reliability criteria violations. TPD has revisited the issue and options studied with the latest updated Maui system models and load forecasts. The options are:

- Alternative 1: Construct a new 69 kV transmission line from Waiinu substation to Kanaha substation.
- Alternative 2: Relocate the existing 23 kV transmission line between Waiinu substation and Kanaha substation and its connected elements to the 69 kV network.
- Alternative 3: Build new additional 69 kV MPP-Waiinu, 69 kV MPP-Puunene, and 69 kV Puunene-Kanaha lines of 556 AAC conductor size.
- Alternative 4: Create a link between Kealahou and Kanaha on the 69 kV network via the anticipated new Waena Power Plant (WPP).
- Alternative 5: Install an additional 23/69 kV tie transformer between WPP and Central Maui Landfill Substation (Sub 95), and reconductor the 23 kV section of transmission line from Kanaha to Sub 95.

Figures 4 and 5 below compare the P-V characteristic curves of the various alternatives for the normal condition and the worst N-1 contingency, respectively. It can be seen that Alternative 2 is the most favorable option under normal conditions and most N-1 contingencies. Figure 5 indicates that Alternative 3 is a significantly better option for surviving the most severe N-1 event, the loss of the 69 kV MPP-Waiinu line; this is due to the option involving the construction of three new transmission lines resulting in an extended transfer limit of power to the 23 kV network and improved system reliability in the event of the loss of a transmission line.

Alternative 3 is a considerably more expensive solution that is only favorable under the condition of losing the 69 kV MPP-Waiinu line; in all other cases, its performance is similar or second to the Alternative 2 option. Figure 5 also indicates that Alternatives 4 and 5 are viable solutions for surviving the event of losing the 69 kV MPP-Waiinu. Figures 6, 7, and 8 compare the P-V characteristics of the various alternatives for the loss of the 69 kV MPP-Puunene line, 69 kV Wailuku-Waiinu line, and 69 kV Kanaha-Kahalui line, respectively. From comparing the P-V characteristics of the five alternatives under various N-1 contingency events, TPD has determined:

- Alternatives 1, 2, and 3 are the only viable solutions,
- Alternatives 4 and 5 will result in voltage collapse in the event of losing the 69 kV MPP-Waiinu line
- Alternative 1 is the least favorable solution - has poorer power transfer limit than Alternative 2 and 3, and will violate voltage criteria when 23 kV network load increases by 5 MW .
- Alternative 2 is most favorable solution under normal condition and most N-1 events, and only consists of the upgrade of existing system elements.

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- Alternative 3 is a viable solution and significantly more favorable in the event of losing 69 kV MPP-Waiinu line but involves the construction of 3 new transmission lines.

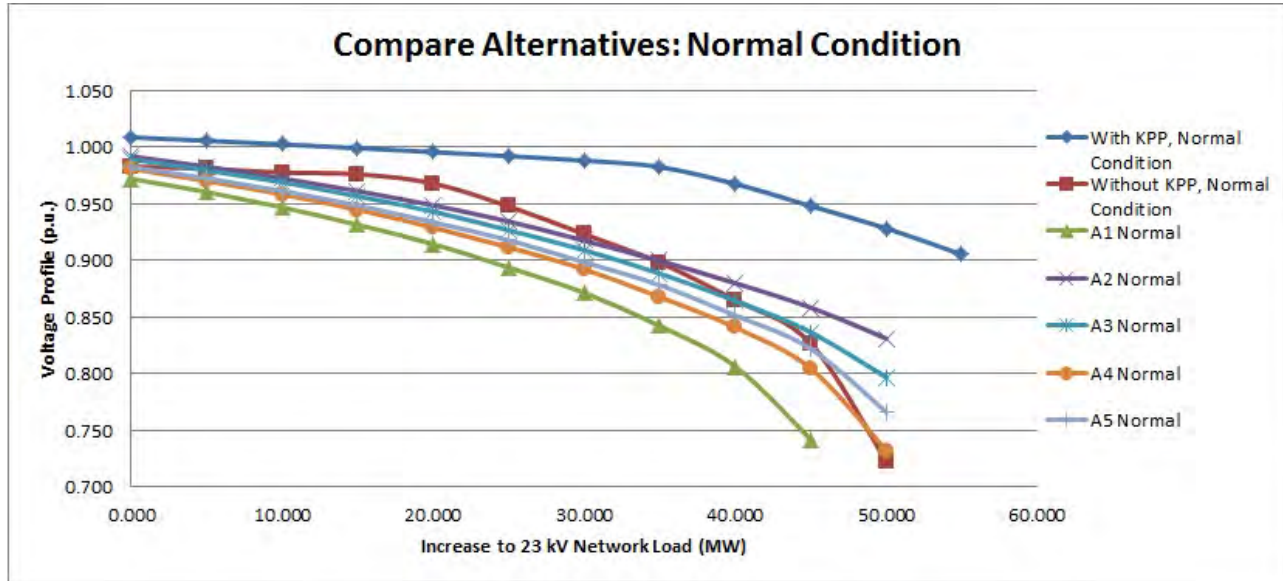


Figure 4: Comparison of P-V characteristics of transmission Alternatives for the normal condition. Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5 are represented by A1, A2, A3, A4, and A5 respectively.

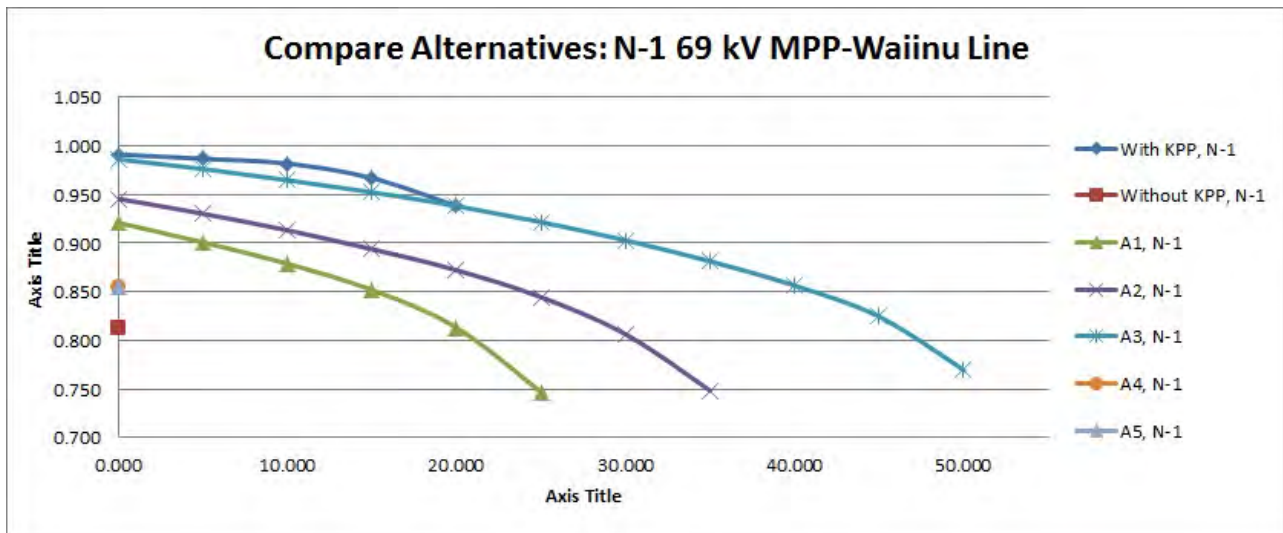


Figure 5: Comparison of P-V characteristics of transmission Alternatives for losing the 69 kV MPP-Waiinu Line. Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5 are represented by A1, A2, A3, A4, and A5 respectively.

Figures comparing P-V characteristics of the scenarios for the rest of the most severe contingencies can be seen in the Appendix.



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TPD recommends Alternative 2 out of the five alternatives considered. Alternative 2 will adequately avoid voltage criteria violations and voltage instability until the 23 kV network has a load growth of 10 MW. Load growth beyond 10 MW will bring about a voltage profile below the acceptable power margin and possibly subject the 23 kV network to an unstable voltage profile. The 23 kV network will reach a growth of 10 MW when the total system peak load grows to approximately 270 MW, which is beyond the forecasted load.

Alternatives 1, 2, and 3 are viable solutions capable of preventing a voltage instability event from occurring on the current system but may not be adequate to endure thermal limit overloading conditions. Several combinations of the five mentioned alternatives with additional system upgrades were considered to address the thermal limit issues; the advantages of combining the alternatives with an additional system upgrade from a voltage stability standpoint will be discussed. The combinations are:

- Combination 1: Alternative 1 combined with the reconductoring of the 69 kV MPP-Waiinu line and 69 kV MPP-Puunene lines to 556 AAC conductor size transmission lines.
- Combination 2: Alternative 1 combined with the construction of a new secondary 69 kV MPP-Puunene transmission line.
- Combination 3: Alternative 1 combined with Alternative 4.
- Combination 4: Alternative 2 combined with the reconductoring of the 69 kV MPP-Waiinu line and 69 kV MPP-Puunene transmission lines to 556 AAC conductor size transmission lines - Combination 4 is the recommended Waiinu-Kanaha Transmission Line Upgrade project.
- Combination 5: Alternative 2 combined with the construction of a new secondary 69 kV MPP-Puunene transmission line.
- Combination 6: Alternative 2 combined with Alternative 4.
- Combination 7: Alternative 3 combined with Alternative 5.

### Waiinu-Kanaha Transmission Line Upgrade project:

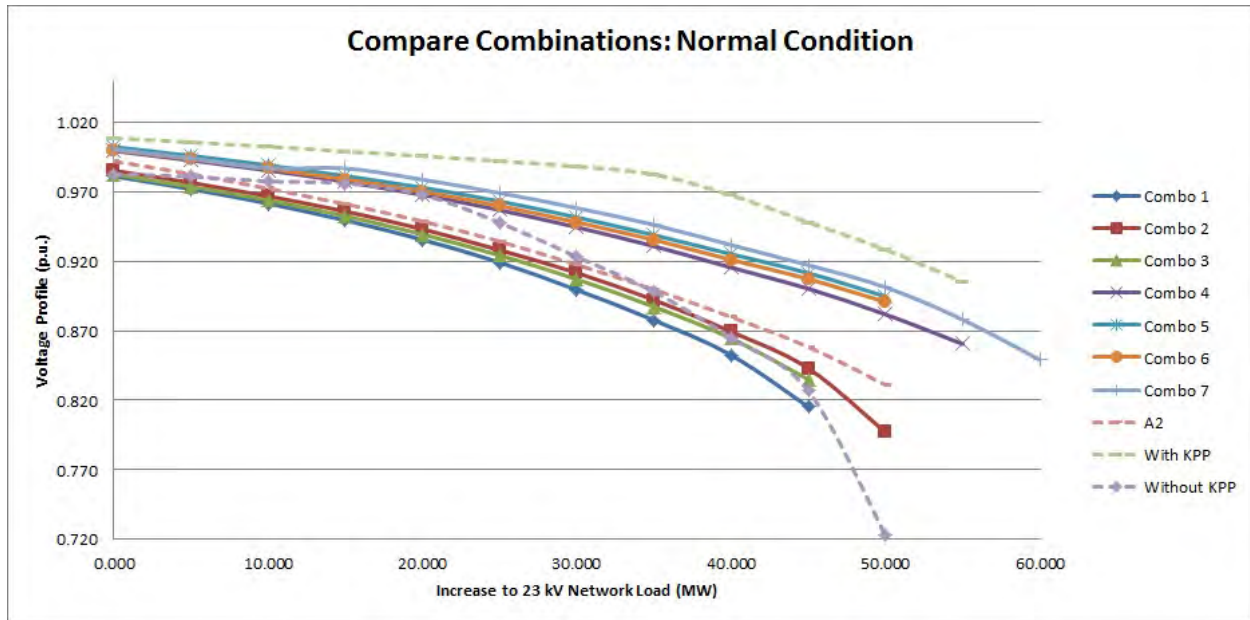
Figures 6 and 7 below show a P-V characteristic comparison of the Maui system with KPP, without KPP, with the Alternative 2 option, and with various combinations of one of the aforementioned alternative options with an additional system upgrade for the normal condition and most severe N-1 condition, respectively.

From a voltage stability standpoint, all combinations mentioned are viable long term solutions capable of maintaining a voltage profile well within the acceptable margin and mitigate unstable voltage profile issues, but it can be seen that only options Combo 5, Combo 6, and Combo 7 produce significantly better P-V characteristics than the suggested Combo 4, which is the recommended alternative in the previous study. However, Combos 5, 6, and 7 involve the construction of one or more new transmission lines. Combo 4 only involves the upgrade of existing transmission lines already on the system (where majority of the line is already capable of being transitioned to 69 kV).

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After revisiting the study with the latest system models and load forecast information, Combo 4 (the Waiinu-Kanaha upgrade project) is still the recommended solution to address the voltage instability issues involved with the retirement of KPP alternative out of all the transmission alternatives.

Figure 8 below shows a P-V characteristic comparison of the Maui system operating with and without KPP, and the system operating without KPP under the scenario that Combo 4 is implemented for the normal condition and most severe N-1 contingency.



**Figure 6: Comparison of P-V characteristics of transmission Combinations for the normal condition. Combination 1, Combination 2, Combination 3, Combination 4, Combination 5, Combination 6, Combination 7, and Alternative 2 are represented by Combo 1, Combo 2, Combo 3, Combo 4, Combo 5, Combo 6, Combo 7, and A2 respectively.**

# Kahului Power Plant Retirement: Voltage Stability Assessment

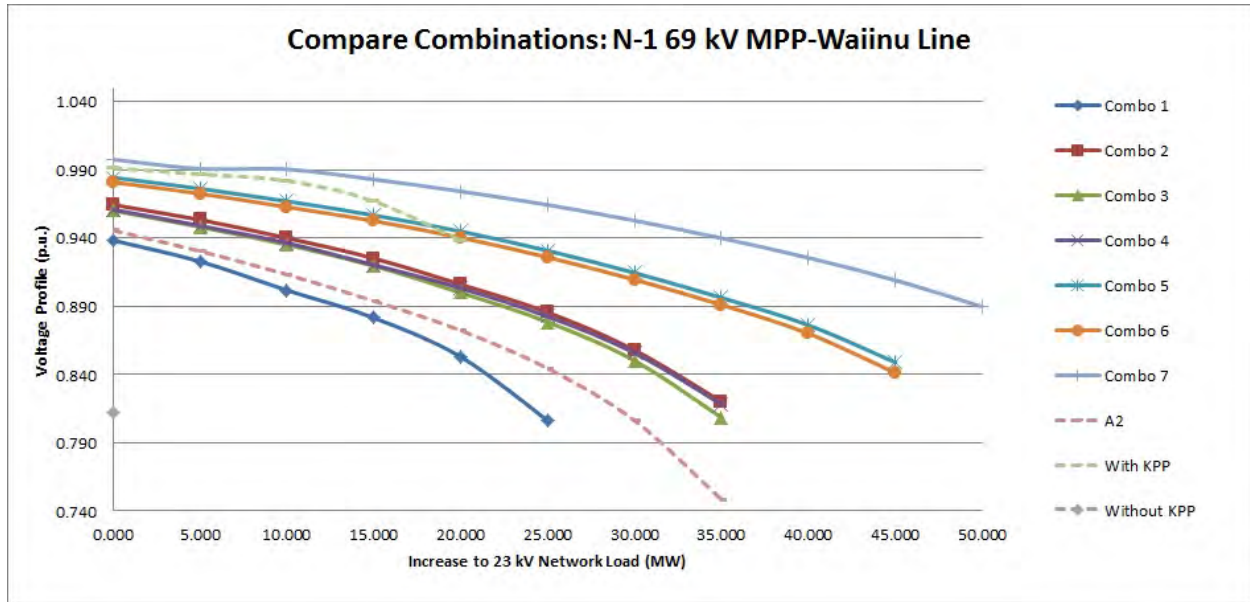


Figure 7: Comparison of P-V characteristics of transmission Combinations for losing the 69 kV MPP-Waiinu Line. Combination 1, Combination 2, Combination 3, Combination 4, Combination 5, Combination 6, Combination 7, and Alternative 2 are represented by Combo 1, Combo 2, Combo 3, Combo 4, Combo 5, Combo 6, Combo 7, and A2 respectively.

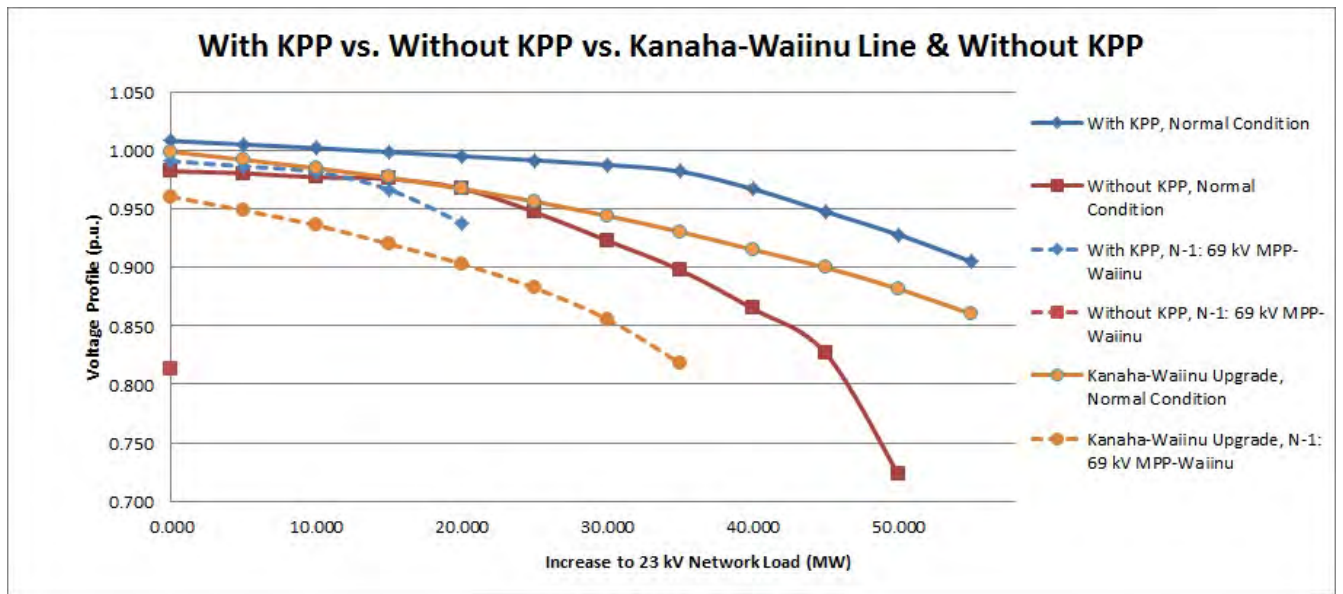


Figure 8: P-V characteristic comparison of the Maui system operating with and without KPP and the system operating without KPP under the scenario that Combo 4 is implemented for the normal condition and most severe N-1 contingency.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### Non-Transmission Alternative (NTA) Solutions

There is an anticipated reserve capacity short fall of approximately 40 MW by year 2019, identified in Section 1.6 of the Maui Electric Adequacy of Supply (AOS) report. TPD has considered the possibility that efforts to procure resources to meet the reserve capacity short fall may void the need for the 23 kV Waiinu-Kanaha line upgrade project and the additional reconductoring of the 69 kV MPP-Puunene and 69 kV MPP-Waiinu transmission lines, and has considered the following Non-Transmission Alternatives (NTA):

- Conversion of some or all existing units at KPP to synchronous condensers.
- New Dispatchable Firm Generation.
- Battery Energy Storage System (BESS).
- Demand Response (DR).

### Synchronous Condenser Option:

A favorable aspect of the synchronous condenser option is that it would take a considerably shorter amount of time to execute than the other NTA alternatives. However, synchronous condensers are reactive support elements that will only supply reactive power to the system. As mentioned before, removing KPP would mean active power demands on the 23 kV network must be supplied solely by the 69 kV network; this will subject the transformers and transmission lines connecting the 23 kV and 69 kV network to heavier loadings that may possibly violate their thermal limit ratings.

From a voltage stability standpoint, the synchronous condenser option is a viable solution for avoiding violations to the voltage criteria and avoiding voltage instability and voltage collapse events; however, it will not mitigate issues regarding thermal overloads on transmission lines and/or tie transformers because synchronous condensers do not provide active power, thus, will not alleviate the extra burden that can be expected to be placed on transformers and transmission lines connecting the 23 kV and 69 kV network when KPP is retired.

KPP is comprised of two large units, K4 and K3, and two smaller units, K1 and K2. K4, K3, K2, and K1 have reactive capabilities of 9.3 MVar, 7.0 MVar, 3.7 MVar, 3.7 Mvar, respectively. Several scenarios were considered: only the largest unit converted to synchronous condenser, the two largest units converted to synchronous condenser, two largest units and one smaller unit converted to synchronous condenser, and all units converted to synchronous condenser. Figures 9 and 10 show the P-V characteristics of the different scenarios of KPP units converted to synchronous condensers for the normal condition and most severe N-1 contingency event.

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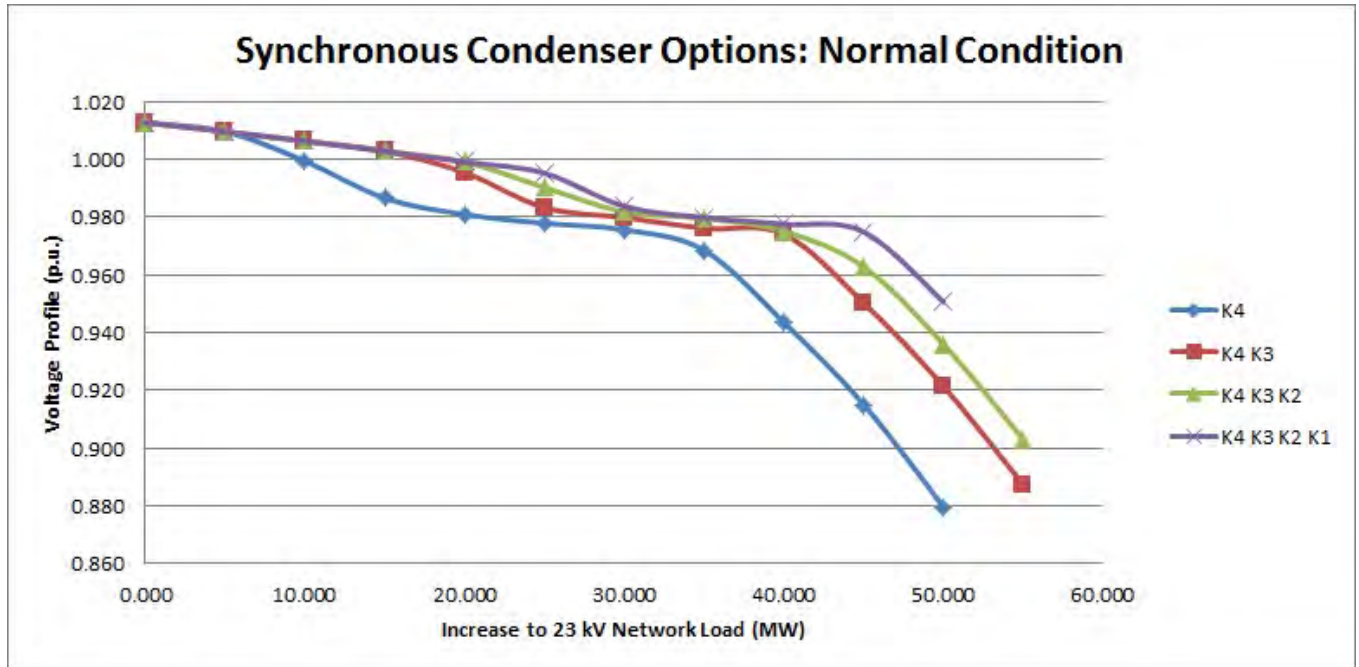


Figure 9: P-V characteristic comparison of different scenarios of KPP units converted to synchronous condensers for the normal condition.

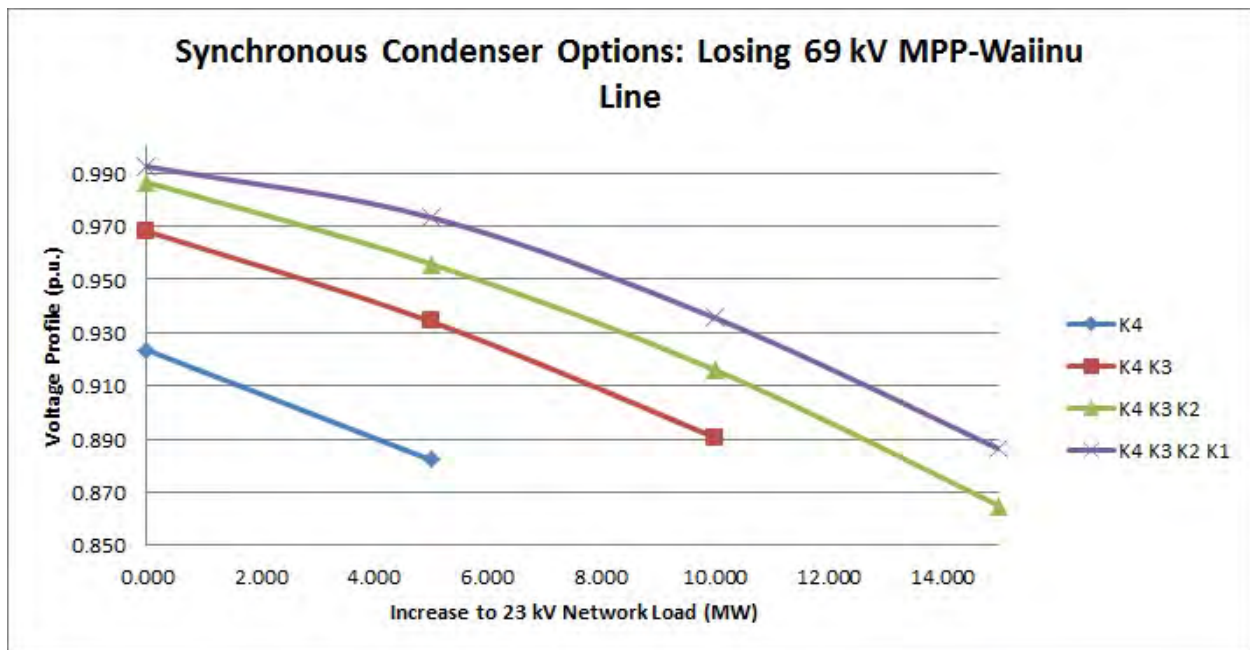


Figure 10: P-V characteristic comparison of different scenarios of KPP units converted to synchronous condensers for the most severe N-1 contingency event.

## New Dispatchable Firm Generation:

If the company intends to procure new generation to meet the reserve capacity shortfall, the new generation units may potentially void the need for the Waiinu-Kanaha upgrade project

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depending on the location of interconnection of the new units. If the new generation is interconnected on the 23 kV network, from a voltage profile standpoint, the system can be expected to behave similar to the existing system with KPP in operation as this would only involve replacing the existing older generation units with new ones – this will not place a burden on the transmission lines and tie transformers that connect the 23 kV and 69 kV network and voltage sources are still close to the 23 kV network load center. However, if the new generation is interconnected to the 69 kV network, the system is expected to experience the same system issues source of generation on the 23 kV being removed; placing new generation units on the 69 kV network will not alleviate burden placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network, and will not provide reactive support to the 23 kV network – this will still result in the 23 kV network becoming heavily dependent on the 69 kV network for power and may possibly overload the transmission lines and tie transformers that connect the 23 kV and 69 kV network past their rated thermal limits and subject voltage sources to be electrically farther from the 23 kV network load center. A few scenarios of new firm generation on the 23 kV network were considered and compared to the existing operating KPP which has an approximate 35 MW capacity; they are: one new 8 MW unit, one new 15 MW unit, and two new 8 MW units. The P-V characteristic comparison of these scenarios for the normal condition and most severe N-1 contingency are shown in Figure 11 and Figure 12, respectively. For the scenario of new generation connecting to the 69 kV network, the capacity of new generation is arbitrary from a voltage standpoint as the option would not mitigate the issues mentioned. For the study, the scenario considered for study is the first stage of the Waena Power Plant (WPP) project proposed by First Wind – a new 17 MW unit at the WPP site near Pukalani; The P-V characteristics of this scenario is compared with the existing system with and without the operation of KPP, shown in Figure 13.

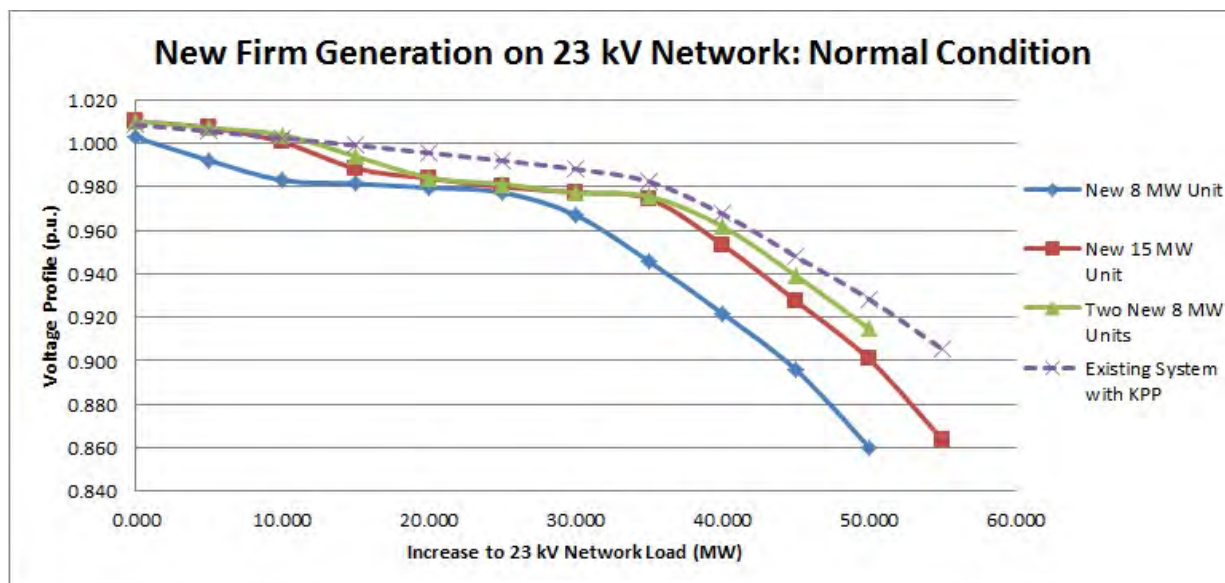


Figure 11: P-V characteristic comparison of different scenarios of new generation of various capacities on the 23 kV network and the existing system for the normal condition.

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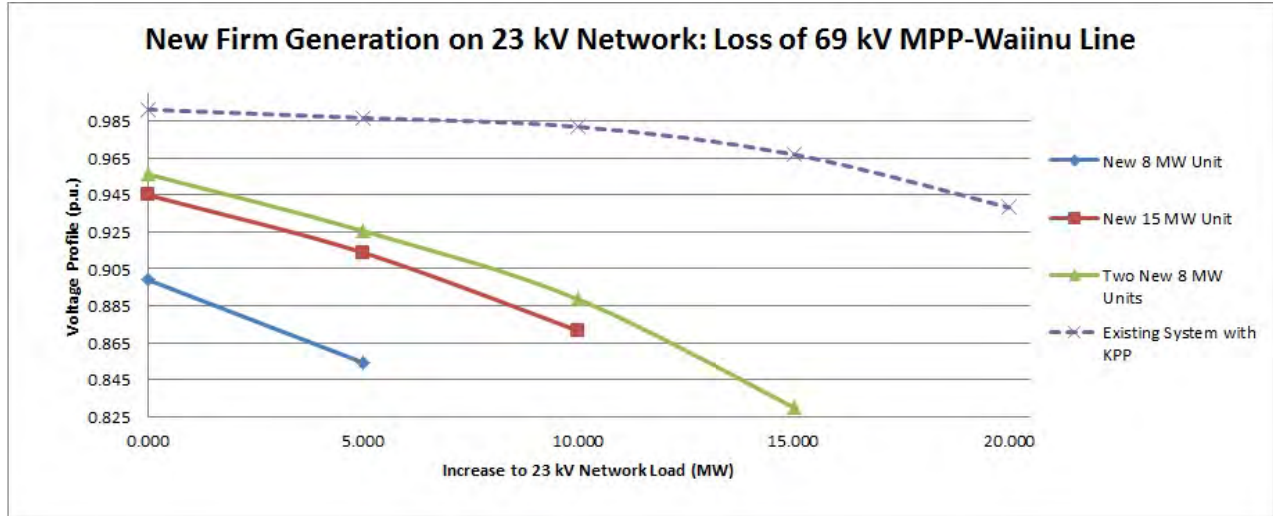


Figure 12: P-V characteristic comparison of different scenarios of new generation of various capacities on the 23 kV network and the existing system for the most severe N-1 contingency event.

It can be observed that the more capacity of new generation added to the 23 kV network, the closer the P-V curve representing new generation approaches the P-V curve that represents the existing system with KPP, which has an approximate 35 MW capacity. This indicates that in order to achieve system characteristics better than the existing system with KPP, the capacity of new generation must be greater than the existing capacity at KPP (i.e. 35 MW). It can be seen that at the existing system load, the new 8 MW unit and new 15 MW unit scenarios settle at point close to the end of a curve – these are unstable voltage points. The two new 8 MW unit scenario is much more favorable as it settles at a point farther away from voltage collapse. Installing more capacity of new generation on the 23 kV network will allow the system to operate farther away from the point of voltage collapse.

Voltage issues arise when total system load reaches 170 MW and is accompanied by a severe N-1 contingency if KPP is decommissioned and no additional system upgrades are implemented. The new generation units must be brought online when total system load reaches 170 MW to avoid violations to the reliability criteria and possible compromise of system reliability. Historically, system load has been observed to remain at 170 MW or above for approximately 7 hours, see Appendix.

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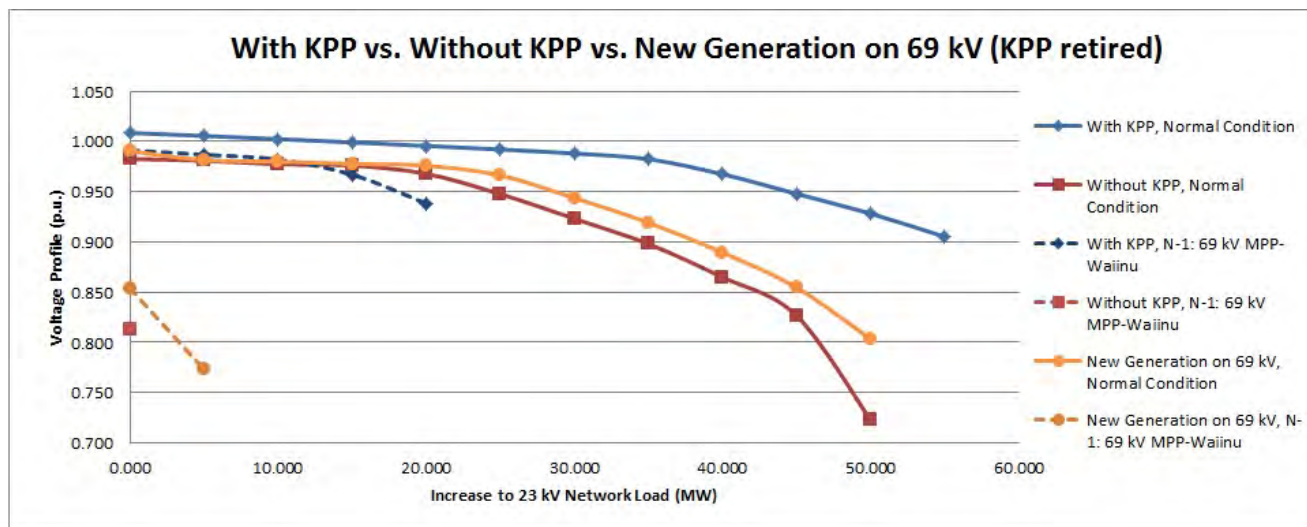


Figure 13: P-V characteristic comparison of the scenario of new generation on the 69 kV network, the existing system with KPP, and the existing system without KPP for the normal condition and most severe N-1 contingency event.

### Battery Energy Storage System (BESS) Option:

It is assumed in this study that BESS will be operated to predominantly provide active power because pursuing a battery for the purpose of providing reactive support would be uneconomical as there are less expensive alternatives available that fulfill these needs such as capacitor banks or the already mentioned synchronous condenser option; in this study, the BESS units are modeled to operate at a 0.95 power factor to reflect a unit which predominantly provides active power and minimum reactive power. The BESS option, if located on the 23 kV network, is anticipated to mitigate the thermal limit violation issues involved with the retirement of KPP because it will supply active power to the 23 kV network which will alleviate the stress placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network when KPP is decommissioned and is also anticipated to mitigate the voltage violation, voltage instability, and voltage collapse issues. However, there are several ambiguities concerning the battery that need to be clarified before it can be determined if the BESS option is a viable, economic, or engineering sound solution to address the issues involved. These ambiguities include: where will the battery be located (on the 23 kV or 69 kV network), will the battery operate as a normal dispatchable unit or solely for the purpose of mitigating system issues during emergency events, what is the size of the battery. For planning purposes, these ambiguities need to be addressed.

Similar to the afore mentioned issue in the discussion concerning the new dispatchable firm generation option, if the battery is placed on the 69 kV, the battery will contribute no significant mitigation measures as the voltage sources are still electrically far from the 23 kV network load center and the burden placed on the transmission lines and tie transformers that connect the 23 kV and 69 kV network is not lessened. However, placing the battery on the 23 kV network will alleviate much of the burden placed on the transmission lines and tie transformers that connect



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the 23 kV and 69 kV network because the battery (i.e. an active and reactive power source) is placed near the load and thus assuages the dependency on power to be supplied by the 69 kV network and aids in mitigating voltages violation, voltage instability, and voltage collapse issues on account that the battery, a voltage source, is closer to the 23 kV network load center. If the battery is operated as a normal dispatchable unit, where the battery will be dispatched to serve peaking system load demands when needed, it raises the issue whether or not there will be sufficient charge in the battery to mitigate system issues in the event of an emergency. However, if the battery is operated to solely be dispatched during emergency events, it raises the question whether or not the battery option is an economical solution. The battery would need to be sized to provide power long enough for the N-1 contingency to be resolved or until total system load recedes below afore mentioned threshold of 170 MW. It has been mentioned that the battery could be used to mitigate system issues just long enough for addition distributed generation sources (fuel units) to be brought online; this option would only be viable if the distributed generation sources, which need to be procured, are on the 23 kV network and would be uneconomical to pursue as the distributed generation source alone would be adequate to mitigate the issues, as seen in the new dispatchable firm generation option.

Several scenarios of different size batteries were considered: a 15 MW BESS, a 20 MW BESS, and a 25 MW BESS. Figures 14 and 15 compare the P-V characteristics of the various sized BESS for the normal condition and most severe N-1 contingency event, respectively. It can be seen in Figure 15 that for all scenarios, the BESS option is viable long term solution capable of mitigating voltage issues; this option is adequate until the 23 kV network load increases by approximately 10 MW, in other words, until the total system load reaches approximately 247 to 250 MW, which is beyond the scope of load forecast.

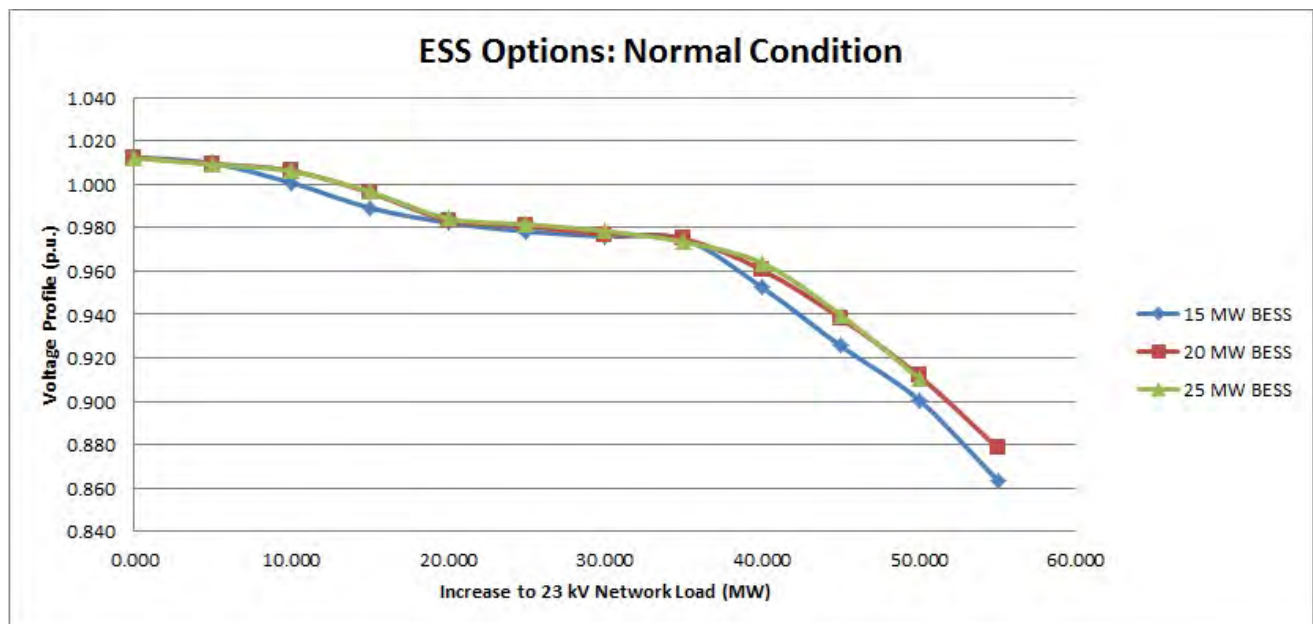


Figure 14: Comparison of P-V characteristics of various sized BESS for the normal condition.

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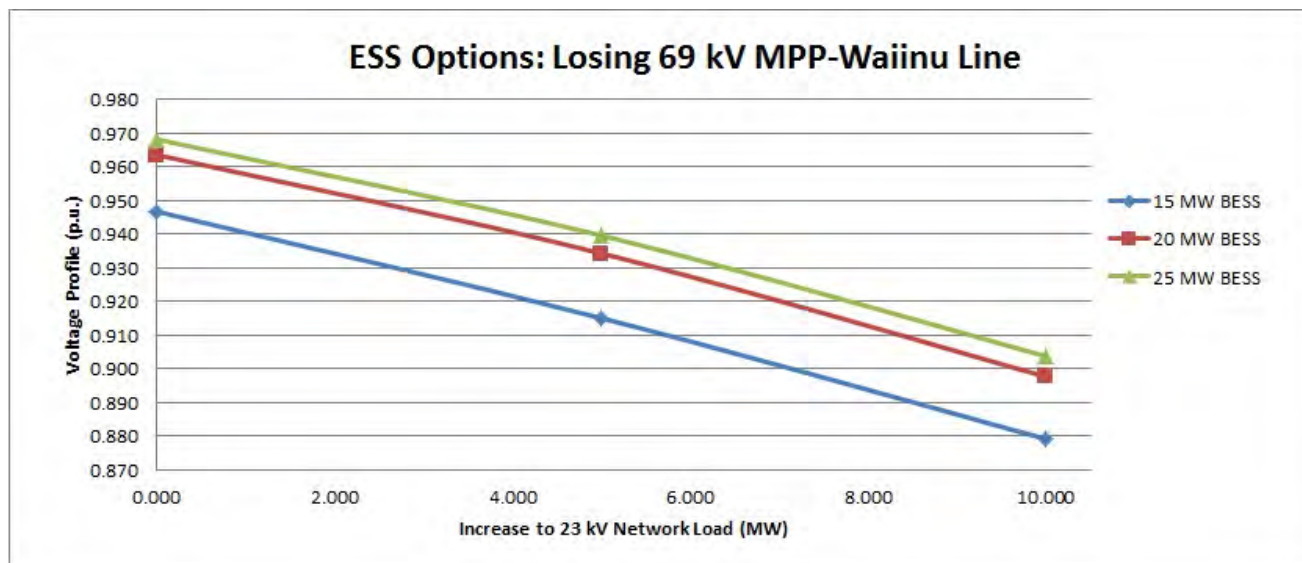


Figure 15: Comparison of P-V characteristics of various sized BESS for the most severe N-1 contingency event.

### Demand Response:

The concept of the Demand Response (DR) option to be utilized for the effort of mitigating issues involved with the retirement of KPP is end-use customer consumption of power will be reduced in response to a contingency event to avoid the risk of jeopardizing system reliability. This should operate similarly to existing load shedding schemes – DR program must execute within several cycles of detecting indications that system reliability is at risk of being compromised. As mentioned, voltage issues arise when total system load reaches 170 MW and is accompanied by a severe N-1 contingency if KPP is decommissioned and no additional system upgrades are implanted. The DR program must drop end-use customer load to maintain total system load within the 170 MW benchmark to avoid voltage violation, voltage instability, and voltage collapse issues in the event of a contingency.

### Comparing the NTA options:

For the purpose of comparing the NTA options, if numerous scenarios were considered for a NTA option, the scenario that produced the most favorable results was selected to be compared against the other options. The scenario of converting all existing units at KPP to synchronous condensers was selected for the synchronous condenser option, the scenario of two new 8 MW units was selected for the option of installing new firm generation units on the 23 kV network option, and the 25 MW BESS scenario was selected for the BESS option to represent its respective NTA option for comparison. Figure 16 and Figure 17 shown below compare the P-V characteristics of the various NTA options against the Kanaha-Waiinu upgrade and existing system with and without the operation of KPP for the normal condition and most severe N-1 contingency, respectively.

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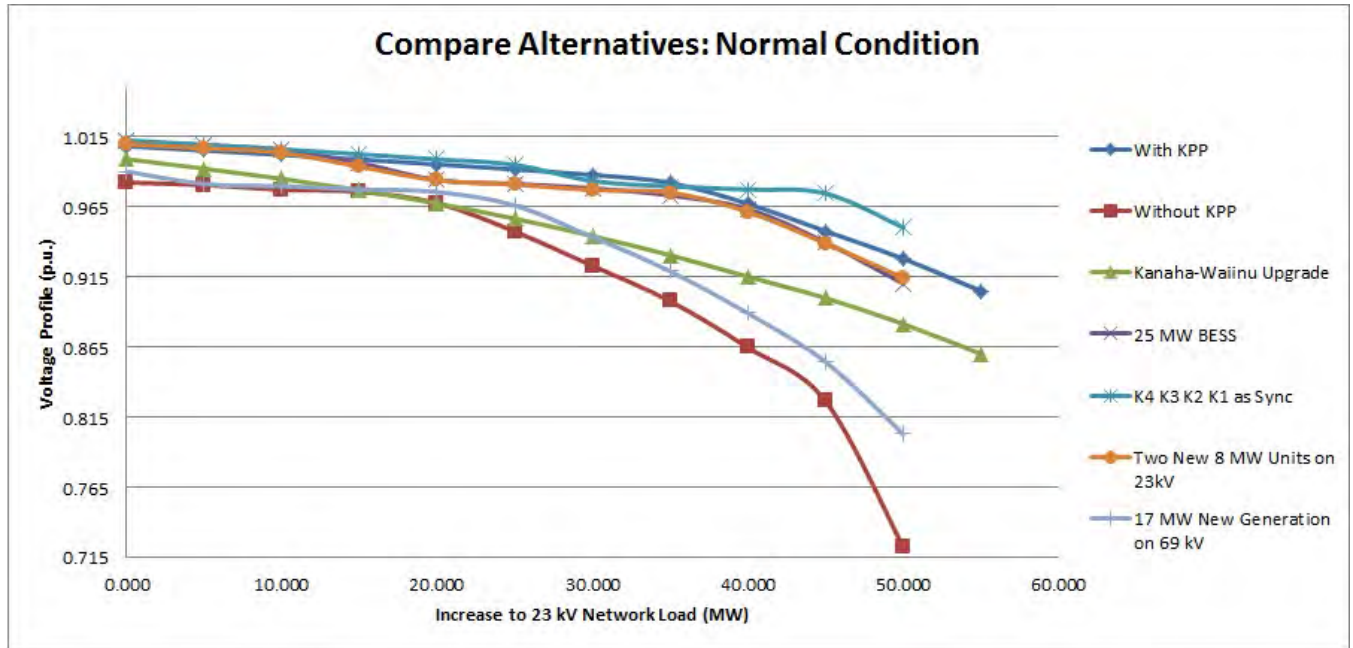


Figure 16: Comparison of P-V characteristics of various NTA options against the Kanaha-Waiinu upgrade and existing system with and without operation of KPP for the normal condition.

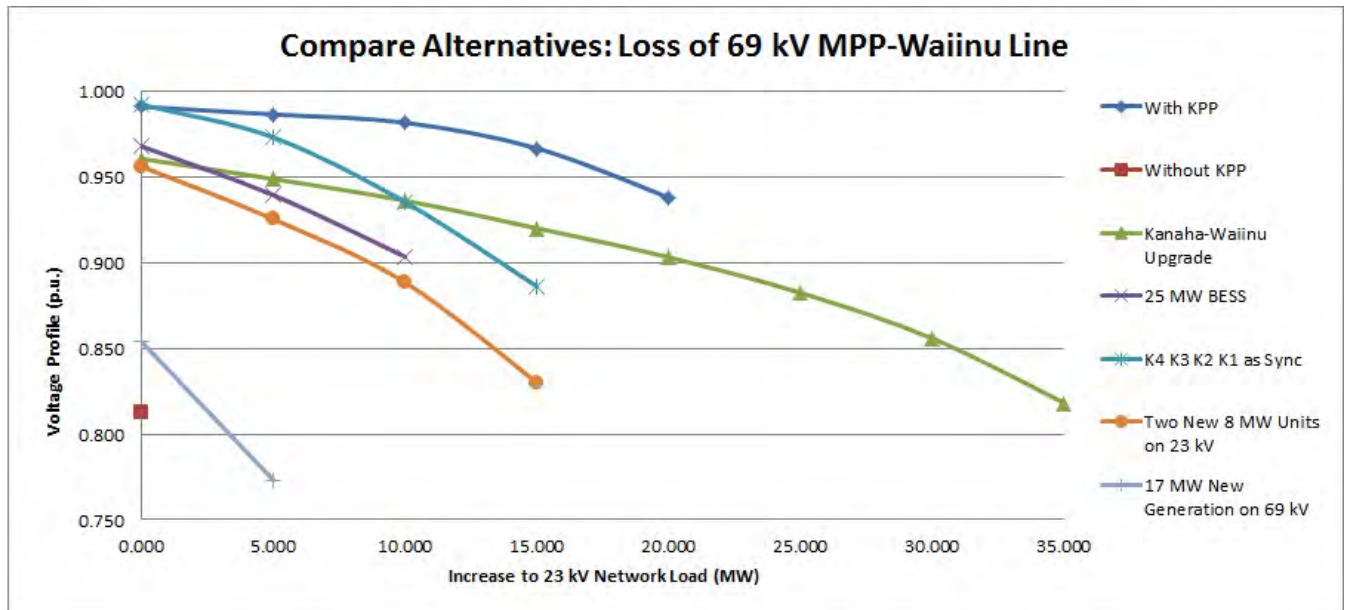


Figure 17: Comparison of P-V characteristics of various NTA options against the Kanaha-Waiinu upgrade and existing system with and without operation of KPP for the most severe N-1 contingency.

Several points should be considered when interpreting Figure 17. The synchronous condenser option seemingly has more favorable results than the BESS and new firm generation on the 23 kV network option, however, results shown are strictly examining the voltage profile; there thermal limit issues involved with the KPP retirement that the synchronous condenser option will

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not mitigate. The capacity values of new firm generation and BESS considered were arbitrarily selected; it should be noted that choosing to install greater capacity values of BESS and new generation (to be installed on the 23 kV network) units will produce P-V characteristics closer to the curve representing existing system with operation of KPP.

## Kahului Power Plant Retirement: Voltage Stability Assessment

### Compare and Contrast Options:

Table 1: Comparison of Transmission and Non-Transmission options studied.

| Options                       | Adequate Until...                             |  |  | Load forecast indicates this will occur in: |
|-------------------------------|---|--|--|---|
|                               | Growth on 23 kV Network load (in MW) reaches: | In other words, when system peak load (in MW) reaches: |  |   |
| Waiinu-Kanaha Upgrade project | 20  | Over 270   |  | N/A*  |
| 15 MW BESS on 23 kV           | 5   | 225  |  | N/A*  |
| 20 MW BESS on 23 kV           | 5 – 8   | 225 – 240  |  | N/A*  |
| 25 MW BESS on 23 kV           | 10  | 247  |  | N/A*  |
| K4 as Sync                    | 2 – 3   | 200 – 203  |  | 2016 – 2017                                 |
| K4 & K3 as Sync               | 5 – 8   | 225 – 240  |  | N/A*  |
| K4, K3, & K2 as Sync          | 10  | 247  |  | N/A*  |
| K4, K3, K2, & K1 as Sync      | 10 – 12                                       | 247 – 260  |  | N/A*  |
| New 8 MW unit on 23 kV        | 0   | 200  |  | 2014 – 2015                                 |
| New 15 MW unit on 23 kV       | 5   | 225  |  | N/A*  |
| Two new 8 MW unit on 23 kV    | 5 – 8   | 225 – 240  |  | N/A*  |
| New 17 MW unit on 69 kV       | 0   | 200  |  | 2014 – 2015                                 |

N/A\* - indicates that the option will be adequate until the system peak load reaches load value that is beyond what is reported in load forecast; the load forecast has forecasted system peak load values until year 2030, thus, these options are adequate even beyond the year 2030 (from a voltage standpoint).

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### Conclusion

From a voltage standpoint, the Waiinu-Kanaha upgrade project, BESS option, synchronous condenser option, and installing new firm dispatchable generation on the 23 kV network option are viable long term solutions to mitigate voltage issues involved with the retirement of KPP. However, considering the possibility of thermal overloads occurring on the transmission lines and tie transformers that connect the 23 kV and 69 kV network when KPP is decommissioned, TPD does not recommend the synchronous condenser option as an alternative to the Waiinu-Kanaha upgrade project. If new firm dispatchable generation is procured to meet the reserve capacity shortfall, installing the new units on the 23 kV network will mitigate voltage issues and is anticipated to mitigate thermal issues involved with the retirement of KPP, however, installing the generation units on the 23 kV network conflicts with MECO's ultimate plan of converting the entire Maui transmission system to 69 kV. On the other hand, the Waiinu-Kanaha upgrade project mitigates voltage and thermal issues, aligns with MECO's ultimate plan, and also increases the reliability of the system in the aspect that the project will provide a second line to feed Waiinu – in the event of the current most severe N-1, losing the MPP-Waiinu line, the upgraded Waiinu-Kanaha line will provide power to the Waiinu substation to feed the 23 kV network load. The BESS option produces similar results to the option which involves installing new firm generation on the 23 kV network if the BESS is placed on the 23 kV network, however, TPD considers it to be uneconomical to pursue the BESS option considering the possible dispatch scenarios of the BESS unit and its similar characteristics to the new firm generation option. TPD recommends that the company's interest in the procurement of new firm generation, BESS, DR, or any other means to meet the approximate 40 MW reserve capacity short fall by 2019 should not affect or void the plan of the Waiinu-Kanaha upgrade project. TPD still recommends the implementation of the Waiinu-Kanaha upgrade project as it will ensure that the retirement of KPP will not jeopardize system reliability and transition portions of the existing 23 kV network to 69 kV, thus progressing MECO's ultimate plan of converting the entire Maui transmission network to 69 kV and improve the overall system reliability.

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# Appendix

## Kahului Power Plant Retirement: Voltage Stability Assessment

The comparison of P-V characteristics for the N-1 events of losing the 23 kV Kanaha-Kahului line, 69 kV Maalaea-Puunene line, and 23 kV Wailuku-Waiinu lines are shown below.

Existing system with and without operation of KPP:

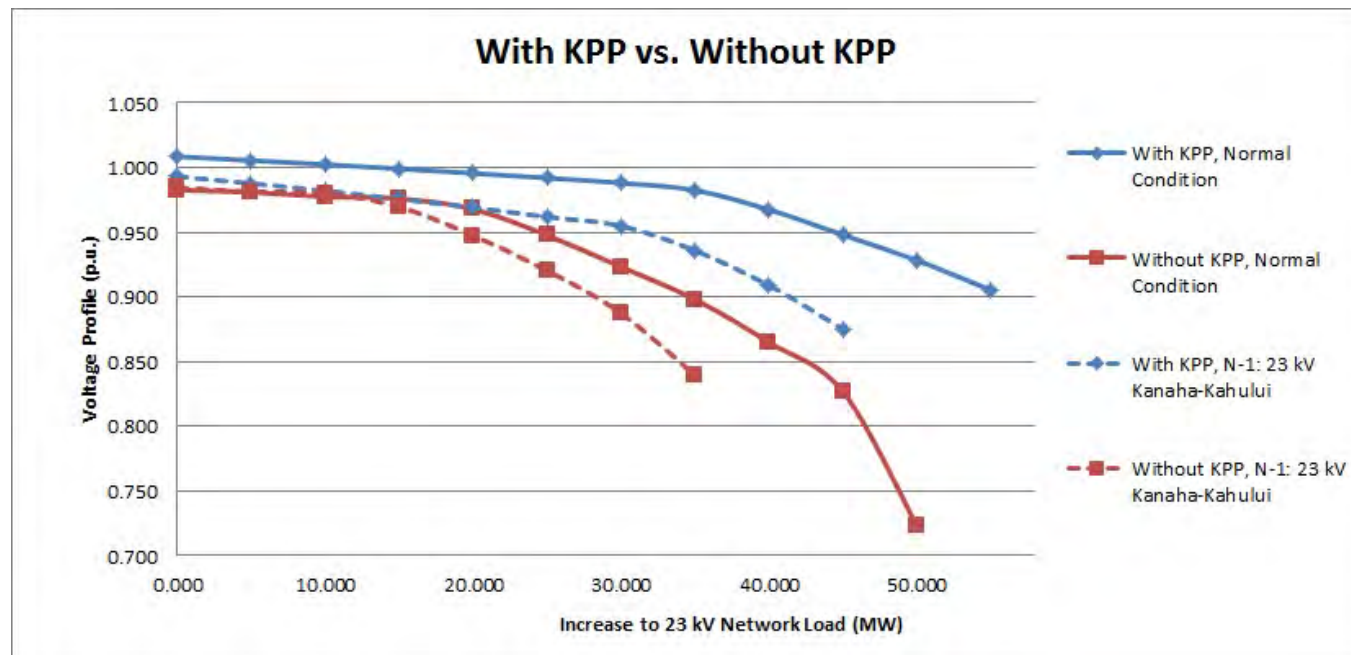


Figure 18: P-V characteristics of existing system with and without KPP for losing 23 kV Kanaha-Kahului Line.

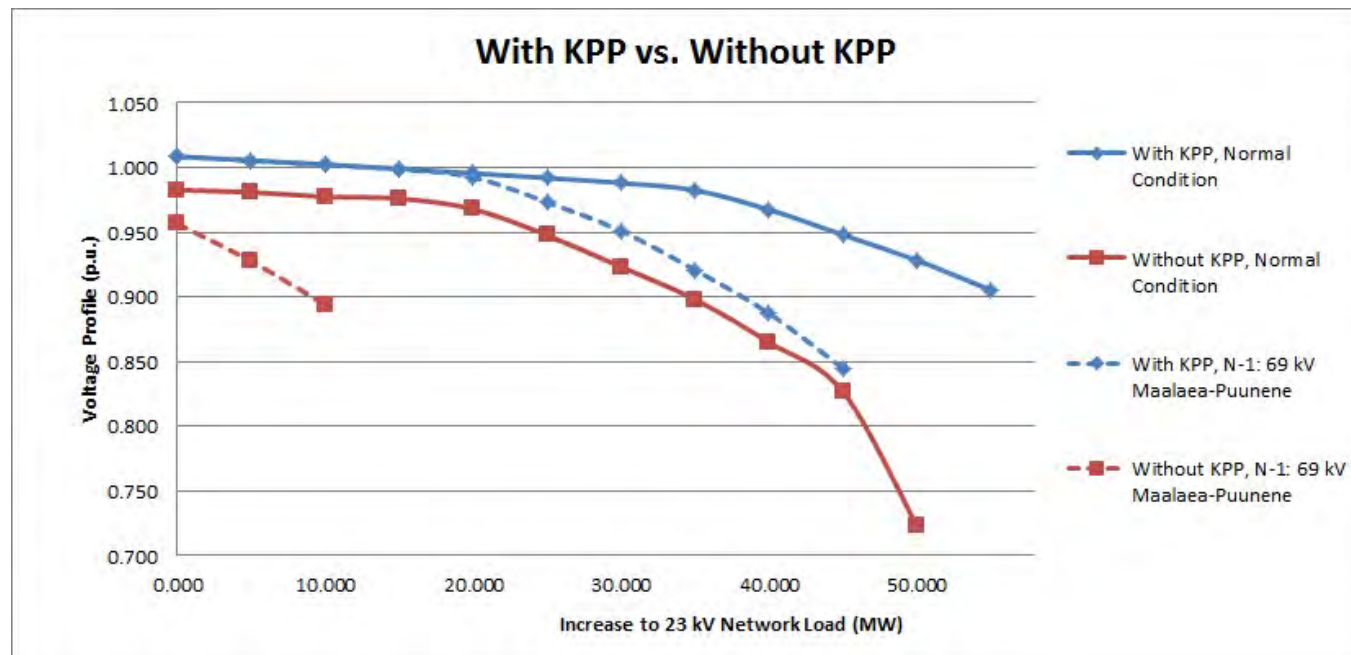


Figure 19: P-V characteristics of existing system with and without KPP for losing the 69 kV MPP-Puunene Line.



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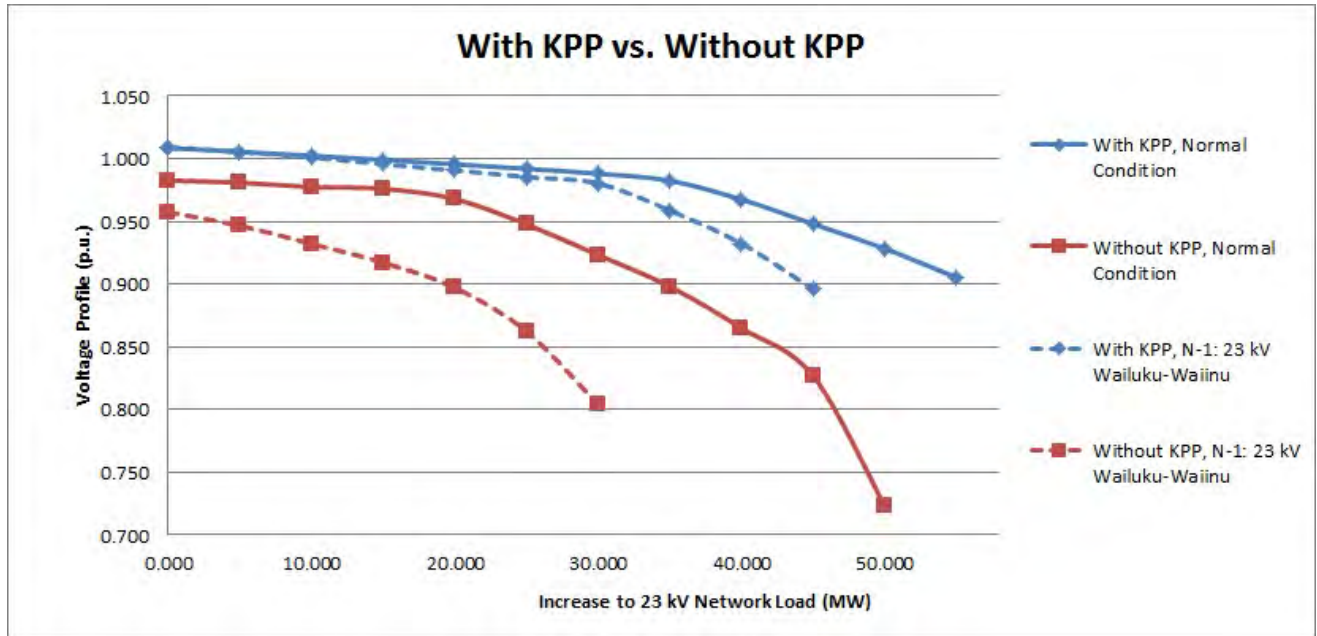


Figure 20: P-V characteristics of existing system with and without KPP for losing 23 kV Wailuku-Waiinu Line.

P-V characteristic comparison of Alternative 1 - Alternative 5:

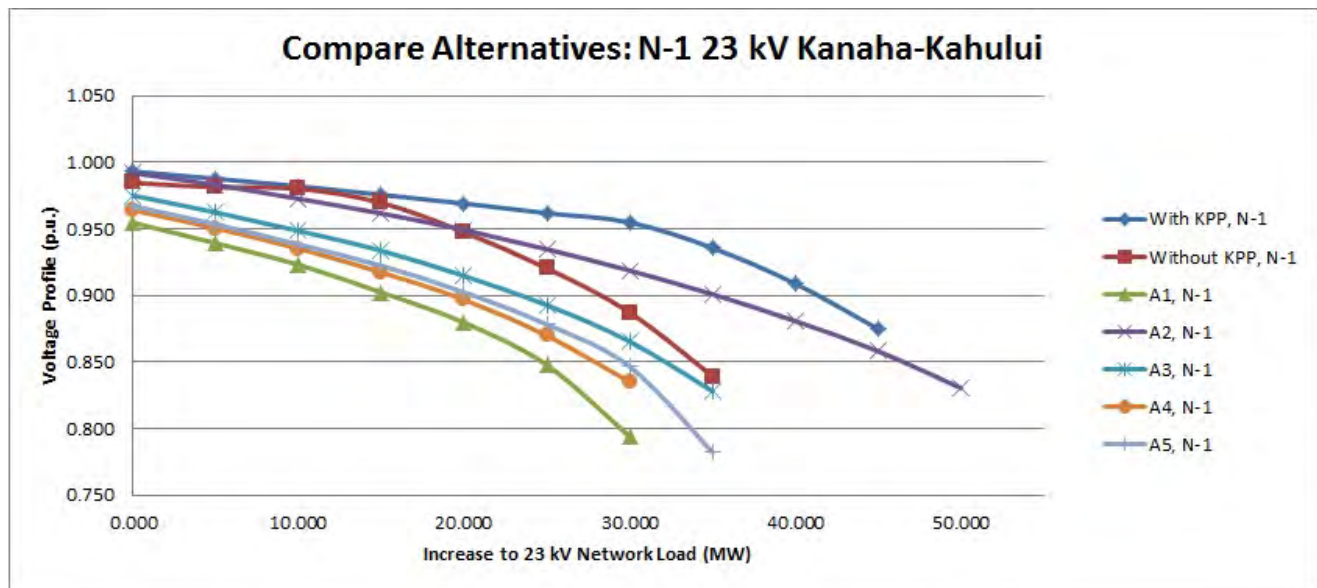


Figure 21: Comparison of P-V characteristics of transmission Alternatives for losing the 23 kV Kanaha-Kahului Line.

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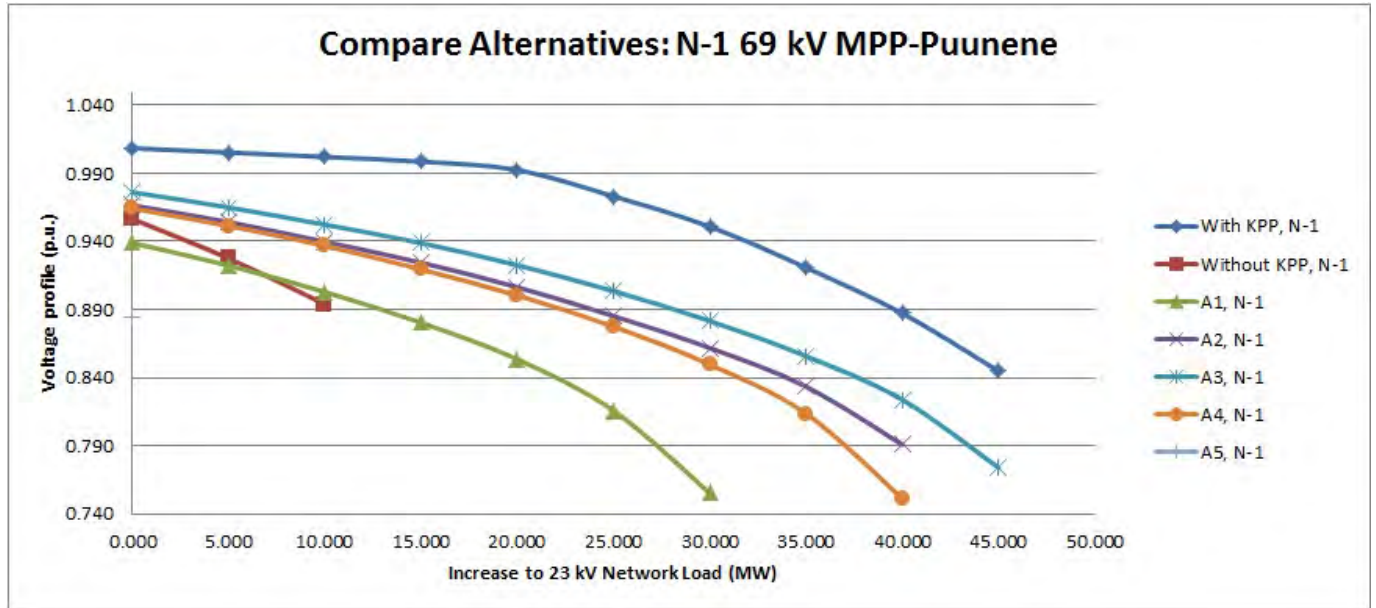


Figure 22: Comparison of P-V characteristics of transmission Alternatives for losing the 69 kV MPP-Puunene Line.

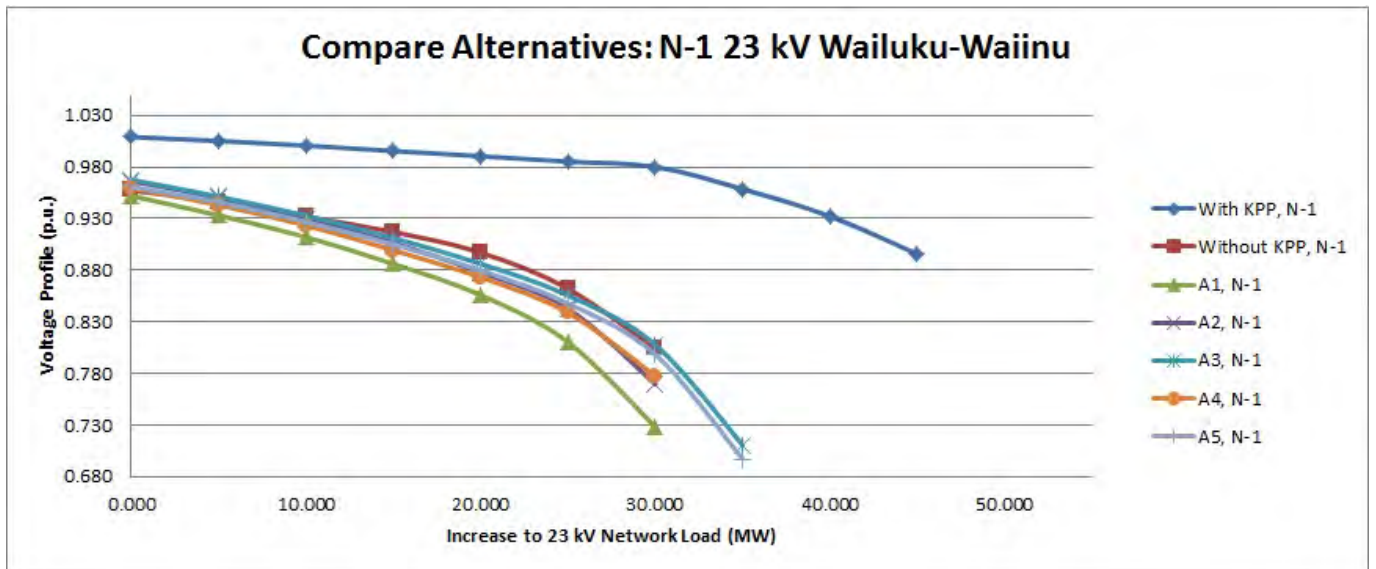


Figure 23; Comparison of P-V characteristics of transmission Alternatives for losing the 23 kV Wailuku-Waiinu Line.

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P-V characteristic comparison of Combination 1- Combination 7:

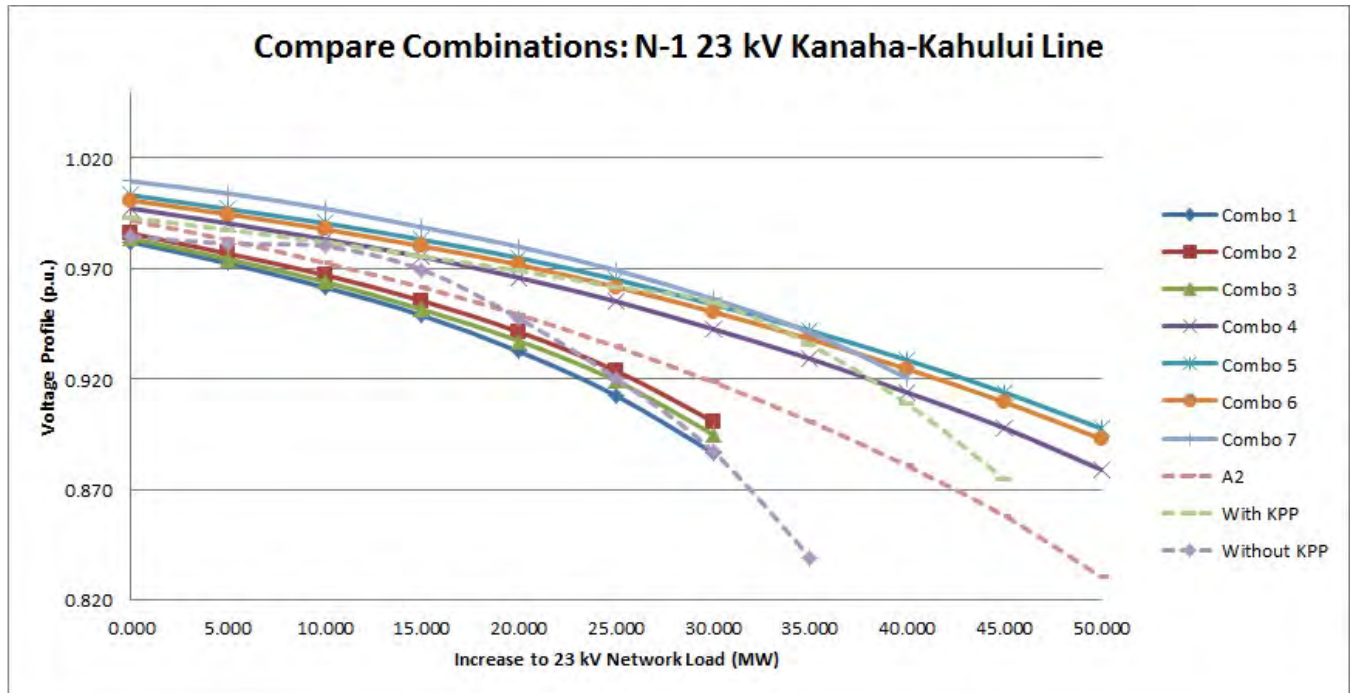


Figure 24; Comparison of P-V characteristics of transmission Combinations for losing the 23 kV Kanaha-Kahului Line.

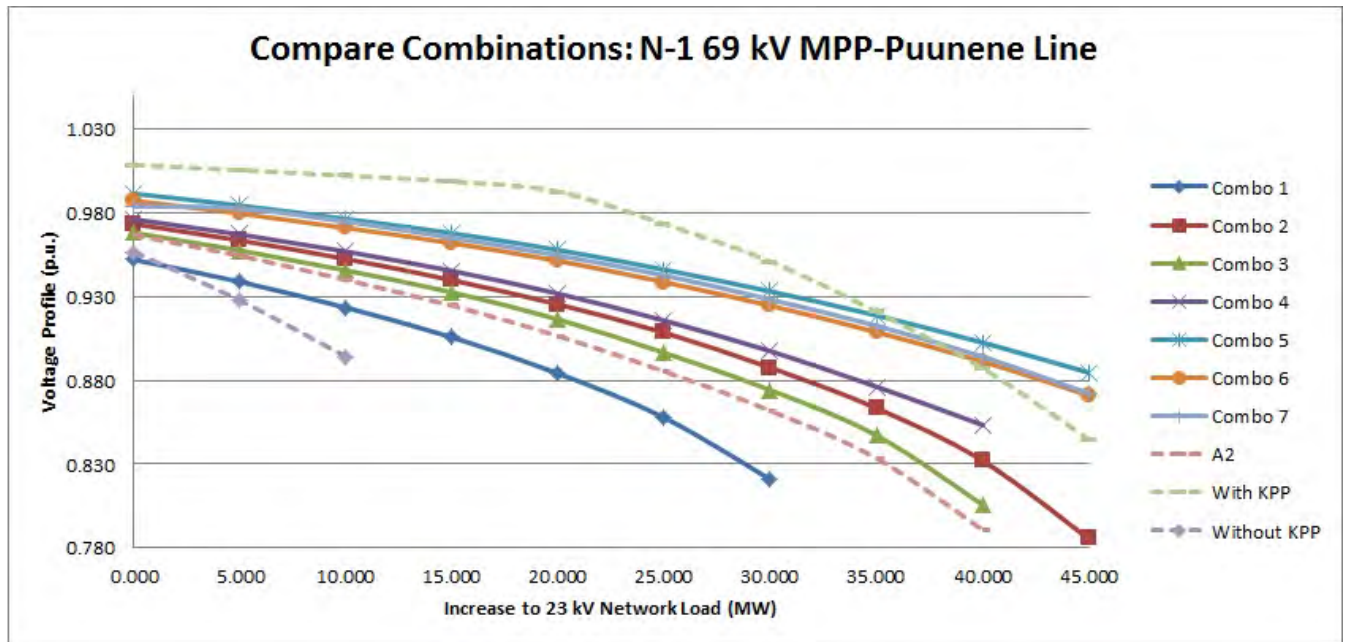


Figure 25 Comparison of P-V characteristics of transmission Combinations for losing the 69 kV MPP-Puunene Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

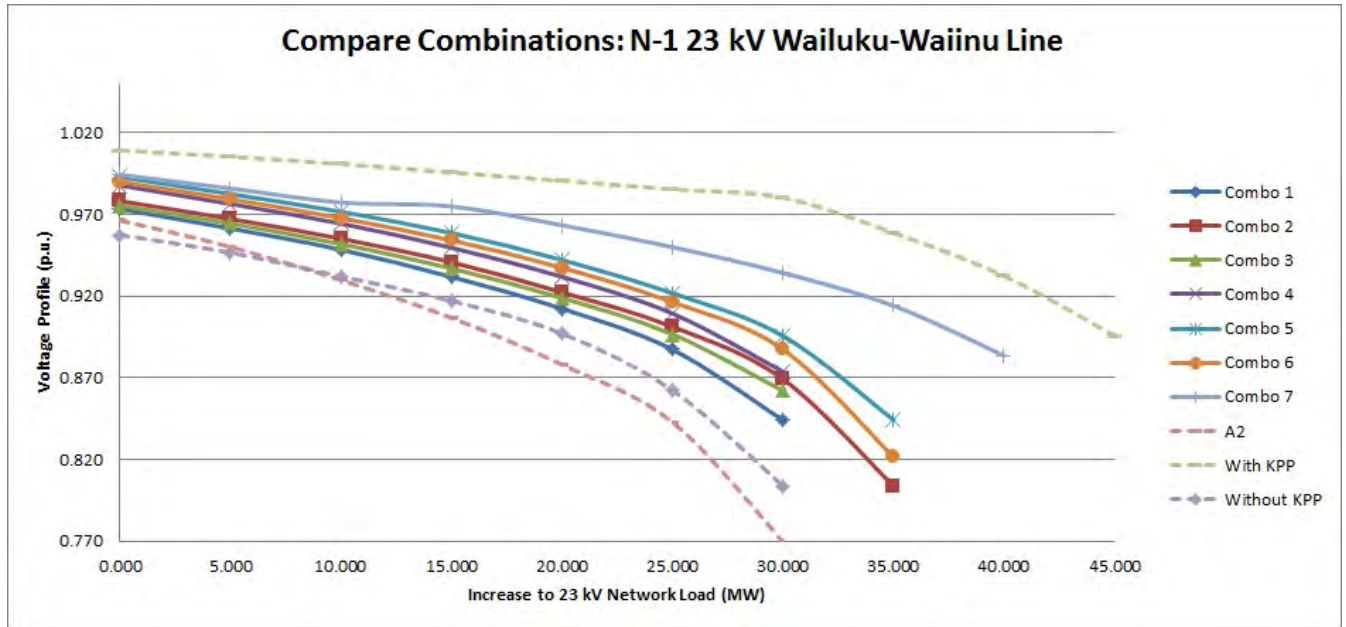


Figure 26: Comparison of P-V characteristics of transmission Combinations for losing the 23 kV Wailuku-Waiinu Line.

Synchronous Condenser Option:

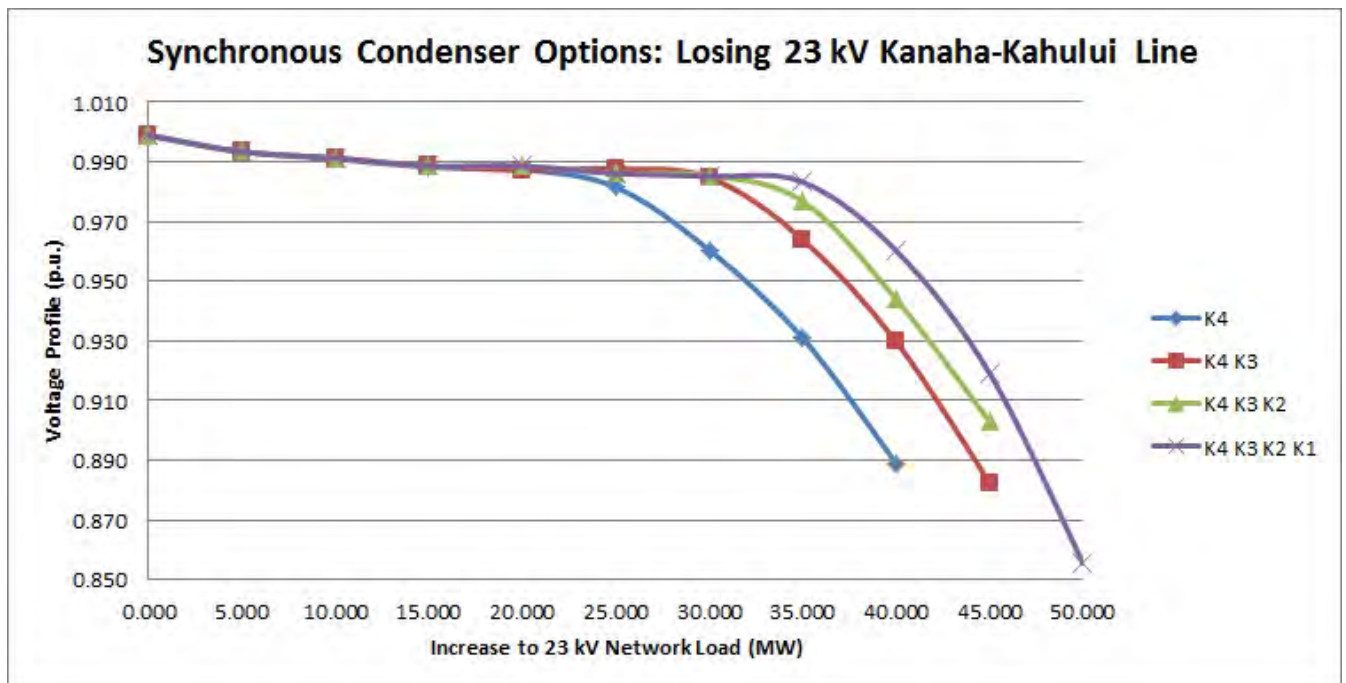


Figure 27: Comparison of P-V characteristics of synchronous condenser options for losing the 23 kV Kanaha-Kahului Line.

# Kahului Power Plant Retirement: Voltage Stability Assessment

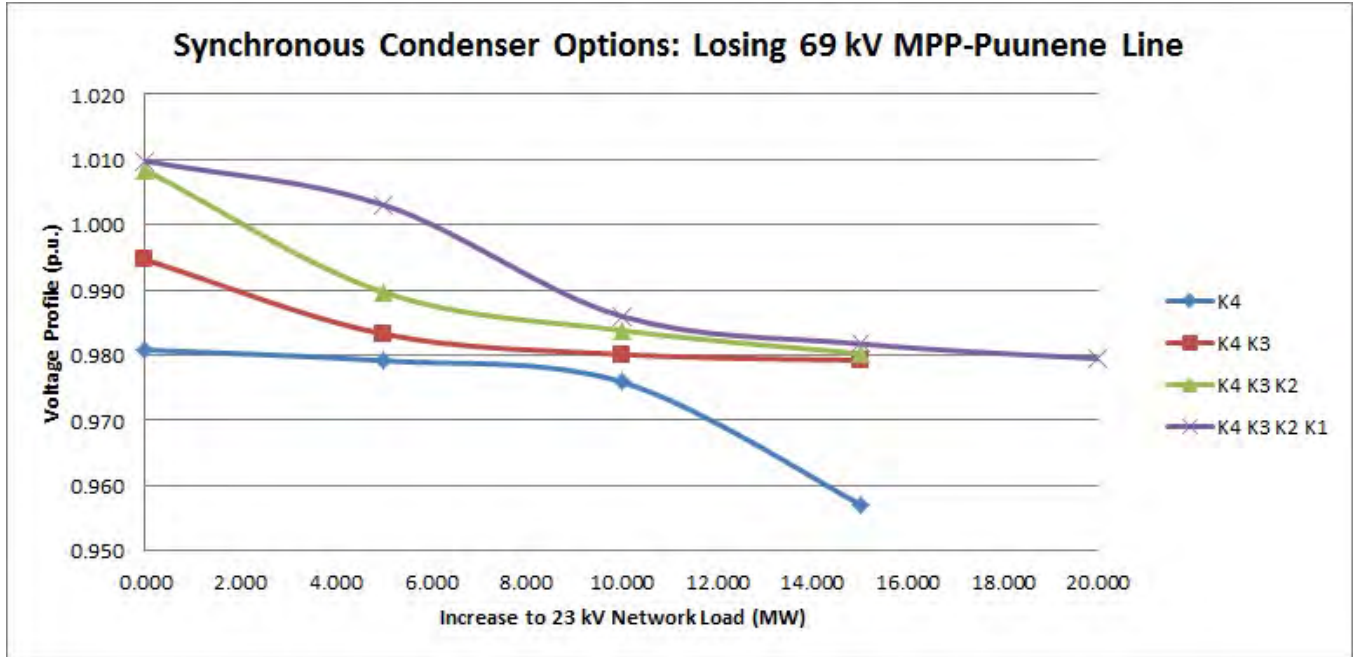


Figure 28: Comparison of P-V characteristics of synchronous condenser options for losing the 69 kV MPP-Puunene Line.

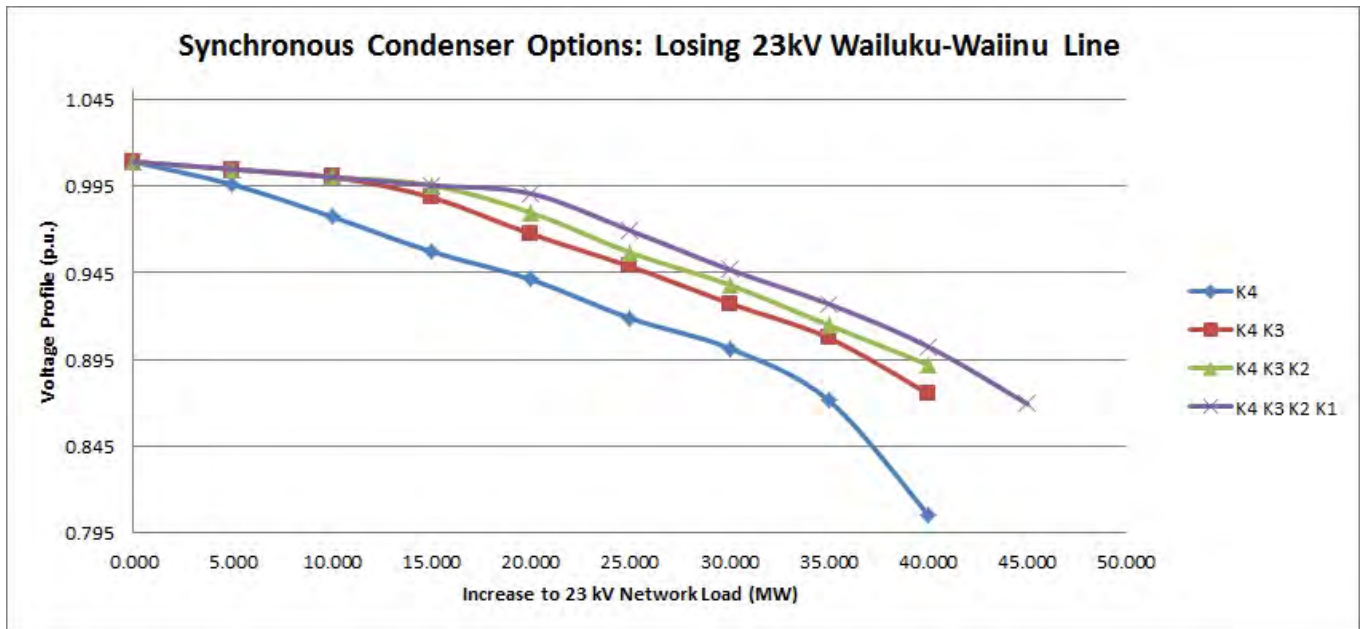


Figure 29: Comparison of P-V characteristics of synchronous condenser options for losing the 23 kV Wailuku-Waiinu Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

### New Firm Generation on 23 kV Network Option:

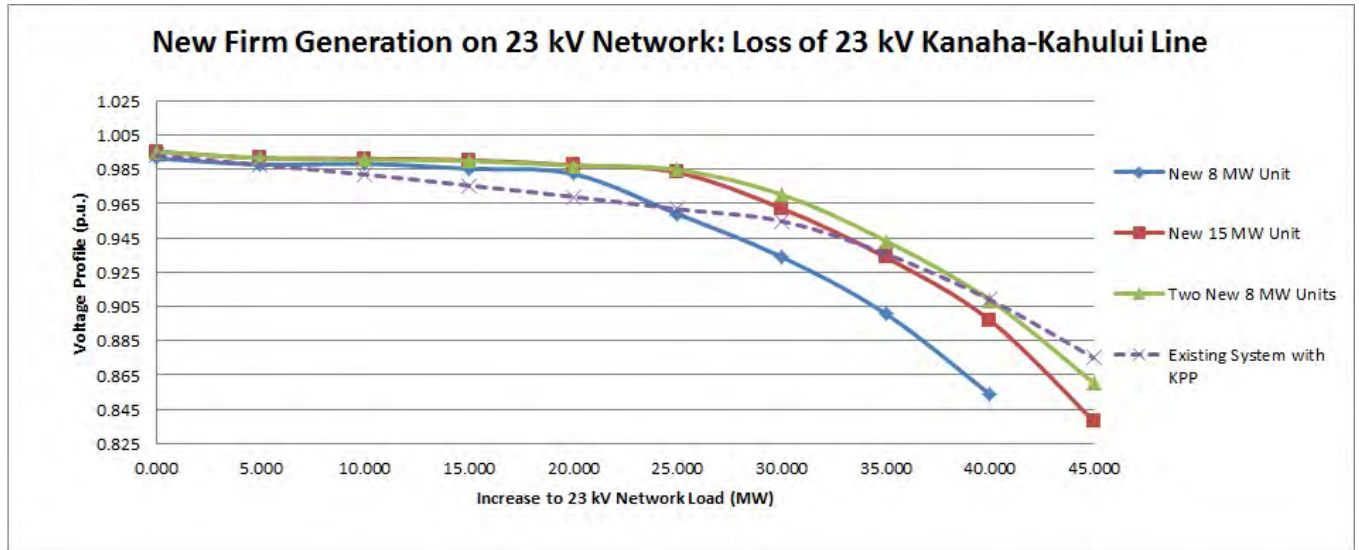


Figure 30: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 23 kV Kanaha-Kahului Line.

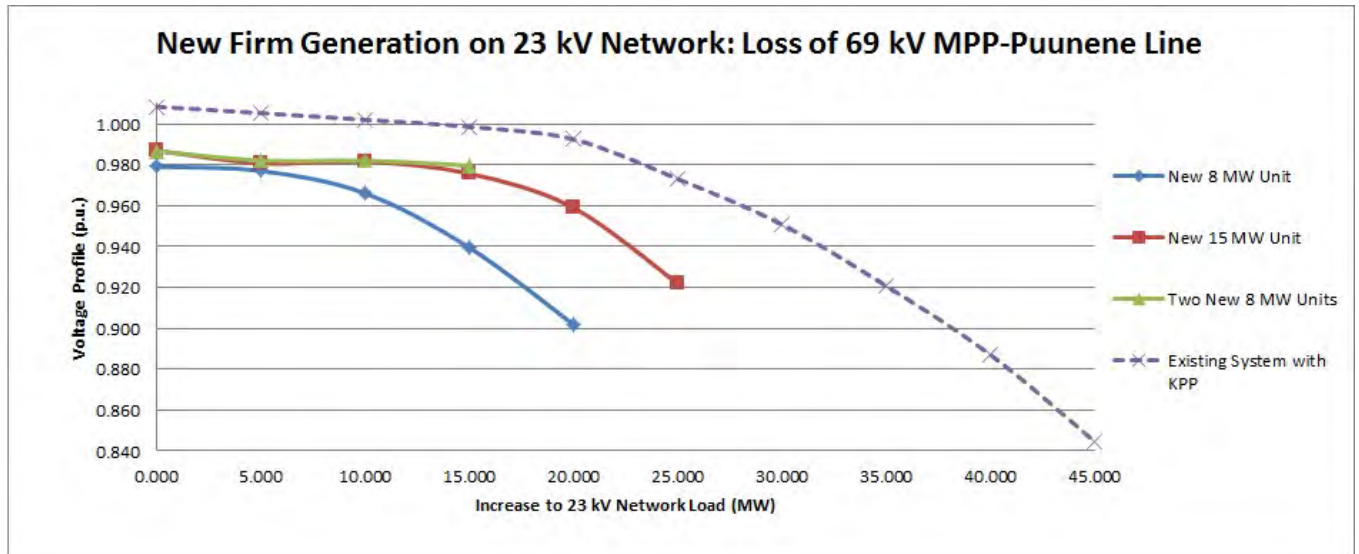


Figure 31: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 69 kV MPP-Puunene Line.

# Kahului Power Plant Retirement: Voltage Stability Assessment

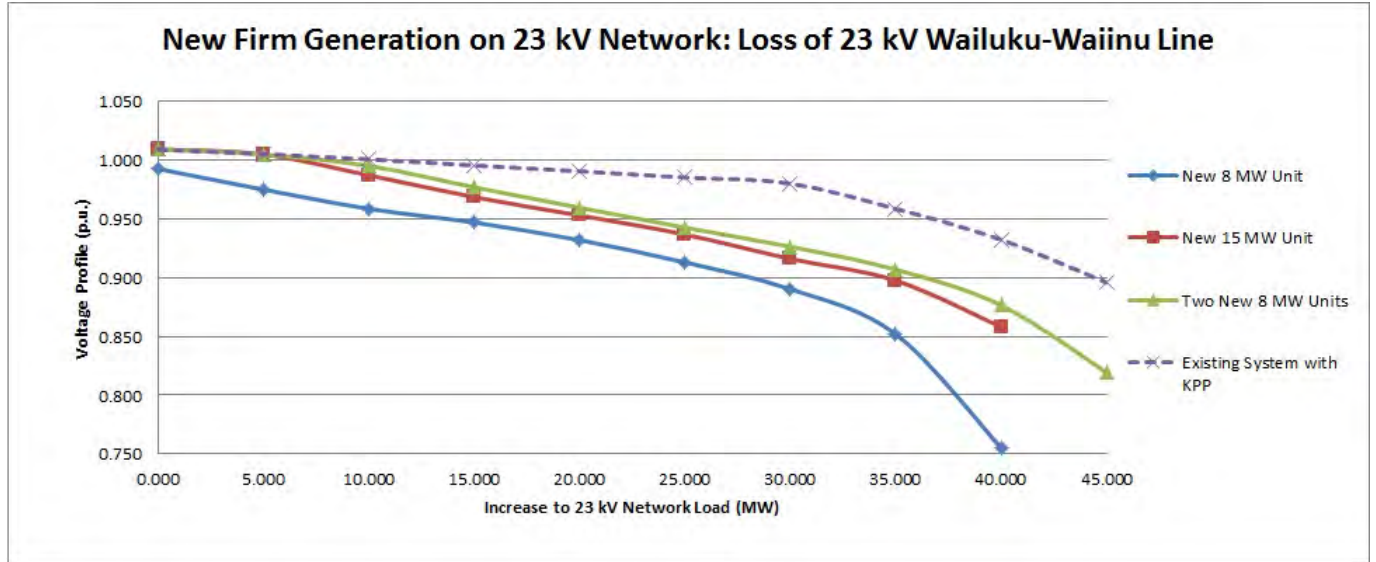


Figure 32: Comparison of P-V characteristics for new firm generation on 23 kV network option for losing the 23 kV Wailuku-Waiinu Line.

## New Firm Generation on the 69 kV Network Option:

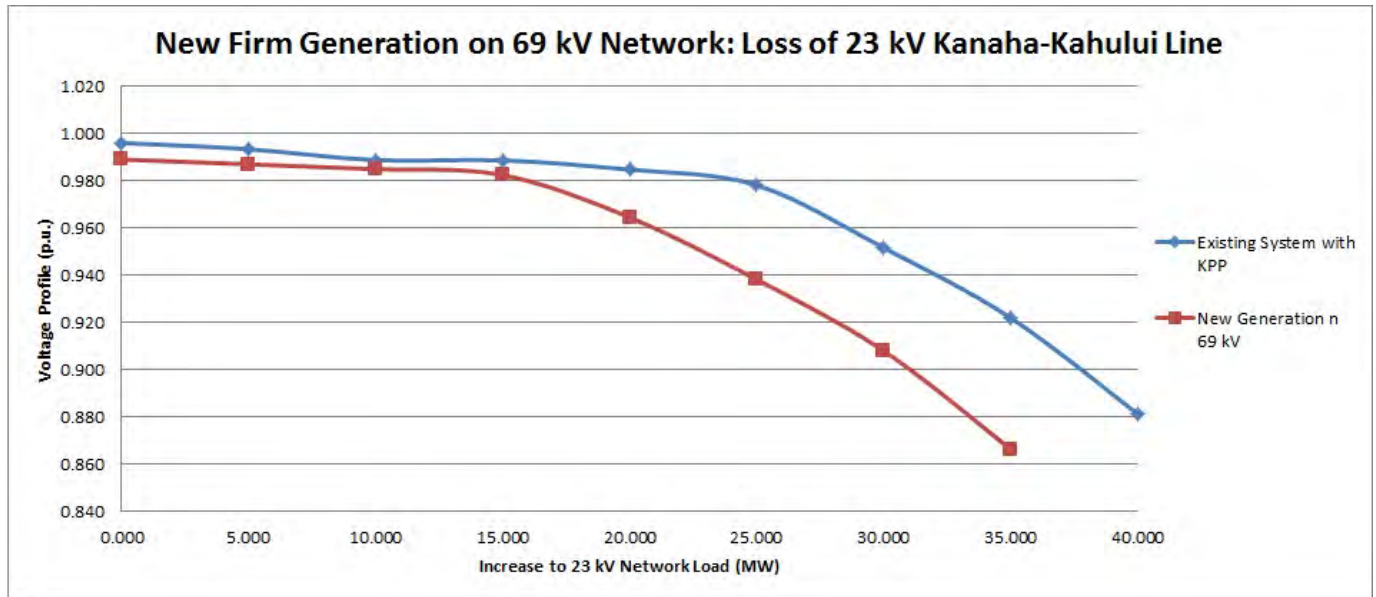


Figure 33: Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 23 kV Kanaha-Kahului Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

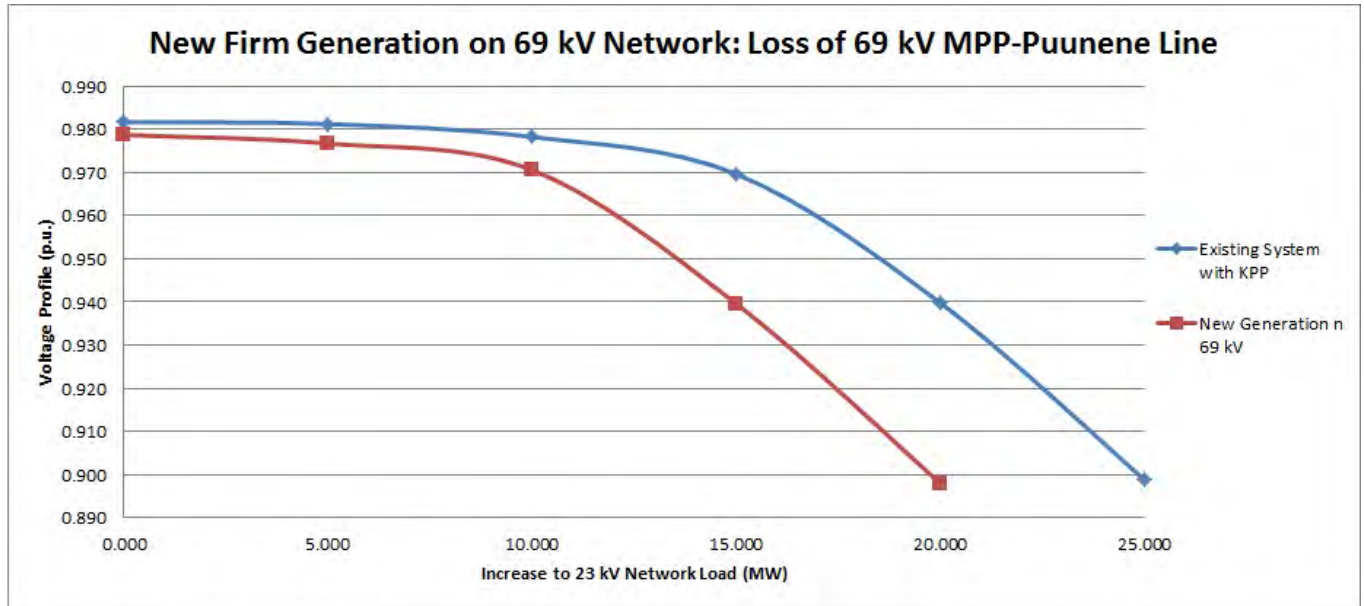


Figure 34: Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 69 kV MPP-Puunene Line.

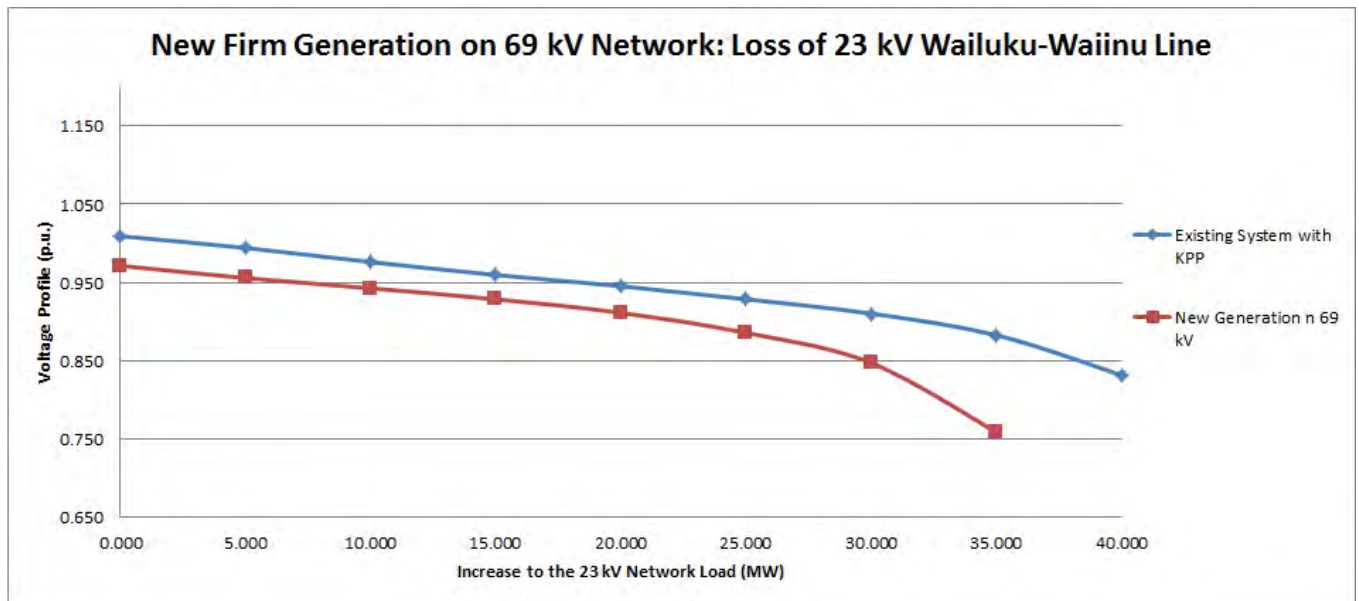


Figure 35; Comparison of P-V characteristics of new firm generation on 69 kV network for losing the 23 kV Wailuku-Waiinu Line.



# Kahului Power Plant Retirement: Voltage Stability Assessment

BESS Option:

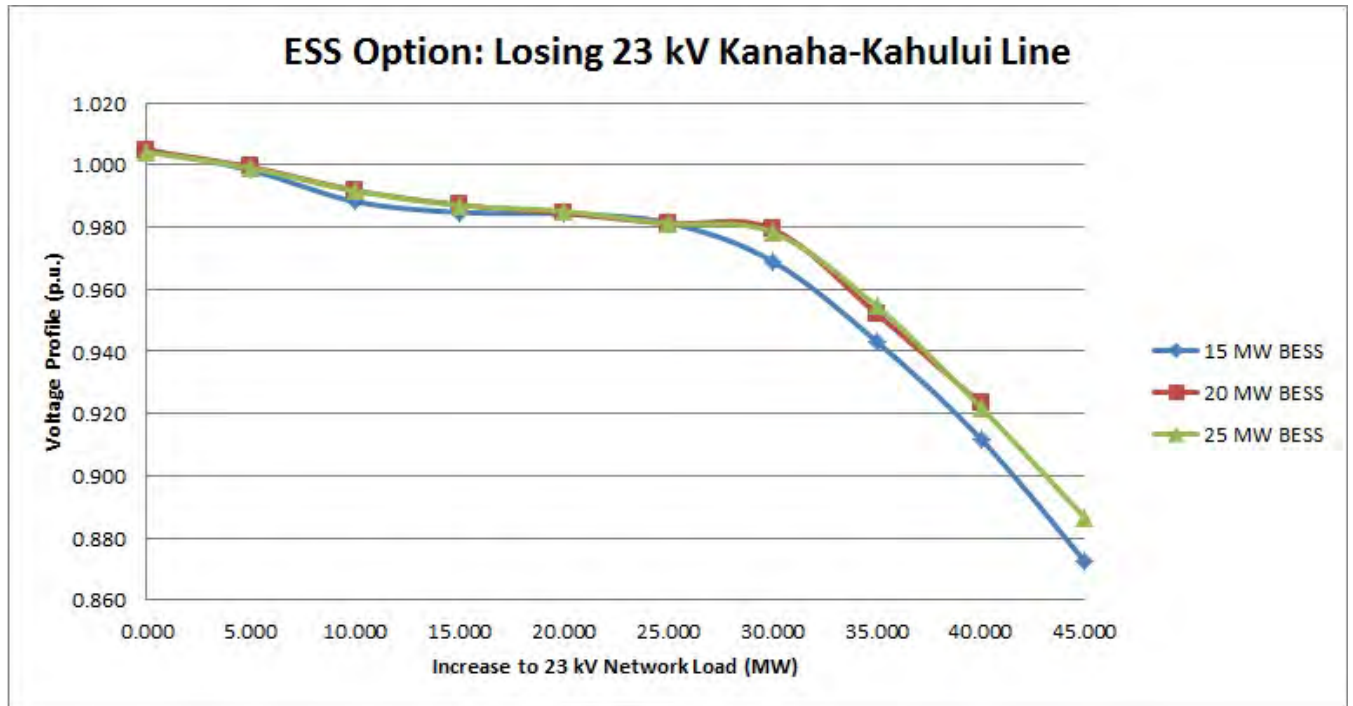


Figure 36: Comparison of P-V characteristics of various BESS options for losing the 23 kV Kanaha-Kahului Line.

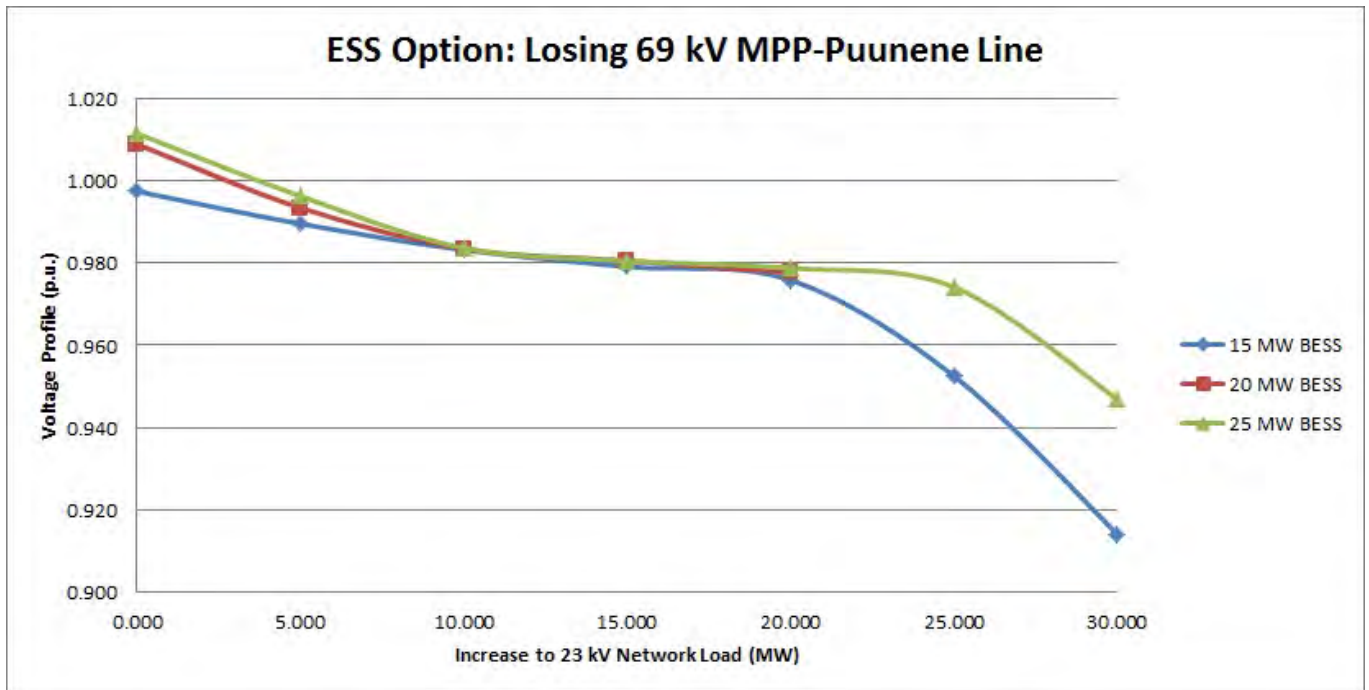


Figure 37 Comparison of P-V characteristics of various BESS options for losing the 69 kV MPP-Puunene Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

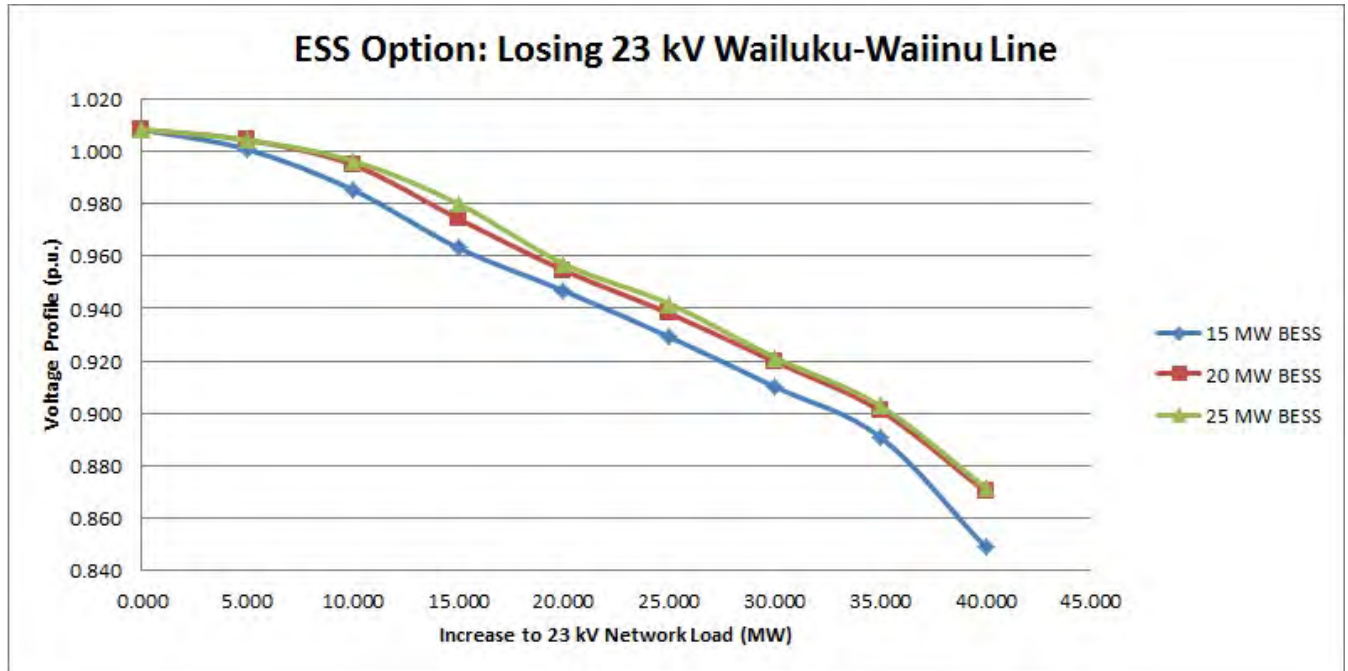


Figure 38: Comparison of P-V characteristics of various BESS options for losing the 23 kV Wailuku-Waiinu Line.

## Kahului Power Plant Retirement: Voltage Stability Assessment

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### System load above 170 MW:

The longest period of time that the Maui system has historically been observed to have remained 170 MW and above within the last year is 7 hours, which occurred on September 23, 2013.

| <b>September 23, 2013</b> |                  |
|---------------------------|------------------|
| Hour                      | System Load (MW) |
| 1                         | 120.2            |
| 2                         | 114.3            |
| 3                         | 109.6            |
| 4                         | 108              |
| 5                         | 114.7            |
| 6                         | 121.1            |
| 7                         | 133.4            |
| 8                         | 147.4            |
| 9                         | 158.1            |
| 10                        | 165.2            |
| 11                        | 165.4            |
| 12                        | 164.5            |
| 13                        | 163.7            |
| 14                        | 167.2            |
| 15                        | 169.3            |
| 16                        | 170.5            |
| 17                        | 174              |
| 18                        | 177.1            |
| 19                        | 178.8            |
| 20                        | 186.1            |
| 21                        | 183.1            |
| 22                        | 170.2            |
| 23                        | 152.6            |
| 24                        | 133.7            |

# Kahului Power Plant Retirement: Voltage Stability Assessment

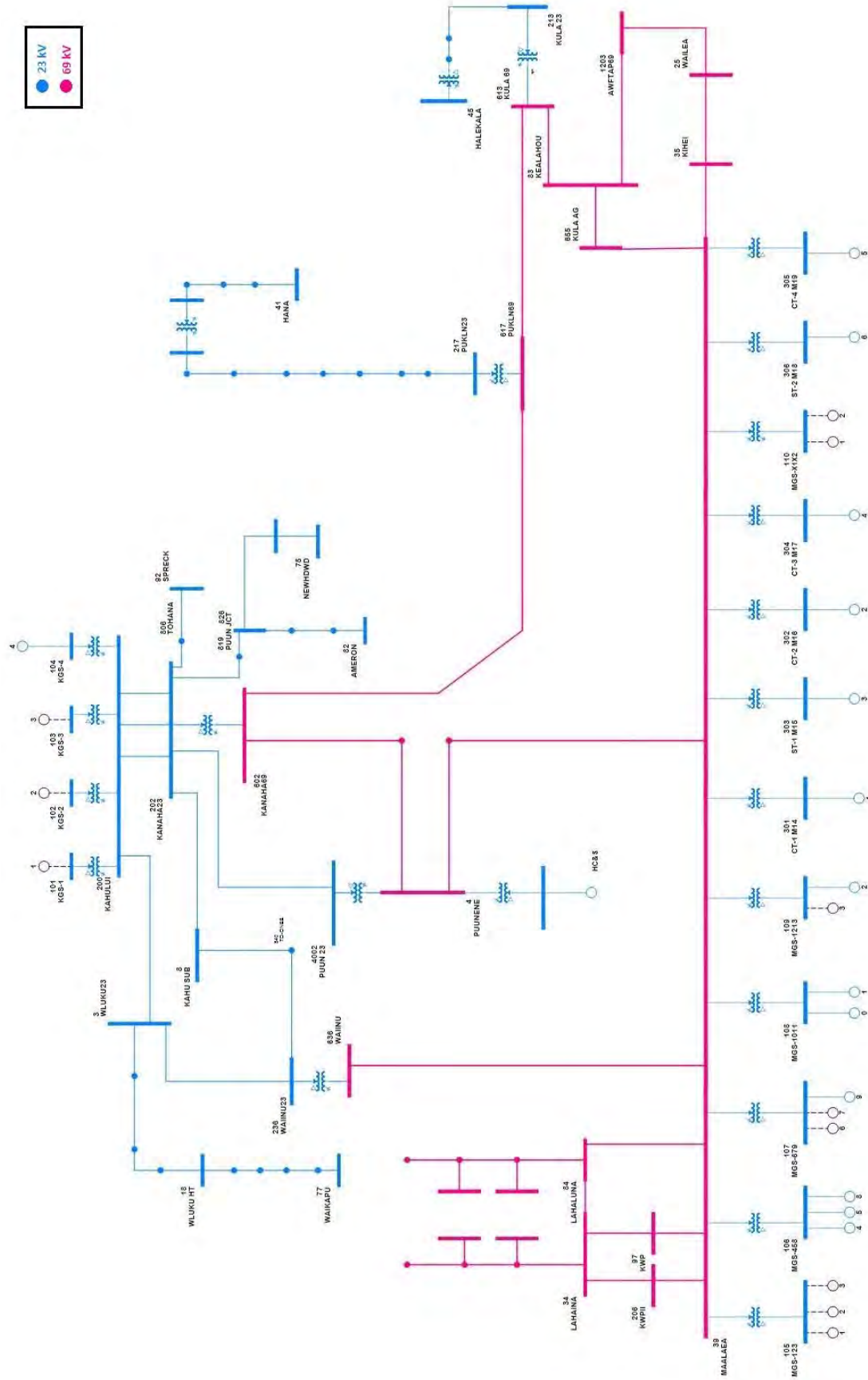


Figure 39: Single line diagram of the existing Maui 23 kV and 69 kV network.

# Kahului Power Plant Retirement: Voltage Stability Assessment

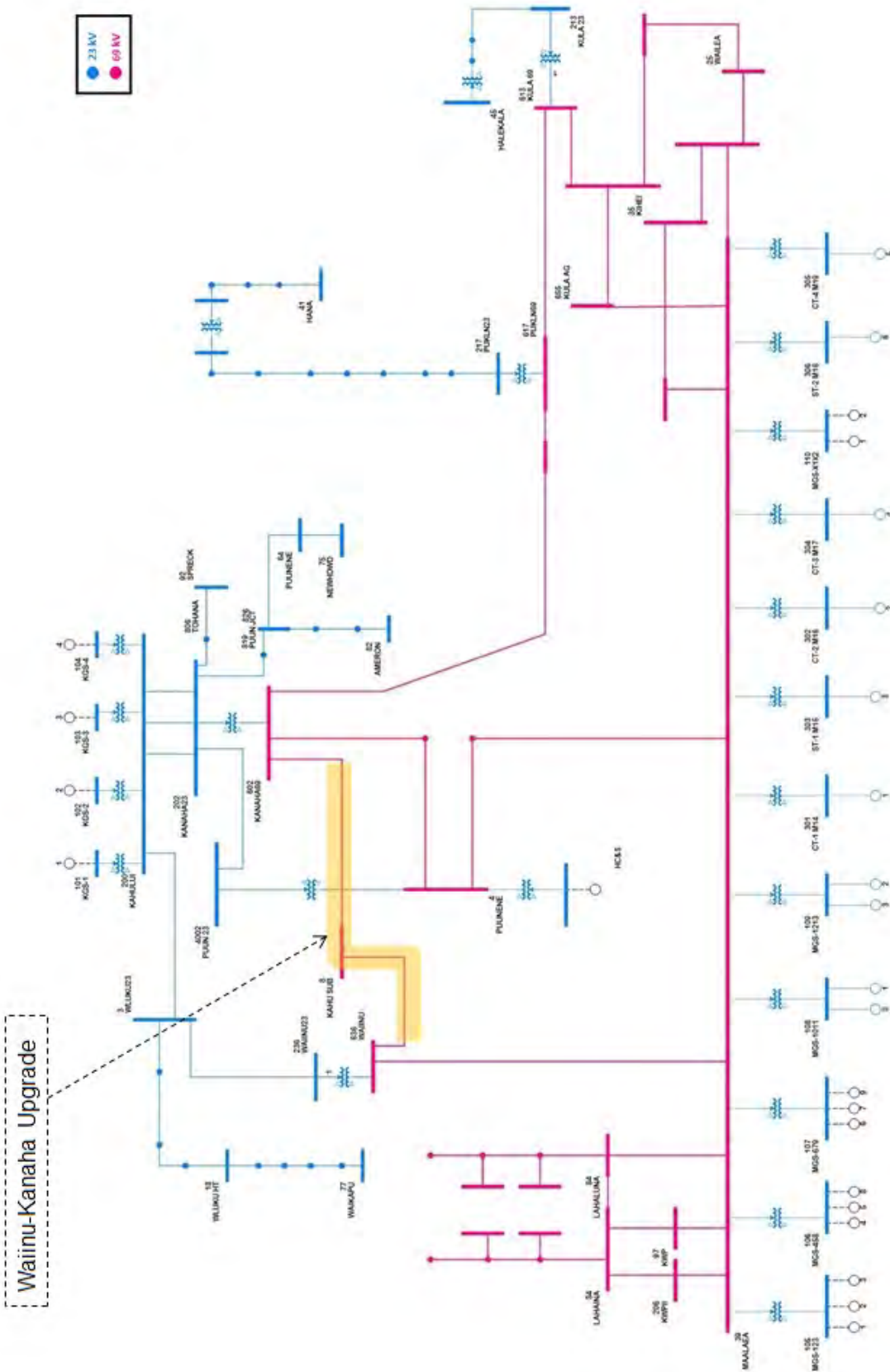


Figure 40: Single line diagram of the existing Maui 23 kV and 69 kV network with Waiinu-Kanaha Upgrade project implemented.

HECO Transmission Planning Division  
 Document Title: Kahului Power Plant Retirement: Voltage Stability Assessment  
 Reference: TPD 2014-21

## Kahului Power Plant Retirement: Voltage Stability Assessment

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**Table 2: Maui System Peak Forecast.**

| <b>Maui Electric Company, Ltd.<br/>(Maui Division)<br/>SYSTEM PEAK FORECAST</b> |             |
|---|-------------|
| Year  | System Load |
| 2013  | 194.5       |
| 2014  | 197.9       |
| 2015  | 199.7       |
| 2016  | 202.1       |
| 2017  | 208.2       |
| 2018  | 214.4       |
| 2019  | 218.3       |
| 2020  | 220.0       |
| 2021  | 221.9       |
| 2022  | 222.6       |
| 2023  | 223.3       |
| 2024  | 223.0       |
| 2025  | 223.3       |
| 2026  | 222.1       |
| 2027  | 220.4       |
| 2028  | 217.1       |
| 2029  | 214.8       |
| 2030  | 210.8       |

## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

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# Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

**Prepared For**  
**Transmission Planning Division**

**Prepared by:**

Transmission Planning Division

Dated: August 1, 2014

Reference: TPD 2014-20

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

Prepared By:



Raja Srivastava

Lead Transmission Planning Engineer

Approved By:



Ron Bushner

Director, Transmission Planning Division



## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

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### **Revision History**

| <b>Date</b>    | <b>Revision Number</b> | <b>Change Description</b> |
|----------------|------------------------|---------------------------|
| August 1, 2014 | Original               | Original                  |
|                |                        |                           |

## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

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### **Executive Summary**

Maui Electric Company (Maui Electric) announced the retirement of Kahului Power Plant (KPP) in the year 2019. Transmission Planning Division (TPD) performed a study to determine the effect of the KPP retirement on the short circuit current at various buses in the Maui transmission system.

The study results show that the retirement of KPP 3 & 4 leads to reduced fault current on the 69 KV and 23 KV transmission systems. The change in fault current could be as much as 5000 amperes. Such a large change in fault current may affect the relay operation and the reliable operation of the transmission system. Therefore, it is necessary to re-evaluate the effect of reduced fault current on the Maui system.

The study also shows that the non-transmission alternatives evaluated to address the impact of the retirement of KPP leads to increased fault current on the 69 KV transmission system. The increase in fault current could be as much as 5000 amperes.

### **Background**

Maui Electric announced the retirement of Kahului Power Plant (KPP) in the year 2014. Transmission Planning Division (TPD) has performed a study to determine the effect of the KPP retirement on the short circuit current at various buses in the Maui transmission system. The results of this study are presented in this report.

TPD has also evaluated the effect of KPP retirement on the transmission line overloading, transformer overloading, bus voltage violations, voltage stability, and transient stability of the Maui electrical system. The results of those studies are presented in separate reports.

Figure 1 shows the interaction of Maui 23 KV transmission system near KPP and the rest of the 69 KV transmission system. The 23 KV transmission system near KPP is shown as an orange cloud. KPP is part of this 23 KV transmission system. After KPP retirement, this 23 KV transmission system depends solely on 69 KV transmission system for supply of generation to meet the load. The three substations where this 69 KV – 23 KV transformation takes place are – Waiinu, Puunene, and Kanaha.

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

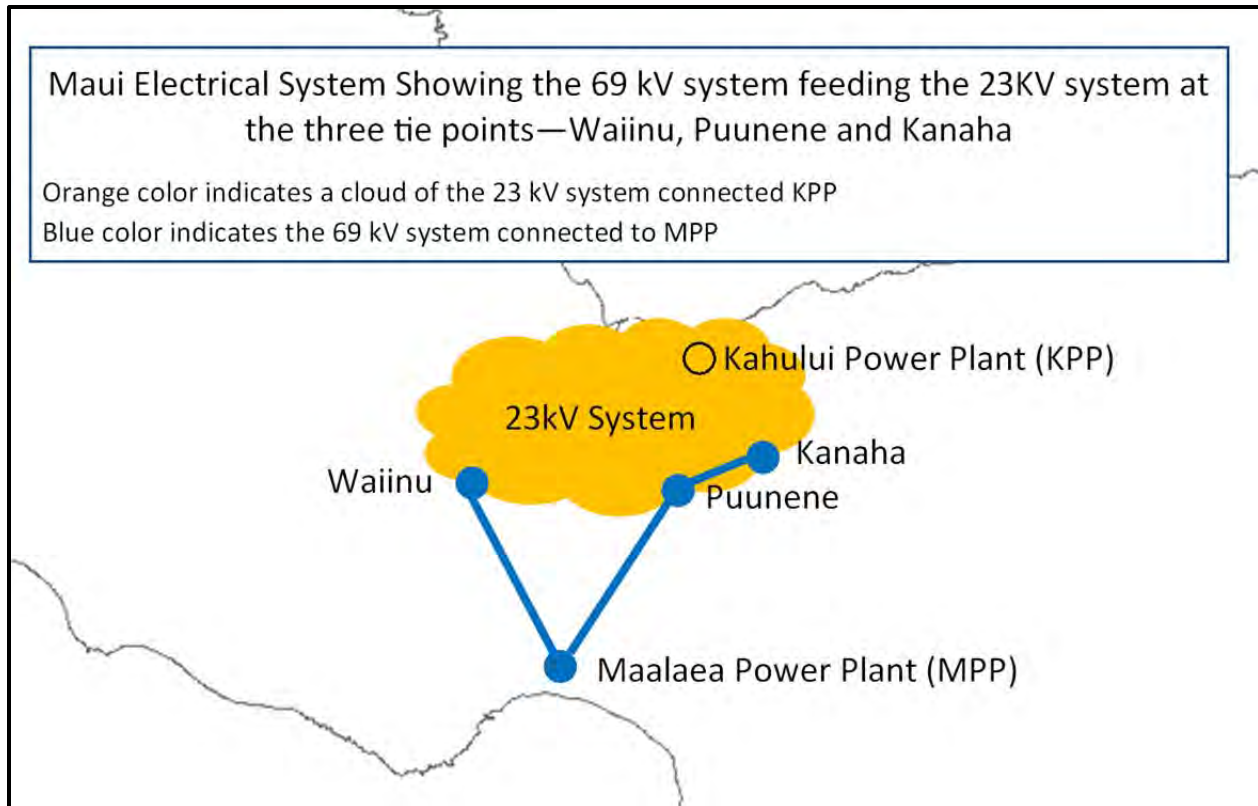


Figure 1 – Maui electrical system showing 69 KV transmission system feeding 23 KV transmission system at three tie points – Waiinu, Puunene, and Kanaha

As part of the KPP retirement study by TPD, PSSE<sup>1</sup> scenarios Case 0 – 5 were created. These scenarios represent the base case and various alternatives considered to alleviate the transmission limitations due to the retirement of KPP. The alternatives considered include transmission alternative, where new transmission upgrades are recommended, and non-transmission alternatives, where no new transmission upgrades are included. The 23kV Waiinu-Kanaha upgrade to 69kV with the reconductoring of MPP-Waiiu and MPP-Puunene is the transmission alternative. These non-transmission alternatives are – a) diesel generators (DG), b) battery (BESS) and c) synchronous condensers. These PSSE scenarios are given in Table 1. The study has also evaluated the effect of KPP retirement on the short circuit current under N-1 conditions. A list of N-1 contingencies are given in Table 2.

**Table 1 – PSSE Models used in the Short Circuit Study**

|        | Scenario Name                          | Scenario Description   |
|--------|--|--|
| Case 0 | Case 0 – 2014 Base Case                | 2014 peak case with HC&S and KPP 3 & 4 on line.  |
| Case 1 | 2019 Base Case plus KPP 3&4 Retirement | 2019 peak case; KPP retired, HC&S retired--retired generation picked up at Maalaea Power Plant |

<sup>1</sup> Power System Simulator for Engineering

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

|        | Scenario Name                                       | Scenario Description  |
|--------|---|---|
| Case 2 | Case 1 plus transmission Upgrades                   | Case 1 plus the following transmission upgrades <ul style="list-style-type: none"> <li>• 23 KV Waiinu – Kanaha upgraded to 69 KV</li> <li>• Reconductor MPP – Waiinu and MPP – Puunene from 336 AAC to 556 AAC</li> </ul> |
| Case 3 | Case 1 plus diesel generators (DG) on 23 KV system. | Case 1 plus diesel generator (DG) on 23 KV system   |
| Case 4 | Case 1 plus battery (BESS) on 23 KV system          | Case 1 plus battery (BESS) on 23 KV system  |
| Case 5 | Case 1 plus synchronous condenser                   | Case 1 plus synchronous condenser on 23 KV system   |

**Table 2 – List of contingencies included in the short circuit study**

| Contingency Name         | Contingency Description                             |
|--------------------------|---|
| None                     | Cases 0 – 5 plus no line outage                     |
| MPP – Waiinu 69 KV line  | Cases 0 – 5 plus outage of MPP – Waiinu 69 KV line  |
| MPP – Puunene 69 KV line | Cases 0 – 5 plus outage of MPP – Puunene 69 KV line |

The topic of short circuit current was evaluated in a recent study by EPS<sup>2</sup>. The study determined that even for very high renewable wind and solar penetration levels considered in the study, there is sufficient short circuit ratio available for proper operation of the inverter based technologies such as solar and wind generators.

### Methodology

PSSE was used to calculate short circuit current. 3-phase fault was applied at each bus in the Maui transmission system. The short circuit currents from PSSE were tabulated.

Post processing of the short circuit current included calculating the percent change in short circuit current in Cases 1 – 5 compared to Case 0.

### Assumptions

- The study is a follow-up of the other studies by TPD on KPP retirement. The assumptions are consistent with the assumptions in the other studies performed by TPD on KPP retirement (thermal analysis, voltage stability analysis, transient stability analysis).
- This study is not a High PV/wind penetration study. This topic has been addressed in a study by EPS referenced in the Background section of this report.
- This study solely focuses on the effect of KPP retirement on the short circuit current at the critical buses in the Maui transmission system.

<sup>2</sup> “Maui Electric Company, Ltd. Curtailment Reduction Plan Impact Study” Dated June 30, 2014

## **Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

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### **Results and Analysis**

The results of the fault current calculations are given in Appendix A of the report. This table contains the percent change in fault current at substations that are 23 KV and larger compared to Case 0 (base case). The changes in fault currents greater than 5% are highlighted with different colors. The green color highlight indicates that the fault current has decreased 5% and larger with respect to the Case 0. The red color highlight indicates that the fault current has increased 5% and larger with respect to the Case 0 with KPP 3 & 4 in service.

There are several generation dispatches in Cases 1 – 5 with respect to Case 0. These generation dispatches cause either the increase in fault current (generation addition) or decrease in fault current (generation retirement). In general, the KPP 3 & 4 retirement, HC&S retirement lead to decreased fault currents and dispatched units at Maalaea Power Plant (MPP) causes an increase in fault currents. These increase and decrease in fault currents are marked as red and green in Table A.1.

A comparison of the fault current for non-transmission alternatives (Case 3, Case 4, and Case5) shows that the changes in fault current are very similar to each other and are also very similar to the Case 0. This is due to the location of the non-transmission alternatives on the 23 KV transmission system that replaces the retired KPP3 & 4 generators. However, if the non-transmission alternatives are located on the 69 KV transmission system, we expect to notice drastic change in fault current.

**Fault Current Due to KPWII Wind Generator** – This study shows that addition of KPWII causes substantial increase in fault current. This is due to the fact that PSSE models KPWII wind generator as synchronous condenser. The substantial increase in fault current is contrary to the fact that inverter based technologies do not contribute significantly to the fault current. PSSE calculations are acceptable for planning studies. However, further adjustments to the fault current will be needed for accurate fault current calculations.

Table 3 shows the changes in short circuit fault current at Maui substations 23 KV and larger for Cases 1 & 2. Only changes greater than 5% have been reported. Whereas the increase in fault current due to KPWII addition is intuitive, the increase in fault current in Case 2 is counterintuitive because the changes in the fault currents are due to many different factors – KPP 3 & 4 retirement, HC&S retirement, KPWII addition, Maalaea 679 on-line, Maalaea 1213 on-line, and various 23 KV and 69 KV transmission upgrades with change in topology. Therefore, the association of increase and decrease in short circuit current to one factor is next to impossible. To establish such an association, we made several runs to quantify the change in short circuit current due to various transmission upgrades and KPP retirements. The results from these simulations have been discussed below.

#### **Table 3 Fault Current at buses that show change by 5 % and larger (Cases 0, 1, and 2)**

*(Green highlights show that the fault current has decreased 5% or larger with respect to Case 0, and red highlights show that the fault current has increased 5% or larger with respect to Case 0)*

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus   | Name       | KV    | 3PH   | Case0  |          | Case1 (Delta %) |         |         | Bus   | Case2 (Delta %) |          |         |
|-------|------------|-------|-------|--------|----------|-----------------|---------|---------|-------|-----------------|----------|---------|
|       |            |       |       | MVA    | Amp      | NoCont          | Cont1   | Cont2   |       | NoCont          | Cont1    | Cont2   |
| Col 1 | Col 2      | Col 3 | Col 4 | Col 5  | Col 6    | Col 7           | Col 8   | Col 9   | Col 1 | Col 11          | Col 12   | Col 13  |
| 4     | PUUNENE    | 69.00 | 3PH   | 641.23 | 5,365.40 | 21.65           | 22.00   | 42.69   |       | 7.15            | 23.67    | (14.06) |
| 23    | PUUKOL B   | 69.00 | 3PH   | 373.99 | 3,129.30 | 0.72            | (0.35)  | (1.52)  |       | 0.79            | 0.17     | (1.02)  |
| 401   | PUUNENEA   | 69.00 | 3PH   | 612.53 | 5,125.30 | 20.61           | 21.07   | 41.70   |       | 2.12            | 23.43    | (22.62) |
| 402   | PUUNENEB   | 69.00 | 3PH   | 646.62 | 5,410.50 | 20.02           | 20.17   | 41.65   |       | 7.60            | 20.79    | (11.24) |
| 602   | KANAHA69   | 69.00 | 3PH   | 597.10 | 4,996.20 | 20.00           | 20.53   | 41.08   |       | (1.37)          | 22.75    | (27.10) |
| 636   | WAIINU     | 69.00 | 3PH   | 529.15 | 4,427.60 | 4.90            | 16.58   | 2.92    |       | (18.33)         | (367.82) | (8.25)  |
| 2060  | KWP1134    | 34.50 | 3PH   | 224.70 | 3,760.40 | (13.03)         | (13.78) | (14.62) |       | (13.01)         | (13.47)  | (14.32) |
| 2061  | KWP11_CLT1 | 34.50 | 3PH   | 223.00 | 3,731.90 | (13.22)         | (13.97) | (14.81) |       | (13.20)         | (13.66)  | (14.51) |
| 136   | WAIINU B   | 12.47 | 3PH   | 88.57  | 4,100.80 | 1.05            | 26.53   | 3.49    |       | (2.15)          | (89.74)  | 0.48    |

### Effect of Transmission Upgrades on Fault Currents

To determine the effect of transmission upgrades on the fault currents, we compared the results of Case 2 (with transmission upgrade) with Case 1 (no transmission upgrade). The change in short circuit current is given in Table 4.

The results show that short circuit current increases. Due to transmission upgrades and change in transmission topology, the equivalent impedances (Thevenin Equivalence) is reduced. The reduction in equivalent impedance gives rise to increased fault current contributions.

**Table 4 – 5% or larger change in Short Circuit Current due transmission upgrades**

*(Case1 is without transmission upgrade and Case2 is with transmission upgrade)*

| Bus | Name     | KV    | 3PH | Case1  |          | Case2 (delta %) |         |         |
|-----|----------|-------|-----|--------|----------|-----------------|---------|---------|
|     |          |       |     | MVA    | Amp      | NoCont          | Cont1   | Cont2   |
| 4   | PUUNENE  | 69.00 | 3PH | 502.43 | 4,204.00 | (18.50)         | 2.14    | (99.03) |
| 401 | PUUNENEA | 69.00 | 3PH | 486.31 | 4,069.10 | (23.29)         | (23.29) | (23.29) |
| 402 | PUUNENEB | 69.00 | 3PH | 517.14 | 4,327.10 | (15.53)         | (15.53) | (15.53) |
| 602 | KANAHA69 | 69.00 | 3PH | 477.67 | 3,996.90 | (26.72)         | (26.72) | (26.72) |
| 617 | PUKLN69  | 69.00 | 3PH | 398.10 | 3,331.00 | (8.87)          | (8.87)  | (8.87)  |
| 636 | WAIINU   | 69.00 | 3PH | 503.22 | 4,210.60 | (24.42)         | (24.42) | (24.42) |
| 3   | WLUKU23  | 23.00 | 3PH | 189.28 | 4,751.30 | 5.03            | 5.03    | 5.03    |
| 40  | ONEHEE   | 23.00 | 3PH | 158.97 | 3,990.40 | 42.65           | 42.65   | 42.65   |
| 236 | WAIINU23 | 23.00 | 3PH | 209.12 | 5,249.50 | 12.78           | 12.78   | 12.78   |
| 840 | TO-ONEE  | 23.00 | 3PH | 196.50 | 4,932.70 | 48.37           | 48.37   | 48.37   |

### Effect of KPP Retirement on 69 KV and 23 KV transmission systems

To determine the effect of KPP retirement on the short circuit current, we created Case 1a from Case 1 by not retiring KPP 3 & 4. Table 5 shows the change in the fault current 5% or larger due to the retirement of KPP 3 & 4. We observe that the change in fault current varies from few amperes to as much as 5000 amperes (Kahului 23 KV substation). Such a large change in fault

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

current may affect the relay operation and thus the reliability of the system. Therefore, it is necessary to review and update the current relay settings after the KPP 3 & 4 retirements.

**Table 5 – 5% or larger change in Short Circuit Current due to the retirement of KPP 3 & 4**

*(Case1 is without KPP 3 & 4 and Case1a is with KPP 3 & 4)*

| Bus  | Name     | KV    | 3PH | Case1a   |          | Case1 (delta %) |       |       |
|------|----------|-------|-----|----------|----------|-----------------|-------|-------|
|      |          |       |     | MVA      | Amp      | NoCont          | Cont1 | Cont2 |
| 4    | PUUNENE  | 69.00 | 3PH | 574.73   | 4,809.00 | 12.58           | 12.56 | 22.84 |
| 25   | WAILEA   | 69.00 | 3PH | 520.99   | 4,359.30 | 4.54            | 3.27  | 5.09  |
| 39   | MAALAEA  | 69.00 | 3PH | 1,118.21 | 9,356.50 | 8.05            | 4.76  | 4.94  |
| 83   | KEALAHOU | 69.00 | 3PH | 546.78   | 4,575.10 | 5.76            | 4.54  | 8.44  |
| 401  | PUUNENEA | 69.00 | 3PH | 555.94   | 4,651.80 | 12.53           | 12.64 | 22.83 |
| 402  | PUUNENEB | 69.00 | 3PH | 587.46   | 4,915.50 | 11.97           | 11.71 | 22.25 |
| 602  | KANAHA69 | 69.00 | 3PH | 546.07   | 4,569.20 | 12.53           | 12.72 | 22.84 |
| 613  | KULA 69  | 69.00 | 3PH | 477.68   | 3,996.90 | 5.89            | 5.08  | 10.26 |
| 617  | PUKLN69  | 69.00 | 3PH | 430.39   | 3,601.30 | 7.51            | 7.39  | 15.61 |
| 636  | WAIINU   | 69.00 | 3PH | 542.07   | 4,535.70 | 7.17            | 17.70 | 5.89  |
| 655  | KULA AG  | 69.00 | 3PH | 545.31   | 4,562.90 | 5.59            | 4.32  | 7.84  |
| 1203 | AWFTAP69 | 69.00 | 3PH | 514.11   | 4,301.80 | 4.56            | 3.34  | 5.33  |
| 3    | WLUKU23  | 23.00 | 3PH | 252.35   | 6,334.50 | 24.99           | 34.46 | 35.83 |
| 5    | MAUI PIN | 23.00 | 3PH | 261.97   | 6,576.00 | 26.27           | 35.01 | 36.75 |
| 7    | WAI WELL | 23.00 | 3PH | 148.96   | 3,739.20 | 16.74           | 27.39 | 25.57 |
| 8    | KAHU SUB | 23.00 | 3PH | 273.78   | 6,872.50 | 27.04           | 35.60 | 37.57 |
| 18   | WLUKU HT | 23.00 | 3PH | 146.35   | 3,673.80 | 16.64           | 27.53 | 25.52 |
| 22   | WS PUMP  | 23.00 | 3PH | 136.64   | 3,429.90 | 15.84           | 26.98 | 24.53 |
| 30   | MOKUHAU  | 23.00 | 3PH | 161.99   | 4,066.40 | 17.92           | 28.51 | 27.12 |
| 33   | WS MILL  | 23.00 | 3PH | 236.00   | 5,924.10 | 23.78           | 33.46 | 34.39 |
| 40   | ONEHEE   | 23.00 | 3PH | 203.03   | 5,096.50 | 21.70           | 31.54 | 31.84 |
| 43   | WAIEHU   | 23.00 | 3PH | 111.30   | 2,793.80 | 13.27           | 24.19 | 20.89 |
| 48   | MAUIBLOC | 23.00 | 3PH | 79.03    | 1,983.90 | 10.35           | 22.62 | 17.25 |
| 64   | PUUNENE  | 23.00 | 3PH | 118.20   | 2,967.10 | 16.07           | 25.73 | 25.07 |
| 73   | KUAU     | 23.00 | 3PH | 89.29    | 2,241.50 | 12.52           | 21.54 | 20.06 |
| 75   | NEWHDWD  | 23.00 | 3PH | 94.25    | 2,365.90 | 13.45           | 23.26 | 21.86 |
| 77   | WAIKAPU  | 23.00 | 3PH | 78.16    | 1,961.90 | 10.26           | 22.53 | 17.12 |
| 82   | AMERON   | 23.00 | 3PH | 94.45    | 2,370.90 | 13.32           | 23.67 | 22.15 |
| 88   | AMERBLDG | 23.00 | 3PH | 97.92    | 2,458.10 | 13.71           | 24.06 | 22.65 |
| 92   | SPRECK   | 23.00 | 3PH | 127.80   | 3,207.90 | 16.66           | 25.52 | 25.27 |
| 93   | PAIAMKA  | 23.00 | 3PH | 99.49    | 2,497.40 | 13.67           | 22.67 | 21.56 |
| 200  | KAHULUI  | 23.00 | 3PH | 381.12   | 9,567.00 | 41.71           | 48.83 | 50.95 |
| 202  | KANAHA23 | 23.00 | 3PH | 384.54   | 9,652.80 | 36.78           | 43.90 | 46.55 |
| 217  | PUKLN23  | 23.00 | 3PH | 94.94    | 2,383.20 | 1.66            | 4.98  | 6.04  |
| 236  | WAIINU23 | 23.00 | 3PH | 272.88   | 6,849.80 | 23.36           | 32.88 | 35.16 |
| 671  | JCT B    | 23.00 | 3PH | 119.30   | 2,994.60 | 14.32           | 25.85 | 22.60 |
| 806  | TOHANA   | 23.00 | 3PH | 190.06   | 4,771.00 | 22.64           | 31.21 | 32.26 |
| 819  | PUUN JCT | 23.00 | 3PH | 207.47   | 5,207.90 | 24.53           | 33.47 | 34.61 |
| 826  |          | 23.00 | 3PH | 171.27   | 4,299.30 | 21.30           | 30.48 | 31.05 |

## Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus  | Name     | KV    | 3PH | Case1a |          | Case1 (delta %) |       |       |
|------|----------|-------|-----|--------|----------|-----------------|-------|-------|
|      |          |       |     | MVA    | Amp      | NoCont          | Cont1 | Cont2 |
| 827  | CONC TAP | 23.00 | 3PH | 100.86 | 2,531.90 | 14.04           | 24.39 | 23.07 |
| 838  |          | 23.00 | 3PH | 80.26  | 2,014.80 | 10.48           | 22.75 | 17.44 |
| 840  | TO-ONEE  | 23.00 | 3PH | 266.07 | 6,678.90 | 26.15           | 34.91 | 36.71 |
| 848  | JCT C    | 23.00 | 3PH | 69.07  | 1,733.90 | 10.49           | 20.46 | 18.10 |
| 858  | PUUOHALA | 23.00 | 3PH | 207.59 | 5,211.00 | 21.58           | 31.59 | 31.71 |
| 892  | BALWNPK  | 23.00 | 3PH | 110.35 | 2,770.10 | 14.83           | 23.75 | 23.00 |
| 893  | PAIAMKA  | 23.00 | 3PH | 101.26 | 2,541.90 | 13.84           | 22.80 | 21.75 |
| 4002 | PUUN 23  | 23.00 | 3PH | 304.23 | 7,637.00 | 25.40           | 32.33 | 35.77 |

### Conclusions

The study results shows that the retirement of KPP 3 & 4 leads to reduced fault current on the 69 KV and 23 KV transmission systems. The change in fault current could be as much as 5000 amperes. Such a large change in fault current may affect the relay operation and the reliable operation of the transmission system. Therefore, it is necessary to re-evaluate the effect of reduced fault current on the Maui system.

The study also shows that the non-transmission alternatives evaluated to address the impact of the retirement of KPP leads to increased fault current on the 69 KV transmission system. The increase in fault current could be as much as 5000 amperes.



# Appendix A

**Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

**Table A.1 – Change in 3-phase fault current with respect to Case 0**

**Notes:**

- Delta % is defined as percent change with respect to Case 0
- Green highlighted cells indicate that the fault current has decreased by 5% with respect to Case 0.
- Red highlighted cells indicate that the fault current has increased by 5% with respect to Case 0.
- Case 0 – 5 are defined in table below
- Contingencies are defined as below.

**Table A.1 – Change in short circuit current with respect to Case 0**

| Bus | Name         | KV        | 3P<br>H | Col<br>I/A | Case0 |              | Case1 (Delta %) |            | Case2 (Delta %) |            | Case3 (Delta %) |            | Case4 (Delta %) |              | Case5 (Delta %) |              |              |              |              |              |              |
|-----|--------------|-----------|---------|------------|-------|--------------|-----------------|------------|-----------------|------------|-----------------|------------|-----------------|--------------|-----------------|--------------|--------------|--------------|--------------|--------------|--------------|
|     |              |           |         |            | MVA   | Amp          | NoC<br>ont      | Con<br>t1  | Con<br>t2       | NoC<br>ont | Con<br>t1       | Con<br>t2  | NoC<br>ont      | Con<br>t1    | Con<br>t2       | NoC<br>ont   | Con<br>t1    | Con<br>t2    |              |              |              |
| 4   | PUUNEN<br>E  | 69<br>00  | 3P<br>H | Col<br>I/A | Col 6 | 5,365.<br>40 | 21.6<br>5       | 22.<br>00  | 42.<br>69       | 7.15<br>06 | 23.6<br>06      | 14.<br>06  | 12.3<br>6       | 12.5<br>4    | 25.7<br>6       | 17.4<br>5    | 9.75<br>5    | 9.52<br>5    | 17.4<br>5    | 20.8<br>9    | 7.46<br>9    |
| 23  | PUUKOL<br>B  | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 3,129.<br>30 | 0.72<br>5       | (0.3<br>5) | (1.5<br>2)      | 0.79<br>2  | 0.17<br>2       | (1.0<br>2) | 0.18<br>0       | 0.32<br>0    | (0.9<br>0)      | 1.62<br>1.20 | 2.36<br>1.20 | 1.62<br>1.20 | 2.36<br>1.20 | (2.5<br>0)   | (3.8<br>3)   |
| 25  | WALEA        | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 4,396.<br>80 | 5.35<br>2       | 4.4<br>7   | 6.5<br>7        | 5.04<br>5  | 5.07<br>5       | 5.1<br>5   | 3.63<br>5       | 4.00<br>5    | 4.13<br>5       | 4.91<br>5.14 | 5.88<br>5.14 | 4.91<br>5.14 | 5.88<br>5.14 | (0.3<br>7)   | 0.29<br>0.28 |
| 29  | NAPILI A     | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 2,624.<br>70 | 0.61<br>8       | (0.2<br>8) | (1.2<br>7)      | 0.67<br>5  | 0.15<br>5       | (0.8<br>5) | 0.15<br>5       | 0.28<br>5    | (0.7<br>5)      | 1.36<br>1.01 | 1.98<br>1.01 | 1.36<br>1.01 | 1.98<br>1.01 | (2.4<br>1)   | (3.1<br>9)   |
| 34  | LAHAINA      | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 4,717.<br>20 | 0.99<br>3       | (0.6<br>3) | (2.4<br>3)      | 1.09<br>6  | 0.14<br>6       | (1.6<br>6) | 0.20<br>6       | 0.42<br>3    | (1.4<br>3)      | 2.37<br>3.46 | 3.46<br>1.72 | 2.37<br>3.46 | 3.46<br>1.72 | (4.5<br>2)   | (5.9<br>3)   |
| 35  | KIHEI        | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 5,113.<br>10 | 7.12<br>10      | 5.7<br>6   | 6.1<br>0        | 7.10<br>4  | 6.54<br>4       | 6.1<br>4   | 5.67<br>4       | 5.96<br>5.01 | 5.01<br>7.07    | 7.42<br>7.07 | 8.49<br>7.07 | 7.42<br>7.07 | 8.49<br>7.07 | 1.02<br>1.64 | 0.55<br>0.55 |
| 39  | MAALAE<br>A  | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 8,959.<br>20 | 3.97<br>20      | 0.8<br>1   | (2.6<br>7)      | 4.19<br>5  | 2.32<br>5       | (1.1<br>5) | 2.56<br>9       | 2.97<br>9    | (0.5<br>9)      | 6.62<br>5.32 | 8.59<br>5.32 | 6.62<br>5.32 | 8.59<br>5.32 | (6.8<br>8)   | (9.6<br>2)   |
| 50  | MAHINA<br>A  | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 2,946.<br>80 | 0.65<br>80      | (0.3<br>4) | (1.4<br>5)      | 0.72<br>8  | 0.14<br>8       | (0.9<br>8) | 0.15<br>8       | 0.29<br>6    | (0.8<br>6)      | 1.51<br>2.21 | 2.21<br>1.11 | 1.51<br>2.21 | 2.21<br>1.11 | (2.7<br>3)   | (3.6<br>1)   |
| 83  | KEALAHU<br>U | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 4,590.<br>00 | 6.07<br>00      | 5.1<br>8   | 11.<br>51       | 4.71<br>1  | 6.00<br>1       | 5.2<br>1   | 3.20<br>8       | 3.55<br>5.67 | 5.67<br>5.12    | 4.09<br>4.97 | 4.97<br>5.12 | 4.09<br>4.97 | 4.97<br>5.12 | (1.2<br>6)   | 1.25<br>1.25 |
| 84  | LAHALUN<br>A | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 4,594.<br>20 | 1.05<br>20      | (0.5<br>3) | (2.2<br>8)      | 1.15<br>4  | 0.22<br>4       | (1.5<br>4) | 0.29<br>8       | 0.50<br>1    | (1.3<br>1)      | 2.40<br>3.48 | 3.48<br>1.77 | 2.40<br>3.48 | 3.48<br>1.77 | (4.3<br>1)   | (5.6<br>9)   |
| 97  | KWP          | 69.<br>00 | 3P<br>H | Col<br>I/A | Col 6 | 5,352.<br>70 | 2.12<br>70      | 0.3<br>3   | (1.6<br>4)      | 2.24<br>8  | 1.20<br>8       | (0.7<br>8) | 1.22<br>8       | 1.46<br>8    | (0.5<br>8)      | 3.61<br>4.81 | 4.81<br>2.89 | 3.61<br>4.81 | 4.81<br>2.89 | (4.0<br>6)   | (5.6<br>2)   |

Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name       | KV | 3P H | Case0  |          |         | Case1 (Delta %) |          |         | Case2 (Delta %) |         |         | Case3 (Delta %) |         |         | Case4 (Delta %) |         |         | Case5 (Delta %) |         |        |
|-----|------------|----|------|--------|----------|---------|-----------------|----------|---------|-----------------|---------|---------|-----------------|---------|---------|-----------------|---------|---------|-----------------|---------|--------|
|     |            |    |      | MVA    | Amp      | Col 6   | NoC ont         | Con t1   | Con t2  | NoC ont         | Con t1  | Con t2  | NoC ont         | Con t1  | Con t2  | NoC ont         | Con t1  | Con t2  | NoC ont         | Con t1  | Con t2 |
| 206 | KWP11      | 69 | 3P H | 623.76 | 5,219.20 | 7       | (0.7            | (2.6     | (4.6    | (0.6            | (1.7    | (3.8    | (1.6            | (1.4    | (3.5    | 0.81            | 2.06    | 0.05    | (7.2            | (6.6    | (8.8   |
| 223 | PUUKOLA    | 69 | 3P H | 417.02 | 3,489.40 | 0.71    | (0.4            | (1.7     | (0.79   | 0.10            | (1.2    | 0.12    | 0.28            | (1.0    | 1.72    | 2.54            | 1.25    | (3.3    | (2.9            | (4.3    |        |
| 250 | MAHINA B   | 69 | 3P H | 347.19 | 2,905.10 | 0.60    | (0.3            | (1.4     | 0.66    | 0.09            | (1.0    | 0.10    | 0.23            | (0.9    | 1.43    | 2.12            | 1.04    | (2.7    | (2.4            | (3.6    |        |
| 401 | PUUNEN EA  | 69 | 3P H | 612.53 | 5,125.30 | 20.6    | 21.41           | 23.4     | 2.12    | 3               | (22.62) | 11.1    | 11.3            | 24.5    | 8.37    | 8.03            | 16.1    | 5.79    | 6.27            | 19.5    |        |
| 402 | PUUNEN EB  | 69 | 3P H | 646.62 | 5,410.50 | 20.0    | 20.17           | 20.7     | 7.60    | 9               | (11.24) | 11.3    | 11.5            | 24.9    | 9.15    | 9.10            | 16.8    | 5.87    | 6.45            | 20.2    |        |
| 602 | KANAHA 69  | 69 | 3P H | 597.10 | 4,996.20 | 20.0    | 20.53           | 22.7     | (1.3    | 5               | (27.10) | 10.3    | 10.5            | 23.6    | 7.53    | 7.13            | 15.2    | 5.08    | 5.53            | 18.6    |        |
| 613 | KULA 69    | 69 | 3P H | 483.51 | 4,045.70 | 7.03    | 6.5             | 7.33     | 4.36    | 4               | 3.9     | 3.55    | 3.89            | 7.91    | 3.84    | 4.47            | 5.81    | (0.3    | 0.26            | 3.94    |        |
| 617 | PUK169     | 69 | 3P H | 446.42 | 3,735.40 | 10.8    | 11.14           | 12.0     | 2.92    | 5               | (4.0    | 5.34    | 5.65            | 14.4    | 4.41    | 4.54            | 9.11    | 1.58    | 2.19            | 10.4    |        |
| 623 | PUUKA 69   | 69 | 3P H | 417.02 | 3,489.40 | 0.71    | (0.4            | (1.7     | 0.79    | 0.10            | (1.2    | 0.12    | 0.28            | (1.0    | 1.72    | 2.54            | 1.25    | (3.3    | (2.9            | (4.3    |        |
| 629 | NAPILI B   | 69 | 3P H | 305.60 | 2,559.60 | 0.54    | (0.3            | (1.2     | 0.61    | 0.09            | (0.8    | 0.10    | 0.22            | (0.7    | 1.28    | 1.88            | 0.93    | (2.3    | (2.1            | (3.1    |        |
| 636 | WAIINU     | 69 | 3P H | 529.15 | 4,427.60 | 4.90    | 16.58           | (367.82) | (18.33) | (82.5)          | 0.40    | 0.40    | 0.28            | (0.3    | 0.63    | (8.0            | 9)      | (4.5    | (5.3            | (4.8    |        |
| 650 | MAHINA B   | 69 | 3P H | 347.19 | 2,905.10 | 0.60    | (0.3            | (1.4     | 0.66    | 0.09            | (1.0    | 0.10    | 0.23            | (0.9    | 1.43    | 2.12            | 1.04    | (2.7    | (2.4            | (3.6    |        |
| 655 | KULA AG    | 69 | 3P H | 545.65 | 4,565.60 | 5.64    | 4.7             | 10.0     | 4.53    | 5.50            | 5.0     | 2.98    | 3.32            | 5.00    | 3.97    | 4.87            | 4.79    | (1.4    | (0.8            | 0.61    |        |
| 823 | PUUKB 69   | 69 | 3P H | 400.00 | 3,347.00 | 0.75    | (0.3            | (1.6     | 0.83    | 0.16            | (1.1    | 0.18    | 0.34            | (0.9    | 1.72    | 2.51            | 1.27    | (3.1    | (2.7            | (4.1    |        |
| 850 | MAHINA A   | 69 | 3P H | 365.90 | 3,061.60 | 0.68    | (0.3            | (1.5     | 0.75    | 0.14            | (1.0    | 0.16    | 0.30            | (0.9    | 1.56    | 2.29            | 1.15    | (2.8    | (2.5            | (3.7    |        |
| 120 | AWFTAP 3   | 69 | 3P H | 517.52 | 4,330.30 | 5.18    | 4.3             | 6.9      | 4.79    | 4.96            | 5.0     | 3.37    | 3.77            | 4.13    | 4.57    | 5.53            | 4.94    | (0.5    | 0.11            | 0.32    |        |
| 971 | KWP34      | 50 | 3P H | 333.59 | 5,582.50 | 0.76    | (0.0            | (0.9     | 0.81    | 0.32            | (0.5    | 0.44    | 0.55            | (0.3    | 1.52    | 2.09            | 1.21    | (1.8    | (1.5            | (2.5    |        |
| 206 | KWP134     | 50 | 3P H | 224.70 | 3,760.40 | (13.03) | (13.78)         | (13.62)  | (13.01) | (13.47)         | (14.32) | (13.27) | (13.19)         | (14.06) | (12.31) | (11.82)         | (12.65) | (15.15) | (14.14)         | (15.86) |        |
| 206 | KWP11_CL 1 | 50 | 3P H | 223.90 | 3,731.90 | (13.22) | (13.97)         | (14.81)  | (13.20) | (13.66)         | (14.51) | (13.47) | (13.39)         | (14.26) | (12.51) | (12.02)         | (12.86) | (15.36) | (15.18)         | (16.06) |        |
| 120 | AUWAHI 34  | 50 | 3P H | 199.13 | 3,332.30 | 0.32    | 1.2             | 3.0      | 0.03    | 1.12            | 1.6     | (0.2    | 0.84            | 1.99    | 0.14    | 1.25            | 2.00    | (1.2    | (0.1            | 1.05    |        |







Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name      | KV    | 3P H | Case0  |       |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |      |      |      |      |      |
|-----|-----------|-------|------|--------|-------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|------|------|------|------|------|
|     |           |       |      | MVA    | Amp   | Col 6 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |      |      |      |      |      |
| 303 | ST-1 M15  | 13.80 | 3P H | 312.06 | 13,05 | Col 6 | 7               | 8      | 9      | 10              | 11     | 12     | 13              | 14     | 15     | 16              | 17     | 18     | 19              | 20     | 21     | 22   | 23   | 24   | 25   |      |
| 304 | CT-3 M17  | 13.80 | 3P H | 405.57 | 16,96 | Col 6 | 0.0             | 1.7    | 2.1    | 2.1             | 0.09   | 0.7    | 1.1             | 1.1    | 0.09   | 0.3             | 0.9    | 0.9    | 0.38            | 0.79   | 0.14   | 0.81 | 1.27 | 0.54 | 1.1  | 1.8  |
| 305 | CT-4 M19  | 13.80 | 3P H | 405.57 | 16,96 | Col 6 | 0.0             | 1.7    | 2.1    | 2.1             | 0.09   | 0.7    | 1.1             | 1.1    | 0.09   | 0.3             | 0.9    | 0.9    | 0.38            | 0.79   | 0.14   | 0.81 | 1.27 | 0.54 | 1.1  | 1.8  |
| 306 | ST-2 M18  | 13.80 | 3P H | 297.95 | 12,46 | Col 6 | 0.23            | 1.0    | 1.6    | 1.6             | 0.34   | 0.3    | 0.8             | 0.8    | 0.18   | 0.0             | 0.6    | 0.6    | 0.74            | 1.16   | 0.50   | 0.74 | 1.16 | 0.50 | 1.0  | 1.7  |
| 804 | HC&S TG4  | 13.80 | 3P H | 416.99 | 17,44 | Col 6 | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | #N/  | #N/  | #N/  | #N/  | #N/  |
| 120 | BURIED_31 | 13.80 | 3P H | 126.96 | 5,311 | Col 6 | 0.2             | 0.9    | 2.5    | 2.5             | 0.5    | 0.70   | 1.2             | 1.2    | 0.6    | 0.48            | 1.72   | 1.72   | 0.4             | 0.65   | 1.58   | 0.4  | 0.65 | 1.58 | 0.4  | 0.65 |
| 13  | KULA 12   | 12.47 | 3P H | 77.4   | 3,585 | Col 6 | 1.52            | 3.6    | 9.3    | 5               | 0.58   | 1.73   | 7               | 7      | 0.75   | 1.10            | 4.41   | 4.41   | 0.71            | 0.73   | 2.15   | 0.71 | 0.73 | 2.15 | 0.34 | 0.76 |
| 98  | KAUHIKO A | 12.47 | 3P H | 32.8   | 1,518 | Col 6 | 1.99            | 3.2    | 6.1    | 8               | 0.32   | 2.04   | 9               | 9      | 0.99   | 1.52            | 3.17   | 3.17   | 0.70            | 0.44   | 1.71   | 0.70 | 0.44 | 1.71 | 1.09 | 1.47 |
| 112 | MAKA 12   | 12.47 | 3P H | 35.5   | 1,646 | Col 6 | 3.72            | 6.8    | 10     | 31              | 2.10   | 5.04   | 1               | 1      | 2.76   | 3.25            | 5.67   | 5.67   | 2.50            | 2.24   | 4.75   | 2.50 | 2.24 | 4.75 | 2.84 | 3.85 |
| 123 | PUUKB 12  | 12.47 | 3P H | 78.2   | 3,624 | Col 6 | 0.15            | 0.0    | 0.3    | 3               | 0.18   | 0.03   | 2               | 2      | 0.08   | 0.12            | 0.4    | 0.4    | 0.37            | 0.54   | 0.29   | 0.37 | 0.54 | 0.29 | 0.5  | 0.4  |
| 125 | WAILEA A  | 12.47 | 3P H | 93.3   | 4,321 | Col 6 | 1.07            | 1.4    | 2.9    | 2               | 0.82   | 1.20   | 2               | 2      | 0.71   | 1.01            | 1.49   | 1.49   | 0.87            | 1.15   | 1.34   | 0.87 | 1.15 | 1.34 | 0.09 | 0.45 |
| 129 | NAPILA 2  | 12.47 | 3P H | 72.4   | 3,353 | Col 6 | 0.13            | 0.0    | 0.3    | 1               | 0.15   | 0.02   | 1               | 1      | 0.07   | 0.10            | 0.4    | 0.4    | 0.33            | 0.48   | 0.25   | 0.33 | 0.48 | 0.25 | 0.4  | 0.6  |
| 134 | LAHAINA 1 | 12.47 | 3P H | 89.2   | 4,133 | Col 6 | 0.10            | 0.1    | 0.4    | 5               | 0.13   | 0.0    | 3               | 2      | 0.02   | 0.06            | 0.4    | 0.4    | 0.36            | 0.54   | 0.26   | 0.36 | 0.54 | 0.26 | 0.6  | 0.9  |
| 135 | KIHEI A   | 12.47 | 3P H | 84.6   | 3,918 | Col 6 | 1.14            | 1.2    | 1.6    | 2               | 1.02   | 1.17   | 7               | 7      | 0.90   | 1.09            | 1.24   | 1.24   | 1.12            | 1.34   | 1.33   | 1.12 | 1.34 | 1.33 | 0.30 | 0.54 |
| 136 | WAINU B   | 12.47 | 3P H | 88.5   | 4,100 | Col 6 | 1.05            | 26     | 3.4    | 9               | 2.1    | 89     | 8               | 8      | 0.03   | 16.0            | 0.16   | 0.16   | 0.0             | 0.4    | 0.1    | 0.0  | 0.4  | 0.1  | 0.4  | 12.4 |
| 139 | MAALA A   | 12.47 | 3P H | 91.9   | 4,258 | Col 6 | 0.27            | 0.0    | 0.3    | 2               | 0.28   | 0.11   | 9               | 9      | 0.18   | 0.22            | 0.9    | 0.9    | 0.54            | 0.75   | 0.45   | 0.54 | 0.75 | 0.45 | 0.5  | 0.7  |
| 150 | MAHINA 12 | 12.47 | 3P H | 77.8   | 3,601 | Col 6 | 0.04            | 0.1    | 0.4    | 4               | 0.06   | 0.0    | 3               | 3      | 0.0    | 0.02            | 0.4    | 0.4    | 0.27            | 0.43   | 0.19   | 0.27 | 0.43 | 0.19 | 0.6  | 0.8  |
| 155 | KULA AG   | 12.47 | 3P H | 45.0   | 2,084 | Col 6 | 0.87            | 1.5    | 4.6    | 1               | 0.40   | 1.03   | 0               | 0      | 0.47   | 0.74            | 1.58   | 1.58   | 0.47            | 0.51   | 0.97   | 0.47 | 0.51 | 0.97 | 0.24 | 0.54 |
| 175 | NEWHD WD  | 12.47 | 3P H | 40.2   | 1,861 | Col 6 | 5.81            | 14     | 13     | 07              | 4.34   | 5.41   | 8               | 8      | 1.2    | 0.1             | 1.96   | 1.96   | 3.7             | 6.7    | 3.9    | 3.7  | 6.7  | 3.9  | 3.1  | 4.7  |
| 177 | WAIKAP1 2 | 12.47 | 3P H | 37.4   | 1,734 | Col 6 | 5.00            | 15     | 10     | 31              | 4.90   | 1.52   | 8               | 8      | 0.9    | 0.33            | 1.73   | 1.73   | 2.8             | 6.6    | 3.1    | 2.8  | 6.6  | 3.1  | 2.4  | 4.5  |

**Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current**

| Bus | Name      | KV    | 3P H | Case0 |          |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |      |      |      |      |     |
|-----|-----------|-------|------|-------|----------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|------|------|------|------|-----|
|     |           |       |      | MVA   | Amp      | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 |      |      |      |      |     |
| 203 | KANAH A   | 12.47 | 3P H | 96.3  | 4,462.60 | Col 6 | 7               | 8      | 9      | 10              | 11     | 12     | 13              | 14     | 15     | 16              | 17     | 18     | 19              | 20     | 21     | 22   | 23   | 24   | 25   |     |
| 204 | KANAH B   | 12.47 | 3P H | 86.9  | 4,025.90 | Col 6 | 4.47            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43 | 4.10 | 4.36 | 4.43 |     |
| 205 | KANAH C   | 12.47 | 3P H | 95.6  | 4,430.40 | Col 6 | 4.47            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43 | 4.10 | 4.36 | 4.43 |     |
| 216 | HAIKU 2   | 12.47 | 3P H | 28.3  | 1,311.20 | Col 6 | 4.47            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43            | 4.10   | 4.36   | 4.43 | 4.10 | 4.36 | 4.43 |     |
| 225 | WAILEA B  | 12.47 | 3P H | 91.9  | 4,255.00 | Col 6 | 1.02            | 1.3    | 1.4    | 1.5             | 1.6    | 1.7    | 1.8             | 1.9    | 2.0    | 2.1             | 2.2    | 2.3    | 2.4             | 2.5    | 2.6    | 2.7  | 2.8  | 2.9  | 3.0  |     |
| 234 | LAHAINA 2 | 12.47 | 3P H | 91.7  | 4,246.10 | Col 6 | 0.12            | 0.1    | 0.2    | 0.3             | 0.4    | 0.5    | 0.6             | 0.7    | 0.8    | 0.9             | 1.0    | 1.1    | 1.2             | 1.3    | 1.4    | 1.5  | 1.6  | 1.7  | 1.8  |     |
| 235 | KIHEI B   | 12.47 | 3P H | 86.0  | 3,981.80 | Col 6 | 1.18            | 1.2    | 1.3    | 1.4             | 1.5    | 1.6    | 1.7             | 1.8    | 1.9    | 2.0             | 2.1    | 2.2    | 2.3             | 2.4    | 2.5    | 2.6  | 2.7  | 2.8  | 2.9  |     |
| 325 | WAILEA C  | 12.47 | 3P H | 93.0  | 4,306.10 | Col 6 | 1.10            | 1.4    | 1.5    | 1.6             | 1.7    | 1.8    | 1.9             | 2.0    | 2.1    | 2.2             | 2.3    | 2.4    | 2.5             | 2.6    | 2.7    | 2.8  | 2.9  | 3.0  | 3.1  |     |
| 335 | KIHEI C   | 12.47 | 3P H | 83.8  | 3,881.30 | Col 6 | 1.18            | 1.3    | 1.4    | 1.5             | 1.6    | 1.7    | 1.8             | 1.9    | 2.0    | 2.1             | 2.2    | 2.3    | 2.4             | 2.5    | 2.6    | 2.7  | 2.8  | 2.9  | 3.0  |     |
| 336 | WAINU C   | 12.47 | 3P H | 88.6  | 4,101.90 | Col 6 | 1.03            | 26     | 32     | 37              | 42     | 47     | 52              | 57     | 62     | 67              | 72     | 77     | 82              | 87     | 92     | 97   | 102  | 107  | 112  |     |
| 405 | WILUKU C  | 12.47 | 3P H | 76.8  | 3,558.20 | Col 6 | 7.44            | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27   | 27   | 27   | 27   | 27  |
| 415 | WILUKU D  | 12.47 | 3P H | 63.8  | 2,956.70 | Col 6 | 6.39            | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26   | 26   | 26   | 26   | 26  |
| 425 | WAILEA D  | 12.47 | 3P H | 84.3  | 3,906.70 | Col 6 | 0.73            | 1.0    | 1.0    | 1.0             | 1.0    | 1.0    | 1.0             | 1.0    | 1.0    | 1.0             | 1.0    | 1.0    | 1.0             | 1.0    | 1.0    | 1.0  | 1.0  | 1.0  | 1.0  | 1.0 |
| 435 | KIHEI D   | 12.47 | 3P H | 89.6  | 4,149.20 | Col 6 | 1.21            | 1.3    | 1.3    | 1.3             | 1.3    | 1.3    | 1.3             | 1.3    | 1.3    | 1.3             | 1.3    | 1.3    | 1.3             | 1.3    | 1.3    | 1.3  | 1.3  | 1.3  | 1.3  | 1.3 |
| 443 | WAIEHUJ 2 | 12.47 | 3P H | 55.1  | 2,553.60 | Col 6 | 5.90            | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27              | 27     | 27     | 27   | 27   | 27   | 27   | 27  |
| 511 | MPINE     | 12.47 | 3P H | 59.8  | 2,769.80 | Col 6 | 7.20            | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26              | 26     | 26     | 26   | 26   | 26   | 26   | 26  |
| 534 | LAHAINA 5 | 12.47 | 3P H | 99.4  | 4,603.20 | Col 6 | 0.08            | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2  | 0.2  | 0.2  | 0.2  | 0.2 |
| 723 | PUIKA 12  | 12.47 | 3P H | 91.0  | 4,215.40 | Col 6 | 0.05            | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2             | 0.2    | 0.2    | 0.2  | 0.2  | 0.2  | 0.2  | 0.2 |
| 729 | NAPILB12  | 12.47 | 3P H | 74.3  | 3,443.80 | Col 6 | 0.11            | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1  | 0.1  | 0.1  | 0.1  | 0.1 |
| 750 | MAHINB 12 | 12.47 | 3P H | 79.1  | 3,664.40 | Col 6 | 0.09            | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1             | 0.1    | 0.1    | 0.1  | 0.1  | 0.1  | 0.1  | 0.1 |





Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus | Name            | KV  | 3P H | Case0 |        |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |         |        |
|-----|-----------------|-----|------|-------|--------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|---------|--------|
|     |                 |     |      | MVA   | Amp    | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont | Con t1 |
| 407 | WAI WELL        | 4.1 | 3P H | 26.3  | 3,655. | 3.66  | 7               | 8      | 9      | 10              | 2.67   | 0.76   | 5.2             | 0.4    | 4.21   | 2.68            | 1.6    | 19     | 20              | 21     | 1.4    | 3.6     | 1.1    |
| 418 | WLUKU HT        | 4.1 | 3P H | 47.6  | 6,607. | 5.35  | 7               | 8      | 9      | 5.08            | 1.37   | 7.7    | 1.2             | 2.28   | 2.62   | 2.8             | 19     | 20     | 21              | 2.3    | 6.6    | 2.0     |        |
| 431 | KAMOLE 4        | 4.1 | 3P H | 13.6  | 1,887. | 4.84  | 7               | 8      | 9      | 2.72            | 5.45   | 1.8    | 3.85            | 4.51   | 4.25   | 3.51            | 3.20   | 4.45   | 4.45            | 4.07   | 4.82   | 4.73    |        |
| 436 | WAINU A         | 4.1 | 3P H | 24.1  | 3,353. | 3.00  | 6               | 7      | 8      | 3.13            | 1.5    | 5.5    | 0.3             | 4.26   | 2.58   | 1.1             | 19     | 20     | 21              | 1.2    | 3.2    | 0.8     |        |
| 440 | ONEHEE 4        | 4.1 | 3P H | 24.2  | 3,362. | 3.49  | 16              | 17     | 18     | 12.7            | 14.9   | 14.    | 0.4             | 4.13   | 3.53   | 0.8             | 19     | 20     | 21              | 0.7    | 3.2    | 0.3     |        |
| 493 | PAIAMKA 1       | 4.1 | 3P H | 33.8  | 4,703. | 6.02  | 23              | 24     | 25     | 3.92            | 4.94   | 5.6    | 0.42            | 3.01   | 5.43   | 0.7             | 19     | 20     | 21              | 0.3    | 3.0    | 0.10    |        |
| 844 | KAHUL 4         | 4.1 | 3P H | 38.2  | 5,301. | 5.33  | 63              | 64     | 65     | 14.9            | 14.8   | 16.    | 0.2             | 2.88   | 3.85   | 1.3             | 19     | 20     | 21              | 1.0    | 4.6    | 0.6     |        |
| 845 | KAHUL 5         | 4.1 | 3P H | 38.2  | 5,305. | 5.28  | 50              | 51     | 52     | 14.9            | 14.8   | 16.    | 0.2             | 3.46   | 4.43   | 1.3             | 19     | 20     | 21              | 1.0    | 4.6    | 0.6     |        |
| 846 | KAHUL 6         | 4.1 | 3P H | 38.2  | 5,301. | 4.71  | 58              | 59     | 60     | 14.9            | 14.9   | 16.    | 0.8             | 2.88   | 3.85   | 1.3             | 19     | 20     | 21              | 1.0    | 4.6    | 0.6     |        |
| 141 | HANA 1          | 2.4 | 3P H | 7.29  | 1,754. | 1.08  | 3               | 4      | 5      | 0.34            | 0.57   | 0.2    | 0.60            | 1.08   | 2.21   | 0.48            | 0.41   | 0.71   | 0.71            | 0.63   | 0.76   | 1.32    |        |
| 142 | KEANAE          | 2.4 | 3P H | 4.96  | 1,193. | 0.54  | 6               | 7      | 8      | 0.22            | 0.06   | 0.1    | 0.32            | 0.73   | 1.91   | 0.33            | 0.38   | 0.47   | 0.47            | 0.23   | 0.34   | 0.90    |        |
| 161 | HOSMER          | 2.4 | 3P H | 5.16  | 1,241. | 0.66  | 6               | 7      | 8      | 0.0             | 0.49   | 0.0    | 0.23            | 0.61   | 0.44   | 0.07            | 0.4    | 0.29   | 0.29            | 0.40   | 0.80   | 0.64    |        |
| 174 | HUELO 1         | 2.4 | 3P H | 2.84  | 684.0  | 0.01  | 1               | 2      | 3      | 0.0             | 0.4    | -      | 0.0             | 0.31   | 0.37   | 0.07            | 0.22   | 0.15   | 0.15            | 0.1    | 0.1    | 0.1     |        |
| 209 | KAILUA A        | 2.4 | 3P H | 2.58  | 620.4  | 0.0   | 3               | 4      | 5      | 0.0             | 0.4    | 0.0    | 0.0             | 0.29   | 0.34   | 0.06            | 0.23   | 0.13   | 0.13            | 0.2    | 0.1    | 0.1     |        |
| 241 | HANA 2          | 2.4 | 3P H | 8.78  | 2,112. | 1.36  | 2               | 3      | 4      | 0.36            | 0.84   | 0.2    | 0.72            | 1.26   | 2.35   | 0.54            | 0.39   | 0.82   | 0.82            | 0.83   | 0.97   | 1.54    |        |
| 422 | WSCO PMP        | 2.4 | 3P H | 48.7  | 11,72  | 5.75  | 15              | 16     | 17     | 6.18            | 2.25   | 8.2    | 1.3             | 0.4    | 1.27   | 3.8             | 8.1    | 6      | 5               | 3.2    | 5.7    | 2.9     |        |
| 430 | MOKU PMP        | 2.4 | 3P H | 26.2  | 6,319. | 3.66  | 13              | 14     | 15     | 3.29            | 0.75   | 5.2    | 0.4             | 1.13   | 2.03   | 1.6             | 4.6    | 1.8    | 1.2             | 1.5    | 3.0    | 1.2     |        |
| 920 | AUWAHI 31_SIEM1 | 0.6 | 3P H | 84.8  | 70,97  | 2.4   | 0.2             | 0.3    | 0.4    | 2.6             | 0.6    | 0.5    | 2.7             | 0.8    | 1.10   | 2.7             | 0.9    | 0.74   | 0.74            | 2.9    | 1.0    | 0.88    |        |
| 920 | AUWAHI 32_SIEM2 | 0.6 | 3P H | 84.4  | 70,68  | 2.4   | 0.3             | 0.4    | 0.5    | 2.6             | 0.6    | 0.5    | 2.7             | 0.8    | 1.09   | 2.7             | 0.9    | 0.72   | 0.72            | 3.0    | 1.0    | 0.87    |        |
| 920 | KWPHI_G EN1     | 0.6 | 3P H | 146.  | 122.9  | 23.   | 23.             | 24.    | 25.    | 23.             | 23.    | 24.    | 23.             | 23.    | 24.    | 23.             | 22.    | 22.    | 23.             | 24.    | 24.    | 25.     |        |

Effect of Kahului Power Plant (KPP) Retirement on Short Circuit Current

| Bus Col | Name      | KV  | 3P H | Case0 |       |       | Case1 (Delta %) |        |        | Case2 (Delta %) |        |        | Case3 (Delta %) |        |        | Case4 (Delta %) |        |        | Case5 (Delta %) |        |        |         |        |
|---------|-----------|-----|------|-------|-------|-------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|-----------------|--------|--------|---------|--------|
|         |           |     |      | MVA   | Amp   | Col 5 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont         | Con t1 | Con t2 | NoC ont | Con t1 |
| 90971   | KWPI_1    | 0.5 | 3P H | 240   | 241.2 | 0.5   | 0.5             | 0.5    | 0.53   | 0.22            | 0.3    | 0.29   | 0.37            | 0.2    | 0.98   | 1.34            | 0.79   | 1.1    | 0.9             | 1.1    | 0.9    | 1.1     | 0.9    |
|         |           | 8   | H    | 25    | 35.90 | 2     | 2               | 8      | 0.93   | 1.85            | 4      | 1.17   | 1.58            | 2.33   | 0.98   | 0.88            | 1.56   | 1.20   | 1.65            | 1.20   | 1.65   | 2.39    |        |
| 44      | DET 03    | 0.4 | 3P H | 15.9  | 19.16 | 3     | 3.2             | 3      | 2.06   | 3.13            | 8      | 0.5    | 0.88            | 2.49   | 1.8    | 4.1             | 1.8    | 1.6    | 2.8             | 1.6    | 2.8    | 1.2     |        |
| 127     | CONCRET E | 0.4 | 3P H | 23.0  | 27.68 | 1     | 9.8             | 3      | 1.56   | 0.2             | 6      | 0.06   | 2.11            | 2.56   | 0.3    | 2.5             | 0.5    | 0.4    | 1.4             | 0.4    | 1.4    | 0.1     |        |
| 148     | MAUBLO C  | 0.4 | 3P H | 10.7  | 12.88 | 2     | 5.6             | 0      | 2.59   | 3.68            | 3      | 0.7    | 0.65            | 2.38   | 2.2    | 4.7             | 2.3    | 1.9    | 3.2             | 1.9    | 3.2    | 1.5     |        |
| 182     | AMERON    | 0.4 | 3P H | 26.6  | 32.02 | 3     | 10              | 10     | 0.4    | 0.66            | 8      | 0.12   | 1.90            | 3.05   | 0.03   | 1.6             | 0.18   | 0.1    | 0.8             | 0.1    | 0.8    | 0.29    |        |
| 188     | AMERBL DG | 0.4 | 3P H | 3.66  | 4.401 | 50    | 6.3             | 4      | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | 15.             | 13.    | 8.6    | 12.             | 8.6    | 12.    | 10.     |        |
| 501     | AUX K1    | 0.4 | 3P H | 13.9  | 16.71 | 0     | A               | A      | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | 60              | 77     | 60     | 34              | 60     | 34     | 98      |        |
| 502     | AUX K2    | 0.4 | 3P H | 10.4  | 12.51 | 0     | A               | A      | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | 11.             | 12.    | 8.6    | 12.             | 8.6    | 12.    | 10.     |        |
| 503     | AUX K3    | 0.4 | 3P H | 10.7  | 12.93 | 6     | A               | A      | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | 67              | 03     | 5.0    | 8.2             | 5.0    | 8.2    | 6.1     |        |
| 504     | AUX K4    | 0.4 | 3P H | 11.8  | 14.28 | 8     | A               | A      | #N/    | #N/             | #N/    | #N/    | #N/             | #N/    | #N/    | 0               | 7      | 5.7    | 9.6             | 5.7    | 9.6    | 8.3     |        |
| 206     | KWPII-2   | 0.4 | 3P H | 139.  | 167.9 | 62    | 9.3             | 8      | 8.4    | 8.7             | 9.2    | 8.5    | 8.5             | 9.0    | 8.0    | 7.7             | 8.2    | 9.6    | 9.5             | 9.6    | 9.5    | 10.     |        |
| 120     | XP_BESS   | 0.4 | 3P H | 101.  | 122.0 | 47    | 2.4             | 5      | 0.5    | 0.63            | 8      | 0.6    | 0.43            | 1.64   | 0.4    | 0.52            | 1.45   | 1.1    | 0.0             | 1.1    | 0.0    | 1.23    |        |
| 33      |           | 0.4 | 3P H | 47    | 47.80 | 9     | 1               | 5      | 0.5    | 0.63            | 8      | 0.6    | 0.43            | 1.64   | 0.4    | 0.52            | 1.45   | 1.1    | 0.0             | 1.1    | 0.0    | 1.23    |        |