Hawaiian Electric Company
Maui Electric Company
Hawaii Electric Light Company

Generation Requirements and Cycling Study

Executive Summary

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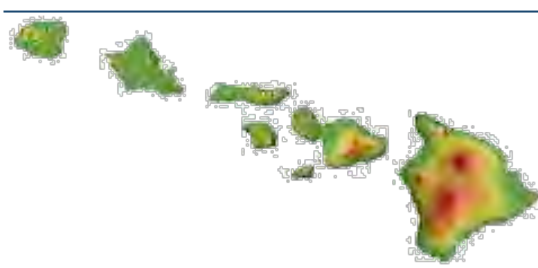

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Introduction

The Hawaii Electric Light Company (HELCO) and Maui Electric Company (MECO) both want to economically and reliably generate as much electricity as possible for their customers from renewable energy sources. Through the year 2012, HELCO generated almost 41% and MECO approximately 18% from renewable sources[1].

Within the next year, HELCO anticipates purchasing power from the Hu Honua biomass facility and soon, HELCO anticipates generating electricity with biofuel purchased from the Aina Koa Pono biofuel facility.

Both utilities sought to increase use of new and existing renewable energy in the most cost-effective way while maintaining reliable power. Toward that end, the utilities contracted Electric Power Systems (EPS) of Anchorage, Alaska to evaluate possible alternatives to the existing generation operations to increase use of renewable energy, while minimizing cost and maintaining reliability.

Current Conditions

Currently, the majority of the power generated by both utilities comes from fossil-fuel generated sources (although for the Hawaii Electric Light Company, renewable energy is approaching the amount of fossil-fuel generation). The fossil-fuel generation helps ensure the system is secure and reliable, and can adjust to changes in customer demand as well as to changes in variable wind and solar power. When replacing fossil-fuel generation with power from renewable sources, both utilities want to ensure that the resultant system is secure, reliable, and economical; that customers are well served; and that contingencies are in place to handle any adverse conditions.

Both utilities have already reduced the use of fossil-fuel generation to accommodate the use of existing renewable energy. Generating even less power from fossil-fuel sources would mean that the resultant generation mix must be more actively managed — cycled (turned on and off) more frequently, monitored as greater reductions in output is experienced, and adjusted to balance output with supply and demand — more often than has been done in the past. Whether these changes in generation continue to support a secure system must be quantified and the resultant costs evaluated.

[1] Neither amount includes electricity generated from distributed solar photovoltaic systems—those systems installed at numerous residential and commercial locations.

EPS Study Purpose

The *EPS Generation Requirements and Cycling Study* analyzed the impact of increasing the use of electricity generated from existing and anticipated renewable sources with emphasis on economy, reliability, flexibility, and performance.

The study identified the minimum unit combinations necessary to maintain reliable power system operations. The study produced estimates for offline cycling costs and recommendations made to improve offline cycling capability for certain units. Finally, the study prepared a preliminary analysis suggesting the possible optimal use of generation to achieve cost savings and decreased curtailed energy. The study's analysis assumed the power systems are able to operate with the minimum combination of units needed to maintain reliability, and are able to routinely cycle offline. The study identified key dependencies and made recommendations for follow-up work necessary to incorporate these results into actual operations. The results and recommendations were obtained thorough analysis of system security constraints, generation costs, and accepted engineering methods.

The Study's Building Blocks

The study took into consideration recent upgrades and changes to both the HELCO and MECO systems, and built models to evaluate and assess numerous conditions on both systems. The study used HELCO-supplied models for distributed photovoltaic generation, fault-induced delayed voltage recovery (FIDVR) phenomenon, unit characteristics (specifically, Puna Geothermal), system dynamics, wind, and total regulation, and an evening peak load dispatch case; and MECO-supplied wind and battery models as well as dispatch cases.

Both HELCO and MECO upgraded their systems in numerous ways during the past year, which helps set the stage for integrating more renewables in the near future. These upgrades added renewable generation capacity, reduced fossil-fuel generation, and fine-tuned their systems to better and more economically meet fluctuating demand.

HELCO added up to 8 megawatts of output to the Puna Geothermal plant (through a power purchase agreement), and also enhanced its grid-support services including increased voltage regulation, frequency response, and automatic generation dispatch control (controlling how and when energy is automatically dispatched into the system by adjusting it to meet demand). The utility also placed the Shipman fossil-fuel unit on dry lay-up (essentially stopping generation).

The utility increased its operating flexibility by reducing, by megawatts, the minimum load rating of generation units that must always operate; by increasing how quickly the Hill oil-fired units ramp up and down to respond to system needs; and by modifying the Keahole unit to allow automatic generation dispatch control during cycling transitions to more efficiently operate when adding or removing the second generator.

HELCO sought acceptance from the Public Utility Commission to increase its renewable portfolio by bringing online the energy and operation of an efficient 20.5 megawatt Hu Honua biomass facility. The proposed power purchase agreement requires the biomass plant to support the grid and operate flexibly (similar to that of fossil fuel steam generators).

MECO took steps to reduce wind energy curtailments by implementing alternate day cycling of Kahului Units 1 and 2, by allocating 10 megawatts of upward regulation and 3 megawatts of downward regulation to the Kaheawa Wind Power (KWP) II battery energy storage systems (BESS), and by limiting the upward regulation on three wind farms to 50 megawatts. All of these measures enable these units to operate more efficiently, and thus more cost effectively.

MECO also modified its automatic generation dispatch control system to incorporate its three wind farms and their battery energy storage systems.

HELCO and MECO continued work with Hawaiian Electric's Operation Integration Department — a leading wind forecasting service — to develop state-of-the-art wind and solar forecasting capabilities.

Both MECO and HELCO have added significant amounts of distributed generation, primarily solar photovoltaics (PV). The study included historical levels of solar PV, and the current projections of reduced demand from the estimates of increased future solar PV. The study recommended assessing the future impact of increasing solar PV on reliability requirements.

How the Study Was Conducted

The study provided insight into how each utility might reliably operate while using more renewable energy generation. The study's results then provided the necessary context for devising next steps. This process can be separated into four phases. The study:

1. Developed cycling costs and identified the measures and equipment modifications necessary to facilitate cycling.
2. Analyzed system security constraints (stability, transmission restrictions, underfrequency load shedding, rate of change of frequency, generation ramping capability, and regulation) and identified the minimum number of units needed to operate for system security.

These results were used to:

3. Run production cost simulations to determine lowest-cost operation while maximizing the use of renewable generation.
4. Devise conclusions, identify key dependences and assumptions, and recommend follow-on actions.

Study Phases

Phase 1: Cycling Costs Study

EPS contracted APTECH (now part of Intertek) to study cycling costs.

APTECH analyzed 10 years of historical data for starting up units and daily changes in their generation output. They measured changes in temperatures and pressures for generation efficiency, and determined the equivalent hot starts (restarting a unit within about eight hours after it has been shut down while the unit is still warm). They also interviewed personnel at both HELCO and MECO about their operating and maintenance procedures.

From this information, APTECH estimated the costs for cycling units currently in continuous operation. The study also recommended placing generators in layup when taken offline for extended periods, and modifying equipment and procedures to facilitate routine cycling.

Phase 2: System Security Constraints

For both the HELCO and MECO system, EPS defined the security constraints that enable increased renewable energy generation while maintaining system security. In other words, while integrating more renewable generation, each utility's system will reliably generate and transmit enough electricity to meet demand during normal conditions and through reasonably expected events, including contingencies (such as outages due to storms or equipment failures), and compensate for the variability from wind and solar.

EPS identified six security constraints:

1. **Stability:** The system continues to operate during a contingency: the minimum number of units required to be online at all times to ensure system stability must be determined. This minimum unit requirement constrains committing and dispatching generation and also directly impacts the system's ability to accept other generation (especially variable or non-conventional renewable generation).
2. **Transmission Restrictions:** The existing transmitting equipment must be kept within their voltage or thermal restrictions so that they are not overloaded and can be reclosed after an outage.
3. **Underfrequency Load Shedding:** Shedding load when a generator is lost — cutting power to certain customers to protect the overall system — must be relatively equal to or below historical amounts in order to preserve customer reliability. The potential loss of customers following generator trips must be evaluated against the performance of new generation when a generator is lost.
4. **Rate of Change of Frequency:** The rate that system frequency declines after the loss of a generator must be equal to or slower than the historical rate. The higher the rate of change of frequency, the greater the chance that the loss of one generator results in losing additional generators.
5. **Generation Ramping Capability:** The rate that generators can increase and decrease output must be equal to or faster than the changes needed to adequately meet the combined effect of customer demand, solar generation, and wind generation in the minutes-to-hour time frame. The combination of units required to meet the ramping capability for customer demand and changes in variable generation must be determined.
6. **Regulation:** The amount of generation available to meet system requirements must be balanced with actual demand within the seconds-to-minutes time frame. The balance is measured as the system frequency. The amount of regulating reserve must be quantified based on the amount of change from customer demand and variable generation to ensure the system can be kept in balance.

In order to evaluate these constraints, wind, hydro, and geothermal generation profiles used for constrained and unconstrained energy must be identified; dynamic and steady-state models must be improved; and the projected generation cost, transmission and generation constraints, and variable generation profiles must be developed.

Resultant Phases

Phase 3: Production Cost Simulations

The results of the cycling cost analysis and the system security requirements were used as the basis for production cost simulations. In other words, after implementing the identified system security requirements, the results of the study determined the most cost effective way to dispatch the generating units, maximizing the use of renewable energy into the generation mix for HELCO and MECO.

More specifically, the production cost simulations studied these questions:

- What are the potential effects on cost and use of renewable energy under the various case studies?
- What general conclusions can be made about possible future operations and procedures to maximize renewable energy while minimizing costs?
- How does the ability to forecast wind power affect the ability to reliably and economically operate the system with maximum renewable energy?

Phase 4: Conclusions and Recommendations

The study derived conclusions for both HELCO and MECO based on the findings of the previous three phases, then recommended steps to implement both immediately and in the future.

Study Findings

The study identified potential operational changes to reduce curtailments from wind, hydro, and solar; maximize renewable energy from new and existing dispatchable resources; and reduce costs while maintaining reliability.

Phase 1. Cycling Costs Study

After estimating the cost of cycling for typical starts, this phase of the study concluded that both HELCO and MECO should:

- Monitor cycling activity and maintenance costs to validate them and ensure they are kept current to reflect actual operating expenses.
- Make necessary plant changes to minimize maintenance and operating costs from increased deep and offline cycling.
- Acquire new equipment and other investments to maintain a unit's integrity when taking that unit offline for more than a week.

Phase 2. System Security Findings

The study determined the combinations of resources capable of meeting each of the six security constraints. Each utility must meet all of these constraints during their normal operations. To ensure a secure and reliable system, the utilities must operate at all times with a combination of units identified as meeting the security constraints.

These stated security constraints suggest that the number of fossil-fuel generators can be reduced from present operation to lower costs and increase renewable energy generation over the long term. This requires that the system be more closely monitored to maintain adequate system reliability because the system would be operating with reduced ability to withstand problems than the historical operation. The study also identified a number of critical issues to be confirmed for each of the HELCO and MECO systems.

HELCO Before Hu Honua Biomass Findings

1. **Stability:** At least two steam units must be online at minimum load, which could include the Puna Geothermal plant.
2. **Transmission Restrictions:** Keahole Combined-Cycle (or an equivalent amount of Keahole generation) must be online during daytime and evening peak demand.
3. **Underfrequency Load Shedding:** At least three large units (such as either Keahole DTCC (Dual-Train Combined-Cycle) or HEP (Hamakua Energy Partners) DTCC, plus Puna Geothermal) must be online.
4. **Rate of Change of Frequency:** At least four large units (such as Keahole DTCC and HEP DTCC) must be online. In some cases, three large units are sufficient.
5. **Generation Ramping Capability:** The generation ramp rate must be greater than four megawatts per minute, which can be met by Puna Geothermal plus at least one additional large unit.
6. **Regulation:** The HELCO system operators adjust the regulation based on the level of wind generation. The study found a reserve capacity of six megawatts plus 1 megawatt for each megawatt of wind power up to a maximum of 15 megawatts (for a total of up to 21 megawatts) to be a close approximation of present operation and can be used in production modeling. No changes to existing operational practice were recommended.

HELCO After Hu Honua Biomass Findings

1. **Stability:** At least two steam units (which can be the renewable energy Hu Honua and Puna Geothermal units) must be online at minimum load.
2. **Transmission Restrictions:** Same as the pre-Hu Honua Biomass case.
3. **Underfrequency Load Shedding:** At least four large units (such as Hu Honua, Puna Geothermal, plus either Keahole DTCC or HEP DTCC) must be online.
4. **Rate of Change of Frequency:** At least four large units (such as Hu Honua, Puna Geothermal, plus either Keahole DTCC or HEP DTCC) must be online.
5. **Generation Ramping Capability:** The generation ramp rate must be greater than four megawatts per minute, which can be met by Hu Honua and Puna Geothermal.
6. **Regulation:** No change from the pre-Hu Honua Biomass case.

MECO Findings

1. **Stability:** No requirement as long as the Regulation constraint is met.
2. **Transmission Restrictions:** Either K3 or K4 and one other small unit must be online during daytime and evening peak demand.
3. **Underfrequency Load Shedding:** No requirement as long as the Regulation requirement is met.
4. **Rate of Change of Frequency:** No requirement as long as the Regulation requirement is met.
5. **Generation Ramping Capability:** The generation ramp rate must be greater than five megawatts per minute, preferably from a Maalaea DTCC unit plus one additional large unit.
6. **Regulation:** Six megawatts or 0.5 megawatts for every megawatt of wind power up to 30 megawatts, plus 1 megawatt thereafter up to a maximum of 50 megawatts must be available to meet changes in wind and in demand.

Phase 3. Production Cost Simulations

The production cost simulations provide insight into how each utility's system might operate.

HELCO Production Cost Simulations

Increased cycling has the potential to reduce curtailments of variable renewable resources for excess energy. Curtailments can be incrementally reduced further after Hu Honua is online.

The study results showed Hu Honua coming online incrementally reduced curtailments. The study estimated the costs incurred to maintain the minimum combination of generating units online for system security when compared to ignoring these system security constraints. The difference between these scenarios estimates the cost of ancillary services. The results for the scenario with Hu Honua reduced the cost of ancillary services by about two-thirds.

The optimal system performance was based on the ability to accurately forecast net load. Net load is customer demand minus the power produced by solar and wind. Although demand can be readily forecast, forecasting solar and wind is more difficult and uncertain. The study conducted a sensitivity examining the dependencies of accurate wind forecasts by varying them. Wind forecasting errors tended to increase production costs. The larger the wind forecast error, the greater the impact on cost. This might also be true for photovoltaic forecasts.

Achieving the optimal system performance also depends on the HELCO and HEP units cycling considerably more than in the past.

When wind and solar forecasts are available, tools will need to be developed to predict, several hours to a day ahead of time, when units need to be taken offline or brought online. This advance timing depends on the time necessary to shut down and restart generators. To minimize costs, the online generation capability (minus production from wind and solar) must meet demand as closely as possible without excess online generation in order to avoid adverse reliability or security impacts.

MECO Production Cost Simulations

Implementing the recommended security requirements and the order in which units are committed to meet load (commitment order) can reduce curtailments and costs. MECO units, however, will cycle extensively with this new commitment order and result in increased cost mitigated somewhat by reduced fuel costs.

As is the case for HELCO, accurately forecasting net load, wind, and photovoltaics becomes paramount to reducing costs. Over predicting wind appears to reduce costs (which is likely because the system will be operated outside of the identified security constraints). Over predicting wind appears to reduce costs.

As with HELCO, achieving the optimal system performance also depends on the units cycling considerably more than in the past.

When forecasts are available, tools will need to be developed to predict, several hours ahead of time, when units need to be taken offline or brought online. This advance timing depends on the time necessary to shut down and restart generators. To minimize costs, the online generation capability (minus production from wind and solar) must meet demand as closely as possible without excess online generation in order to avoid adverse reliability or security impacts.

Phase 4. Conclusions and Recommendations

The study concluded that renewable energy could potentially be increased while keeping the system reliable by operating the system with the minimum generation required for security. By reducing the number of generating units online, renewable energy from both dispatchable as well as from variable sources can be maximized; and that curtailments for both HELCO and MECO could be significantly reduced from historical or projected 2013 levels.

Increased renewable energy, however, will result in considerable cycling costs of HELCO, MECO, and independent power producer (IPP) steam units. Short-term unit commitment programs as well as wind and solar energy prediction programs, properly implemented, can result in cycling cost savings and decreased curtailment energy.

Increasing renewable generation while decreasing steam generation means that both HELCO and MECO will be operating closer to their respective constraints, placing additional risk on both systems. Both systems must satisfy all identified constraints in order to maintain the level of reliability required of bulk power systems. Fewer online fossil-fuel generation coupled with increased unit cycling places greater — and more critical — individual performance requirements and system response of the remaining units.

The study recommended that HELCO and MECO:

- Evaluate the production cost simulations to determine potential operational changes that can reduce curtailments and costs.
- Use deterministic analysis to run additional sensitivities on the production cost simulations to determine the best way to commit and dispatch generation units.
- Review the study's results to identify any potential pitfalls and other items needing further study.
- Continue to refine wind and solar forecasting, develop more accurate near-term forecasts, understand the impact of forecasting errors on committing units, and integrate those strategies into daily operations.
- Develop procedures for committing and dispatching generation units (with increased renewables) that incorporate the variability of forecasting and decisions for cycling.
- Continue to monitor and evaluate actual cycling costs.
- Test and monitor how existing units perform to ensure they can perform as simulated in the study.
- Monitor the reliability of the system when integrating more renewable energy.

HELCO Recommendations

To best attain the results presented in the study and to operate securely, HELCO should:

- Test the rate of change of frequency capability of each turbine; update the models with these limitations.
- As photovoltaic usage increases, monitor the change in net load ramp rates.
- Develop accurate models of the photovoltaic systems (especially frequency and voltage characteristics).
- Confirm the assumed response characteristics of the Puna Geothermal and Hu Honua units; update the models and conclusions accordingly.
- Confirm the sub-minute ramping rate, and the regulation requirements and capability.
- For the wind turbine generators, confirm the capability assumed in the study to supply regulation.
- Confirm the regulation capability of wind generation; update the models accordingly.
- Test the existing HELCO and IPP generation; update the models accordingly.

MECO Recommendations

To best attain the results presented in the study and to operate securely, MECO should:

- Monitor the data of actual wind ramps and deviations.
- As more wind data becomes available, evaluate the regulation and ramping requirements.
- As photovoltaics usage increases, monitor the change in net load ramp rates.
- Develop accurate models of the photovoltaic systems (especially frequency and voltage characteristics).
- Test the capability of existing and new battery energy storage systems (BESS) through testing; update the models accordingly.
- Accurately model wind turbine generators and BESS, including their control response of how they best contribute to system disturbances.
- Ensure that BESS and wind inertia controls act cohesively during system disturbances.
- Confirm the regulation capability of wind; update the models accordingly.
- Test and update the existing MECO generation models.

Study Caveats

Operating with only the minimum generation required for security constraints identified in this study will allow for increased integration of renewable generation while maintaining acceptable reliability. These results, however, are based on a study and not on actual implementation. Operating with these minimum security requirements presents increased risk over historical operation. HELCO and MECO must assess the actual results by testing and analyzing their actual operations. Differences most likely will occur between the actual implementation results and the study's assumptions. Differences in equipment performance, ability to forecast wind and solar production, ability to forecast demand, development of unit commitment tools for the operators, the true costs and capabilities of offline cycling, and other relevant considerations will have a material impact on the actual operation to achieve the lowest cost, increased use of renewable energy, and maintain a reasonably secure power system.

This impact must be identified and integrated into daily operations.

Both utilities must continuously evaluate changes in operations in order to best achieve the goals of keeping costs reasonable, using more renewable energy, and operating their systems securely.

Conclusions

From the study and its incumbent results, HELCO and MECO have drawn the following conclusions.

HELCO Conclusions

HELCO's production cost simulations indicate that curtailments can be reduced while significantly increasing renewable energy. To minimize these curtailments while keeping production costs down requires a critical ability to accurately forecast variable generation and net load.

Cycling costs from some units (HELCO and HEP) will increase while reducing curtailments, which will be mitigated somewhat by lower fuel costs. Capital investments and operational changes must accompany increased unit cycling and, as a result, cycling costs might be reduced.

Wind predictions impact costs by falling short of generation reserve requirements, which appears to reduce costs.

MECO Conclusions

The study was able to simulate curtailment reductions which MECO must attempt to match during its day-to-day operation.

Increased cycling coupled with new voltage constraints allows for a significant increase in renewable generation during peak demand periods. This increased cycling, while minimizing curtailments, significantly increases costs which is somewhat mitigated by fuel cost savings.

Accurately forecasting net load, wind, and photovoltaics becomes paramount to reducing costs. Over predicting wind appears to reduce costs.

Implementation Strategy

To begin implementing the study's findings, HELCO and MECO will begin developing production cost models that better evaluate ways to maximize renewable energy and minimize curtailments while maintaining reliability and reducing both system and generation costs.

The utilities will continuously look for ways to better integrate renewable energy and to lower generation costs without compromising reliability or system security, and then implement these methods when appropriate. System operators will also be aware of the minimum generation to maintain system security.

The utilities will also analyze these models to identify key system dependencies and to create action plans for transitioning to the optimal mix of current resources for committing and dispatching generation.

Finally, HELCO and MECO will add cost-effective renewable energy generation (displacing fossil-fuel generation), then optimize committing and dispatching a changing generation mix with the costs of ancillary services and all other costs related to the changing resources.