

Ancillary Services Definitions and Capability Study

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Task 2: Energy Modeling and Scenario Analysis

Prepared by

GE Energy Consulting

Submitted by

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Ancillary Services Definitions and Capability Study

Part 1, Tasks 1-2, Final Report For Hawaii Natural Energy Institute

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imagination at work

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Foreword

This report was prepared by General Electric International, Inc. acting through its Energy Consulting group based in Schenectady, NY through the support of the Hawaii Natural Energy Institute and under a contract with the Research Corporation of the University of Hawaii. Technical and commercial questions and any correspondence concerning this document should be referred to:

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1 Study Background and Objectives

The purpose of this study is to identify, define and quantify ancillary services necessary to integrate new generation resources, including renewable generation, for bulk power systems and particularly the Hawaiian Islands. The results of this study may be: incorporated into the Hawaii Reliability Standards Working Group's proposals for new reliability standards; used to develop recommendations for revised generation interconnection technical requirements; provided to the Hawaii Public Utility Commission for consideration and adoption; and used to inform the Hawaii utilities' Integrated Resource Planning process.

The GE team has been deeply involved in analyzing the impact of renewable generation on the HECO systems and has performed 9 system-level studies over the past 5 years. The power output from Variable Generators (VG) such as wind and solar plants, by definition is variable. Also, there is a certain amount of uncertainty associated with this generation in the hours preceding actual operations. The generation from VGs is not only variable within the hour and is also variable on a longer timeframe such as daily, weekly and monthly time frame. The variability of VGs within the hour (along with the variability associated with the load) is handled by the system operator through the use of regulation and load-following (spinning) reserves. This study will leverage the findings of the renewable impact studies performed by GE.

The project focuses on four tasks¹:

- Task 1: Define a standardized set of ancillary services along with their associated definitions (in functional, technology-neutral, performance based terms) that can be used to meet the operational needs of Hawaii and other bulk power systems, and provide for the integration of variable generation technologies.
- Task 2: Assess resource technologies (generation, transmission, storage, and demand response (DR)) for their ability to support the respective ancillary services, to maximize the diversity and optionality for ancillary service acquisition and delivery.
- Task 3: Identify the physical requirements of the ancillary services needed for each Hawaiian island (Oahu, Maui, Big Island).
- Task 4: Outline considerations for specifying / acquiring ancillary services for the Hawaii grids that protect reliability, incent renewable generation, and minimize production costs.

This report presents the results of Tasks 1 and 2 of the study. The results of Tasks 3 and 4 will be presented in a separate report.

¹ After the study was commenced, it was decided that Task 1 should be generic and address all ancillary services that are in service or under development in the U.S., as well as internationally, regardless of their applicability to the Hawaii system. The applicability of the ancillary services to the Hawaii system was included as a portion of Task 3 of the study. Therefore, in Task 1, the difficulty in adopting some of the researched ancillary services for the Hawaii system will be acknowledged, but not discussed in detail.

2 Summary of Results

Ancillary services are required to maintain reliable operations of the electric power system. With Hawaii Natural Energy Institute (HNEI), in cooperation with the Hawaii Reliability Standards Working Group (RSWG), GE has worked to identify, define and quantify ancillary services necessary to integrate new generation resources, including renewable generation, for the Hawaiian Islands. This written summary report for Tasks 1-2 and the attached PowerPoint slides in Appendix A documenting Tasks 1-2², comprise the Part 1 final report from GE for use by HNEI and the Hawaii RSWG. This portion of the study focuses on ancillary services definitions, interconnection requirements and technologies capable of providing these ancillary services in technology-neutral, functional terms. These definitions may not reflect the current practices on the Hawaiian Islands for delivering ancillary services, but the ancillary services as defined here represent viable options for any electric power system to maintain reliable operations and should be considered as options for the Hawaiian Islands. Table A.2-1 summarizes the ancillary service definitions.

² 2012_12_10_Hawaii_Ancillary_Services_Report_PART1FINAL.pptx

Table A.2-1 Ancillary Services Definitions

| Ancillary Service: Normal and contingency conditions | Brief Description: | Notes: |
|---|---|--|
| Frequency Responsive Reserves/ Primary Frequency Response: | Automatic response triggered by frequency swings. Typically deployed during contingency events. Arrests and helps to recover the frequency change. | <ul style="list-style-type: none"> - Immediate response - Typically less than 15 min - Provided continuously - Proportional to frequency deviation |
| Regulation: | Used continuously during normal operations to correct short-term imbalances between supply and demand. Deployed via AGC signals. | <ul style="list-style-type: none"> - At least every 6 seconds - Typically 5-10 min - Provided continuously - Magnitude varies, proportional to size of imbalance |
| Load Following: | Slower than "Regulation" and used primarily during normal operations. Typically deployed via economic dispatch to correct an imbalance that will occur in the future. | <ul style="list-style-type: none"> - Response time and duration needs to be established - Anticipated to be continuous - Magnitude varies, proportional to size of imbalance |
| Contingency Conditions | | |
| Spinning Reserves: | Type of contingency reserve that consists of resources which are connected to the power system and poised, ready to respond immediately. | <ul style="list-style-type: none"> - Response is immediate will full response within 10 min - Various durations - Intermittent use, after a disturbance - Magnitude varies |

| | | |
|----------------------------------|--|---|
| Non-spinning Reserves: | Type of contingency reserve that consists of resources which are capable of providing full response within a specified time; however, the response does not need be immediate. | <ul style="list-style-type: none"> - Full response within 10 min - Various durations - Intermittent use, after a disturbance - Magnitude varies |
| Replacement Reserves: | Deployed following a contingency event. Intended to replenish contingency reserves; response does not need to begin immediately. | <ul style="list-style-type: none"> - Response within 30 to 60 min - Various durations - Intermittent use, after a disturbance - Magnitude varies |
| Additional Services | | |
| Black Start: | Provided by resources capable of starting themselves quickly without support of an external electricity source. Used to restore a power system following a major blackout. | <ul style="list-style-type: none"> - Resources available after a black-out - Various durations - Only after a black-out - Magnitude varies |
| Reactive Power/ Voltage Support: | Provided by resources capable of injecting/consuming reactive power which is required to maintain voltages within acceptable limits throughout the power system. | <ul style="list-style-type: none"> - Response in seconds - Various durations - Provided continuously - Typical power factor range of 0.95 leading to 0.95 lagging |

The Part 2 final report documents the GE study results for Tasks 3-4 and provide analysis of Hawaii-specific scenarios including comparison of current practices on the Hawaiian Islands to the ancillary services and interconnection requirements proposed in Part 1. Part 2 offers a number of procedures and methodologies to determine the need for, provide, and value ancillary services for an electric system. While the examples and data used in Part 2 are Hawaii-specific, the procedures and approaches outlined should be applicable and useful for any system.

2.1 Key Terminology

The following definitions for key terminology are relevant throughout the content of this study and should be interpreted as described below.

Area Control Error (ACE):

The instantaneous difference between a Balancing Authority's net actual and scheduled interchange, taking into account the effects of Frequency Bias and correction for meter error. Source - NERC Glossary (2008)

Conventionally, **ACE = (NIA – NIS) – 10B (FA – FS) – IME**, where:

NIA is the algebraic sum of actual flows on all tie lines.

NIS is the algebraic sum of scheduled flows on all tie lines.

B is the Frequency Bias Setting (MW/0.1 Hz) for the Balancing Authority. The constant factor 10 converts the frequency setting to MW/Hz.

FA is the actual frequency.

FS is the scheduled frequency. FS is normally 60 Hz but may be offset to effect manual time error corrections.

IME is the meter error correction factor typically estimated from the difference between the integrated hourly average of the net tie line flows (NIA) and the hourly net interchange demand measurement.

Due to a lack of inter-area power flows, the definition of ACE has been modified for Hawaii. Specifically, for **Hawaii, ACE = – 10B (FA – FS)**. This modified definition of ACE is still applicable for Hawaii as it correctly represents the fact that 100% of difference between supply and demand will manifest itself as a frequency error. Source - Revised definition per Hawaii RSWG Glossary

Automatic Generation Control (AGC):

Equipment that automatically adjusts generation, storage devices, and/or responsive load in a Balancing Authority Area from a central location to maintain the Balancing Authority's interchange schedule, plus the Frequency Bias (i.e. ACE). Source - NERC Glossary (2008) with modifications to accommodate additional resource types such as load and storage devices

Although AGC was originally conceived as a means to provide fast (3-6 second signals) to generators, the concept of leveraging AGC to provide "MW raise/lower" commands to demand-side and storage resources is equally applicable and is in practice in some locations.

Droop Response:

Droop response is a near instantaneous means of proportionally adjusting a resource's real-power to resist a change in frequency; allowing a system of resources to operate in a stable manner.

The magnitude of a given resource's response is proportional to the frequency deviation and typically characterized by "x%" droop. For example, a resource with operating range available will provide

100% additional output per “x%” change in system frequency. Response is typically a percentage of the resource’s full-capability.

Droop response can be provided by any frequency-sensitive resource.

Resource:

A resource may consist of any generation, storage, load (i.e. demand-side), or transmission technology.

Spinning / Non-Spinning:

Historically, the terms “spinning” and “non-spinning” have referred to the rotational nature of synchronized generators. Over time, this terminology has migrated to imply the “relative state of readiness and responsiveness” as it relates to the ability for a resource to fulfill its ancillary obligation. In an effort to leverage contemporary industry vernacular, this latter interpretation was adopted for use in this presentation.

3 Study Results

3.1 Task 1: Identify and define ancillary services needed for integration of new generation resources, including various renewable generation technologies

Every bulk system requires a suite of ancillary services to provide grid reliability today and to integrate variable renewable generation. The objective of Task 1 is to gather information to help define a standard set of ancillary services with functional performance requirements/definitions, interconnection requirements and other system considerations. Although each power system uses the same ancillary services in functional terms, in practice there are significant differences across regions and balancing areas in which entities produce specific ancillary services and how these services are acquired, controlled, delivered and compensated. Thus it is important to distinguish between the functional role of each ancillary service and the local, system-specific practices for its provisioning (for instance, whether a particular service is performed only by a utility-owned generator or included as an operational interconnection requirement of third party generators). Tasks 1 and 2 therefore describe the ancillary services, and include descriptions to distinguish some of the ways by which Hawaii's electric systems name and deliver these services today.

GE identified and defined all of the ancillary services that are currently being used or under development in different parts of the world, in regulated as well as deregulated regions, with a focus on real-power energy balancing services such as regulation, load following and various types of contingency reserves which are impacted more by renewables. The purpose of this task is to gather the most recent information and best practices with respect to ancillary services with the full understanding that some of these ancillary services may not be applicable to the Hawaii utilities.

Ancillary services³ are those functions performed by the equipment and people that generate, control, transmit, and distribute electricity to support the basic services of generating capacity, energy supply, and power delivery. They are required to maintain reliable operations of the electric power system. In addition to ancillary services, other interconnection requirements are placed on resources to ensure reliable operation of the grid. These ancillary services and interconnection requirements enable the system operator to meet the required operations and reliability standards set by NERC. The ancillary services, interconnection requirements, and reliability standards are dependent on the characteristics of a power system.

³ FERC defines ancillary services as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."

The set of ancillary services that provide direct support for the reliable and economic operation of the power system are:

Real-Power Energy Balancing Services

- Frequency Responsive Reserve /Primary Frequency Response
- Regulation
- Load Following
- Spinning Reserve
- Non-Spinning Reserve
- Replacement Reserves

Additional Services

- Black Start
- Reactive Power/Voltage Support

Generation characteristics that are specified via Interconnection Requirements are:

- Power Factor & Voltage Control
- Voltage and Frequency Ride Through
- Ramp Rate Limits and minimum response
- Over and Under Frequency Controls
- Inertia

Real power balancing services that come into play during normal and contingency operating conditions are shown in the figures below. **Figure 3-1** and **Figure 3-2** illustrate the operational timeframes for some services.

Operational Time Frames

Relationship during **Normal** Operating Conditions

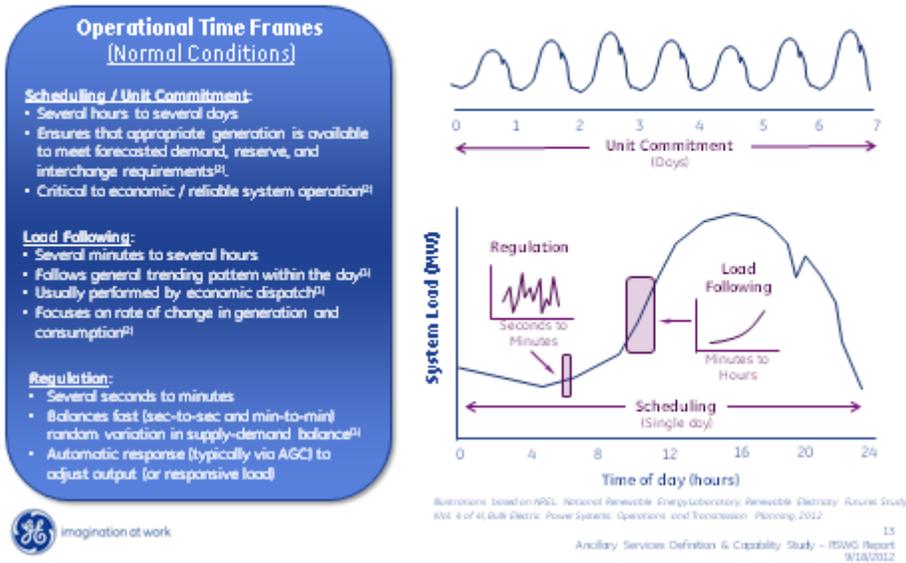


Figure 3-1 Normal Operating Conditions

Operational Time Frames

Relationship during **Contingency** Operating Conditions

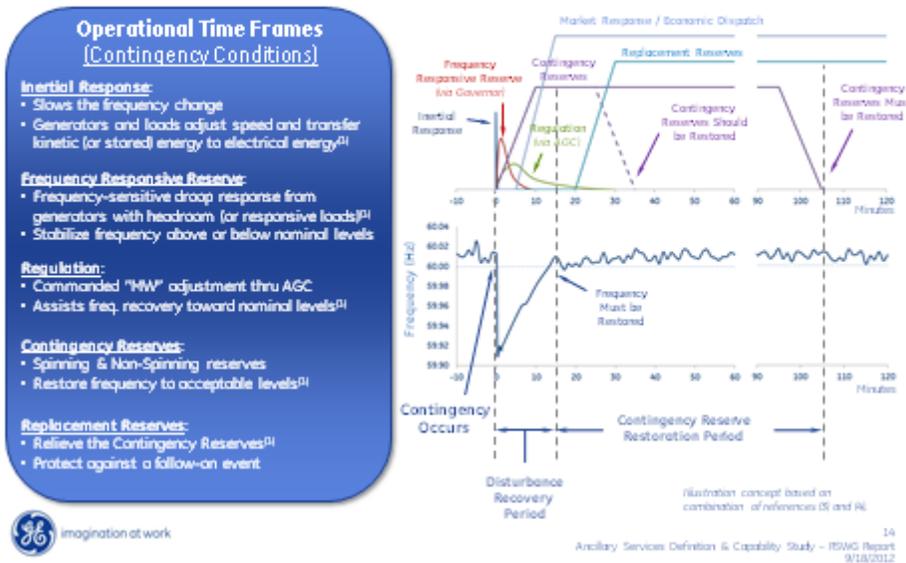


Figure 3-2 Contingency Operating Conditions

The purposes of these ancillary services are defined below. See the attached PowerPoint slides in Appendix A entitled "2012_12_10_Hawaii_Ancillary_Services_Report_PART1FINAL.pptx" slides 17-27 for the detailed definition for each ancillary service in functional terms for its performance requirements (e.g., reaction speed for service provision, time duration, deployment frequency, and MW magnitude of response). Differences from these functional definitions and the current practices of the Hawaiian Islands are explored in Part 2 of this study.

For normal and contingency conditions:

Inertial Response: Provides system stability during normal conditions; slows frequency change during contingency events. Provided by synchronized resources (also via power electronics). Inertial response is not obtained as an ancillary service. Rather it is autonomously provided by all synchronous units. It can also be provided by variable generators if they are equipped with synthetic inertia feature. These inertial response requirements for VGs are addressed through the interconnection requirements.

Frequency Responsive Reserves/ Primary Frequency Response: Automatic response triggered by frequency swings. Typically deployed during contingency events. Arrests and helps to recover the frequency change.

Regulation: Used continuously during normal operations to correct short-term imbalances between supply and demand. Deployed via AGC signals.

Load Following: Slower than "Regulation" and used primarily during normal operations. Typically deployed via economic dispatch to correct an imbalance that will occur in the future.

For contingency conditions:

Spinning Reserves: Type of contingency reserve that consists of resources which are connected to the power system and poised, ready to respond immediately.

Non-spinning Reserves: Type of contingency reserve that consists of resources which are capable of providing full response within a specified time; however, the response does not need be immediate.

Replacement Reserves: Deployed following a contingency event. Intended to replenish contingency reserves; response does not need to begin immediately.

Additional Services:

Black Start: Provided by resources capable of starting themselves quickly without support of an external electricity source. Used to restore a power system following a major blackout.

Reactive Power/ Voltage Support: Provided by resources capable of injecting/consuming reactive power which is required to maintain voltages within acceptable limits throughout the power system.

The definitions and details of these ancillary services are summarized in Table XX below and discussed in further detail in Appendix A.

Table A.3-1 Ancillary Services Definitions

| Ancillary Service: Normal and contingency conditions | Brief Description: | Notes: |
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| Load Following: | Slower than "Regulation" and used primarily during normal operations. Typically deployed via economic dispatch to correct an imbalance that will occur in the future. | <ul style="list-style-type: none"> - Response time and duration needs to be established - Anticipated to be continuous - Magnitude varies, proportional to size of imbalance |
| Contingency Conditions | | |
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3.1.1 Developments in Ancillary services – Emerging regulations, services and requirements

Recent developments in ancillary services for several regions in North America were researched to help identify emerging and additional services that may be applicable to Hawaii. As renewable penetration increases, many systems are challenged to examine existing and future requirements for reliability. Here are some highlights of the findings of this research.

Inertial Response (ERCOT)⁴

ERCOT is evaluating requirements for inertial response. Introduced tool (2010) to monitor online conventional generation, spinning reserves, and ratio of wind to total generation ... system operator can adjust unit commitment if available inertial response is insufficient.

Primary Frequency Response

Frequency Responsive Reserve (WECC):

A Frequency Responsive Reserve (FRR) procedure was proposed by WECC in 2005⁵.

NERC BAL-002-WECC-1 (2008) requires 50% of contingency reserves to be spinning AND frequency responsive. NERC BAL-012-WECC-2-CR (*FRR Criterion*, 2009) establishes minimum required FRR to prevent under-freq. load shedding (UFLS) during loss of generation event.

Primary Frequency Response (ERCOT):

ERCOT is the only balancing area that guides its minimum frequency response. The protocols also discuss the required primary frequency response from wind powered generation resources with standard generation interconnection agreements signed after January 1, 2010. Wind units are required to provide primary frequency response in response to high system frequency similar to a thermal unit with a droop of 5%.

Secondary Frequency Response

Load Following (CAISO): Flexible Ramping Revised Draft Proposal – August 2012

In WECC there is a stakeholder effort to develop market-based flexible ramping products. The load following service attempts to provide sufficient ramping and flexibility to handle 5-minute supply/demand changes.

Analogous to Load Following: Flexible ramping product addresses ramping issue before the binding real-time dispatch (RTD) ... Regulation addresses ramping issue after binding RTD.

As part of NERC Project 2010-14.1 standard BAL-012-1 is developed to require a balancing authority to develop and document plants for the appropriate mix of operating reserves. This will include adequate Regulating Reserve, Contingency Reserve and Frequency Responsive

⁴ Reference [3] NREL: National Renewable Energy Laboratory, Operating Reserves and Variable Generation, August 2010

⁵ See above footnote 5, Reference [3]

Reserve. Comments have been received (period closed July 2012) and are available here: http://www.nerc.com/docs/standards/sar/comments_received_BAL-012_070312.pdf

Hawaii requires 100% of all contingency reserves to be frequency responsive.

Ramp Capability for Load Following (MISO): MISO white-paper - July 2011

MISO is investigating improved Load Following options ... considering several approaches for “pre-ramping” resources for better future interval positioning.

They appear to be gravitating toward a “market product” which prices ramp capability. An incentive is provided to participate to avoid “out of merit” dispatch. The price would be “cleared” based on resource opportunity cost, and “paid-for” thru cost allocation similar to other ancillary products.

Regulation Performance Compensation (FERC Order 755): Issued in October 2011

FERC found “current methods for compensating resources for the provision of regulation are unduly discriminatory”. Order 755 requires all RTOs and ISOs to modify their tariffs to provide for a two-part payment to regulation resources:

- 1st Part: Payment for keeping a resource’s capacity in reserve in the event that it is needed to provide regulation.
- 2nd Part: Payment shall be a performance payment that reflects the amount of work that each resource performs in real-time.

3.1.2 Interconnection Requirements

Interconnection standards enable the system to meet its reliability standards by requiring generators:

- To have certain capabilities that directly helps with the system reliability
- To have certain capabilities that enable it to provide ancillary services that are required for system reliability.

VER Interconnection Requirements

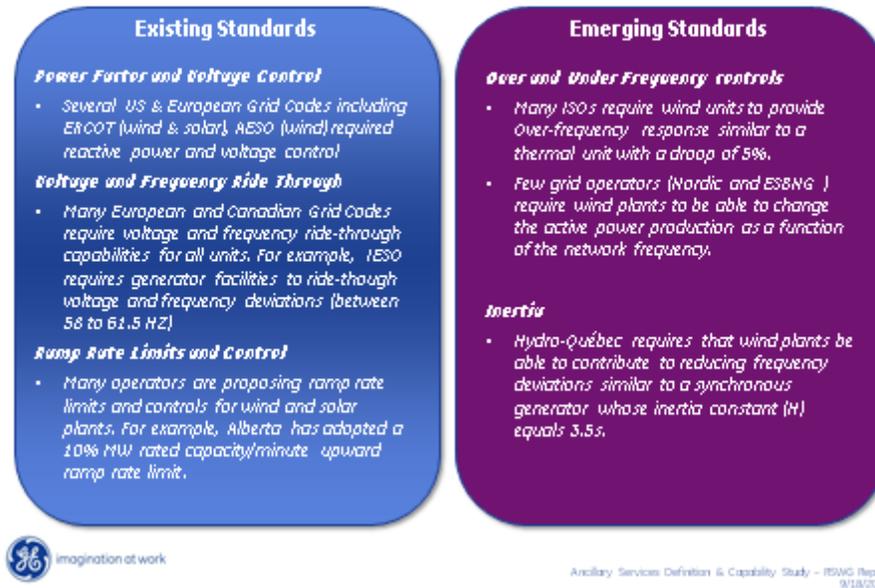


Figure 3-3 Interconnection requirements for Variable Energy Resources

More information on these interconnection requirements and example of regions that have implemented some of these interconnection standards can be found in Appendix A slides 44-52. More detail on recommended interconnection requirements can be found in the Part 2 report and are summarized in Table A.3-2 below.

Table A.3-2 *Interconnection Requirements*

| Interconnection Requirement: | Brief Definition: |
|----------------------------------|--|
| Reactive Power & voltage Control | Capability to provide reactive power output within a certain power factor range and the capability to regulate voltage within this range |
| Fault Ride-through | Capability of the generator to ride-through (predetermined) temporary voltage and frequency deviations |
| Ramp Rate Limits and Control | Capability to ramp limit the output of a generator under certain conditions |
| Over and under Frequency Control | Capability to automatically increase and decrease (sustained) output under low and high frequency conditions respectively |
| Inertia | Capability to provide an immediate response to a drop in system frequency |

Per a recent NREL paper (spring 2012): common active power control requirements in the US for wind are as follows:

- Curtailment control
- Ramp rate control (for curtailments and startup)
- Regulation UP (for under-frequency)
 - Adjustable droop
- Regulation down for over-frequency
 - Adjustable droop
- High wind shutdown
- Rate variation control
- Inertia
- Primary frequency response

Of the above, a couple of the key developments with respect to interconnection requirements are discussed below.

Inertia Requirement for Hydro Quebec:

Hydro-Québec requires that wind plants be able to contribute to reducing frequency deviations similar to a synchronous generator whose inertia constant (H) equals 3.5s

Primary Frequency Response Requirement for ERCOT:

Many ISOs require wind units to provide Over-frequency response similar to a thermal unit with a droop of 5%.

Few grid operators (Nordic and ESBNG) require wind plants to be able to change the active power production as a function of the network frequency. In ERCOT, wind units are required to provide primary frequency response in response to high system frequency similar to a thermal unit with a droop of 5%.

Recommendations regarding which of the above-mentioned ancillary services and interconnection requirements are suitable for Hawaii will be discussed in Task 3.

3.1.3 Other Considerations

Several additional considerations affect ancillary service delivery and system economics and the ability to meet renewable energy goals. These considerations cannot be addressed directly by interconnection requirements or ancillary services. There may be a need for other mechanism as listed below.

Reduced Minimum Generation Capability:

Enabling resources to operate with reduced minimum generation capacity increases the potential for increased online reserves and the potential for more granular ancillary service participation. More online reserves may help avoid curtailment of renewable and lower cost generating assets. This should also improve system-level load following capability and provide options for improved portfolio management to hedge against uncertain conditions. In general, there needs to be a mechanism within power systems such as planning rules or tariffs to incent more flexibility in generators, i.e. lower turndown, faster ramp rate, shorter start time and the ability to cycle.

Short-circuit Strength:

Short-circuit levels on transmission lines may decrease if synchronous generators are replaced by renewables. Synchronous generators may need to be online to maintain minimum short-circuit levels on the system. Relays and protection devices that detect short circuits by monitoring the current and need a minimum current for reliable operation (lower limit for short circuit levels). Since Hawaii anticipates high penetrations of renewables, additional studies are recommended to try and identify any issues with short-circuit strength.

Short-circuit Ratio:

The short circuit ratio as seen at the point of interconnection of non-synchronous generators can decrease. This can happen even at the same level of commitment of synchronous generators but at higher penetration of non-synchronous resources. The decreased short-circuit ratio can lead to controller instability issues in the power electronics control of wind and solar generators.

Load Shaping:

Load shaping considers proactive movement of demand-side resources or non-dispatchable load to provide a more manageable daily load shape, i.e. incentivize / prohibit charging of PEVs at certain times of day. "Load shaping" may provide an opportunity to reduce the amount of other ancillary services that are required. We anticipate that this would be a procedural implementation rather than ancillary-service based approach. System operators need to carefully consider how to monitor, incentivize, and enforce the targeted load adjustments.

3.1.4 Unique characteristics of Hawaiian system warrant attention to ancillary services and interconnection requirements

The unique characteristics of the Hawaii system needs to be taken into account in order to determine the additional ancillary service and interconnection requirements. These characteristics are discussed below.

- The Hawaiian Islands are comprised of relatively small island systems: HECO~1200 MW, MECO ~200MW, HELCO~195 MW peak load. The relative small island systems make it challenging to maintain frequency.
- There are no interconnections between the Hawaiian Islands or the Mainland. Any imbalance between load and generation affects frequency, a small frequency bias.
- There is a higher Rate of Change of Frequency (ROCOF) due to system events. The ratio of unit size or renewable energy project size to system size is high.
- Hawaii has leaner operations than other systems. There is a relatively high cost of energy and ancillary services (that are currently provided as a bundled service with energy) due to high fuel prices.
- Historical reasons such as existing purchase power agreements, system requirements for UFLS, ROCOF, transmission constraints, ramping, physical and emission limits require the use of some Must run/scheduled units.
- Each Hawaiian Island has a single vertically integrated utility, multiple IPPs and third-party dispersed generation with no centralized power markets to purchase or sell excess generation
- While fewer opportunities for transaction "liquidity", ancillary service value can be calculated/estimated to provide incentives/payments to providers of ancillary services – ancillary services do not need to remain in bundled utility offering.
- The Hawaiian Islands have large amounts of distributed generation.

- Clean Energy Mandate includes RPS target of 40% and 4,300 GWH reduction for Energy Efficiency Portfolio Standards by 2030; high wind and solar generation potential in MECO, geothermal in HELCO.
- Hawaii has specific operating criteria to maintain system frequency and voltage and provide adequate reserves.

The unique characteristics of the Hawaii system will be taken into account while determining the applicability of the researched ancillary services and interconnection requirements.

The current operating criteria of note and the impact on the current provision of ancillary services on the Hawaiian Islands are included in Task 3.

3.2 Task 2: Identify which technologies can provide each ancillary service.

Using the ancillary service definitions developed in Task 1, GE identified and summarized in a table which generation, transmission, storage and demand-side technologies are able to provide each ancillary service given current technology capabilities and fuel availability, without screening or limiting the options with respect to economic cost-effectiveness. As requested, GE generally limited technologies to those that are available in commercial or pilot applications today and provide current deployment cost estimates, but do not speculate about future cost projections.

The generation technologies are broken down by fuel (for example, gas units) and type (for example, simple cycle gas turbine) without focus on the actual make or model. GE Identified the approximate resource size for each technology and each ancillary service. Background and reference citations as available for each technology and ancillary service capability match are provided.

Table A.3-3 Ancillary Services Capabilities by technology

| Technologies | Ancillary Services Compatibility | | | | | | | | |
|--|----------------------------------|------------------------------|------------|----------------|------------------|----------------------|---------------------|-----------------|-------------|
| | Inertial Response | Frequency Responsive Reserve | Regulation | Load Following | Spinning Reserve | Non-Spinning Reserve | Replacement Reserve | Voltage Support | Black Start |
| Generation | | | | | | | | | |
| Solar Thermal | A | T | T | T | T | --- | --- | A | T |
| Solar Photovoltaic (Transmission Connected) | T | T | T | T | T | T | T | T | --- |
| Wind (non-synchronized / power conversion) | A | A | A | A | A | T | T | A | --- |
| Wind (synchronized) | A | A | A | A | A | T | T | A | T |
| Hydropower | A | A | A | A | A | A | A | A | A |
| Geothermal | A | A | A | A | A | --- | --- | A | T |
| Biomass | A | A | A | A | A | --- | --- | A | --- |
| Coal | A | A | A | A | A | --- | --- | A | --- |
| Combined Cycle (Gas/Oil: Sm. HD/Aero) (1x1) | A | A | A | A | A | A | A | A | A |
| Combined Cycle (Gas/Oil: Heavy-duty) (1x1) | A | A | A | A | A | A | A | A | A |
| Simple Cycle (Gas/Oil: Small HD/Aero) | A | A | A | A | A | A | A | A | A |
| Simple Cycle (Gas/Oil: Heavy-duty) | A | A | A | A | A | A | A | A | A |
| Reciprocating Engines (Gas/Diesel/Bio) | A | A | A | A | A | A | A | A | A |
| Energy Storage | | | | | | | | | |
| Pumped Hydropower | A | A | A | A | A | A | A | A | A |
| CAES - Comp. Air Energy Storage | E | E | E | E | E | E | E | E | T |
| Solid Batteries | E | E | A | E | A | E | E | E | E |
| Flow Batteries (Redox) | T | T | T | T | T | T | T | T | T |
| Flywheels | E | E | A | --- | --- | --- | --- | T | --- |
| PEV | T | T | E | T | T | T | T | T | T |
| Fuel Cells (PEM) | T | T | T | T | T | T | T | T | T |
| Demand Response | | | | | | | | | |
| Fast Auto DR | T | A | A | T | A | A | A | --- | --- |
| Direct Load Control | T | A | E | T | A | A | A | --- | --- |
| Interruptible Load | T | A | T | T | A | A | A | --- | --- |
| Price Responsive Demand | T | T | T | T | A | A | A | --- | --- |
| Transmission | | | | | | | | | |
| Synch. Cond.: Large motor frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: Air-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: H2-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Shunt FACTS devices (STATCOM, SVCs)* | --- | --- | --- | --- | --- | --- | --- | A | --- |
| HVDC Transmission Technologies* | --- | --- | --- | --- | --- | --- | --- | A | A |
| Desirable Attributes / Retrofit Options | | | | | | | | | |
| Improved Turndown (MinGen) Capability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Elevated Ramp-rate Capability | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Faster Startup Capability | | | | | | ✓ | ✓ | | |
| *Dynamic voltage support | | | | | | | | | |

| | |
|---|---|
| A | Available commercially |
| E | Emerging capability in demonstration phase |
| T | Technically feasible, but not currently being pursued |

Note: GE Wind Turbines are capable of providing governor response with a dead-band of up to +/- 36 mHz. For frequency deviations that extend beyond +/- 36 mHz, the default response for the turbine governors is to provide a proportional response back to the droop characteristic. Further, synthetic inertia can also be availed from the wind turbines in events of severe frequency excursions. The stored kinetic energy in the wind blades can be released during such events to assist the grid and arrest the frequency drop and frequency nadir. GE Wind Turbines have a deadband of 200 mHz for provision of synthetic inertia. For AGC-based "MW raise/ MW lower" regulation signals, the governor dead-band does not apply. Wind turbines are also capable of providing sufficient responsiveness for spinning reserve; however, a related factor that needs to be considered is the required duration that the spinning reserve response must be sustained once it is deployed. The required response period is more directly tied to the site-specific wind sustainability than the equipment itself.

Table A.3-4 Technology characteristics

| Technologies | Plant Size (MW) | | | | Cost Estimates | | Flexibility | | | |
|--|-----------------|-------------------|-------------------|---------|--|---|---------------------|---|---|---|
| | Minimum | Minimum (Typical) | Maximum (Typical) | Maximum | Total Overnight Cost in 2010 (2009 \$/kW) for stated size (MW) | Resource Size Assumed in Cost Estimate (MW) | Turndown Load Level | Ramp Rate Capability (thermally stable) | 10-Minute Output Available (from offline) | 30-Minute Output Available (from offline) |
| Generation | | | | | \$/kW | MW | %MW | %MW/min | %MW | %MW |
| Solar Thermal | 0.1 | 1 | 100 | 200 | \$4600 - 8100 | 200 | 12-15% | 3-7%* | 0% | 0% |
| Solar Photovoltaic (Transmission Connected) | 0.001 | 0.05 | 5 | 150 | \$2100 - 3900 | 10 | --- | Rapid* | 100% | 100% |
| Wind (non-synchronized / power conversion) | 0.001 | 1 | 100 | 450 | \$1500 - 2500 | 100 | < 10% | Rapid* | 100% | 100% |
| Wind (synchronized) | 0.001 | 1 | 100 | 450 | \$1500 - 2500 | 100 | < 10% | Rapid* | 100% | 100% |
| Hydropower | 0.001 | 0.5 | 50 | 650 | \$2200 - 4800 | 500 | 20-40% | 25-100% | 100% | 100% |
| Geothermal | 0.05 | 1 | 30 | 180 | \$2500 - 9900 | 50 | 12-15% | 3-7% | 0% | 0% |
| Biomass | 0.1 | 5 | 50 | 75 | \$2900 - 5800 | 50 | 35-40% | 3-7% | 0% | 0% |
| Coal | 0.1 | 10 | 400 | 1300 | \$1900 - 3900 | 600 | 35-40% | 3-7% | 0% | 0% |
| Combined Cycle (Gas/Oil: Sm. HD/Aero) (1x1) | 10 | 25 | 60 | 120 | \$1000 - \$1800 | 55 | 20-40% | 20-40% | 0-75% | 75-100% |
| Combined Cycle (Gas/Oil: Heavy-duty) (1x1) | 60 | 120 | 300 | 500 | \$900 - 1500 | 615 | 25-70% | 3-11% | 0-60% | 10-100% |
| Simple Cycle (Gas/Oil: Small HD/Aero) | 1 | 20 | 40 | 100 | \$800 - 1300 | 45 | 25-50% | 25-50% | 0-100% | 100% |
| Simple Cycle (Gas/Oil: Heavy-duty) | 40 | 80 | 200 | 330 | \$500 - 800 | 211 | 15-70% | 4-16% | 0-75% | 100% |
| Reciprocating Engines (Gas/Diesel/Bio) | 0.01 | 1 | 5 | 20 | \$700 - 1300 | 10 | 50% | 35% | 100% | 100% |
| Energy Storage | | | | | | | Resp. Time | %MW/min | %MW | %MW |
| Pumped Hydropower | --- | 100 | 1000 | --- | \$1000 - 3000 | 500 | 10s | 25-100% | 100% | 100% |
| CAES - Comp. Air Energy Storage | --- | 50 | 500 | --- | \$600 - 1600 | 260 | 1-10min | 4% | 100% | 100% |
| Solid Batteries | 0.1 | 1 | 20 | 50 | \$1000 - 4000 | 50 | 100ms | 500% | 100% | 100% |
| Flow Batteries (Redox) | --- | 0.1 | 20 | 50 | \$1700 - 4200 | 50 | 100ms | 500% | 100% | 100% |
| Flywheels | 0.1 | 1 | 20 | 40 | \$900 - 1100 | 20 | 1-4s | 1500% | --- | --- |
| PEV | --- | 0.02 | 0.05 | --- | --- | --- | 100ms | --- | --- | --- |
| Fuel Cells (PEM) | 1E-04 | 0.001 | 0.1 | 10 | \$3,000 | 1 | 10s | 500% | 100% | 100% |
| Demand Response | | | | | | | | | | |
| Fast Auto DR | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Direct Load Control | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Interruptible Load | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Price Responsive Demand | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Transmission | | | | | | | | | | |
| Synch. Cond.: Large motor frame | --- | 0 | 50 | --- | --- | --- | --- | --- | --- | --- |
| Synch. Cond.: Air-cooled generator frame | --- | 38 | 113 | --- | --- | --- | --- | --- | --- | --- |
| Synch. Cond.: H2-cooled generator frame | --- | 198 | 478 | --- | --- | --- | --- | --- | --- | --- |
| Shunt FACTS devices (STATCOM, SVCs) | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HVDC Transmission Technologies | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Desirable Attributes / Retrofit Options | | | | | | | | | | |
| Improved Turndown (MinGen) Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elevated Ramp-rate Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Faster Startup Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |

More detailed descriptions of each resource are included on slides 58-87 of Appendix A.

4 Part 1 Summary

Part 1 of the Hawaii Ancillary Services study focuses on ancillary services definitions, interconnection requirements and technologies capable of providing these ancillary services in functional terms. They may not reflect the current practices on the Hawaiian Islands but represent viable options for any electric power system to maintain reliable operations and should be considered as options for the Hawaiian Islands. The ancillary services are currently provided to the Hawaiian Islands under bundled service by the utility operators. Part 2 of the final report will document the GE study results for Task 3-4 and provide analysis of Hawaii specific scenarios including comparison of current practices on the Hawaiian Islands to proposed ancillary services and interconnection requirements. The interconnection requirements can help designate some of the desired capabilities required to deliver ancillary services. These services may be provided by a utility or independent power producer and compensated in accordance to the value that capability brings to the system, to be discussed in Task 3 and 4.

5 References

- [1] NREL: National Renewable Energy Laboratory, Renewable Electricity Futures Study (Vol. 4 of 4), Bulk Electric Power Systems: Operations and Transmission Planning, 2012
- [2] NERC: North American Electric Reliability Corporation, Special Report: Potential Reliability Impacts of Emerging Flexible Resources, November 2010
- [3] NREL: National Renewable Energy Laboratory, Operating Reserves and Variable Generation, August 2010
- [4] Kirby, B., Proposed Ancillary Services, October 31, 2011
- [5] Kirby, B., Ancillary Services: Technical and Commercial Insights, July 2007
- [6] NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011
- [7] Hawaii Reliability Standards Working Group, Glossary of Terms, Version 1 – 2012, Docket No. 2011-0206
- [8] NERC: North American Electric Reliability Corporation, NERC IVGTF Task 2.4 Report: Operating Practices, Procedures, and Tools, March 2011
- [9] Black & Veatch, Cost and Performance Data for Power Generation Technologies, February 2012
- [10] US Energy Information Administration (EIA), Annual Energy Outlook (AEO), Energy Market Module (EMM), 2011
- [11] Gas Turbine World (GTW), Performance Specifications, 2012 Edition, Volume 42
- [12] Bechtel Corporation, Concentrated Solar Thermal Plants Downstream of the Solar Field – Design/Optimization of the Associated Power Generation Cycle
- [13] Power Engineering, Hydroelectricity: The Versatile Renewable, June 1, 2009
- [14] GE Energy, Western Wind and Solar Integration Study, Prepared for National Renewable Energy Laboratory, May 2010
- [15] Oak Ridge National Laboratory, National Hydropower Association, Hydropower Research Foundation, Summary Report on a Summit Meeting: Pumped Storage Hydropower, September 2010
- [16] Renewable Northwest Project, Summary Report on Coal Plant Dynamic Performance Capability, August 2010
- [17] GE Energy (Miller, N., Leonardi, Bruno), New York Independent System Operator, Feasibility Evaluation of Energy Storage for Black Start Services on the NYISO System, December 16 2011
- [18] Milligan, M., Kirby, B., Utilizing Load Response for Wind and Solar Integration and Power System Reliability, Presented at WindPower 2010, Dallas, Texas, May 23–26 2010
- [19] Hawaii Renewable Energy Development Venture Technology Assessment - Grid Energy Storage Systems (<http://www.hawaiiirenewable.com/wp-content/uploads/2009/12/16.-Energy-Storage.pdf>)
- [20] Pratt, Rob (Pacific Northwest National Laboratory), Najewicz, Dave (GE Appliances), Opportunities for Mass Market Demand Response to Provide Ancillary Services, October 2011
- [21] Raslter, Dan (EPRI), Akhil, Abbas (ERPI), Gauntlett, Dave (AECOM), Cutter, Eric (E3), Energy Storage System Costs 2011 Update Executive Summary - Presented to Storage System Suppliers, February 22 2012
- [22] Freund, Sebastian (GE GRC), Shu, Mark (GE Energy), Stoffer, Bart (GE Energy), 2010 insights: Grid-base energy storage, January 19 2011
- [23] Young, Russell (GE Energy), Manz, Devon (GE Energy): Utility Energy Storage, 2010

- [24] Federal Energy Regulatory Commission, Assessment of Demand Response & Advance Metering, Staff Report, February 2011
- [25] http://www.ercot.com/content/gridinfo/etts/flywheel/presentations/PSWG_meeting_082410.pdf
- [26] http://www.beaconpower.com/files/Beacon_Power_presentation_ESA%206_7_11_FINAL.pdf
- [27] DOE, Office of Energy Efficiency and Renewable Energy: 2010 FUEL CELL TECHNOLOGIES MARKET REPORT, June 2011

6 Appendix A - 2012_12_10_Hawaii_Ancillary_Services_Report_P ART1FINAL.pptx

Ancillary Services Definitions & Capability Study Part 1, Task 1-2, Final Report

December 10, 2012

Prepared by: GE Energy Consulting

Prepared for: Hawaii Natural Energy Institute (HNEI) and Hawaii Reliability Standards Working Group (RSWG)



imagination at work

Table of Contents

Ancillary Services Definition & Capability Study

Study Background and Objectives

Key Terminology

Study Results:

- Task 1 – Identify and Define Ancillary Services
 - Real Power Ancillary Services
 - Ancillary Service Definitions
 - Ancillary Services Allocations (on the Mainland)
 - Interconnection Requirements
 - Hawaii Specific Differences/Additions
- Task 2 - Identification of technologies capable of providing each ancillary service:
Enabling Technology Details

References

Study Background and Objectives

Ancillary Services Def. & Cap. Study

Overview of Study

Purpose:

Study sponsored by HNEI with support and guidance from Hawaii RSWG to identify, define, and quantify ancillary services required to support new generation (including renewable generation) for bulk power systems and particularly the Hawaiian islands.

Objectives:

- Define a standardized set of ancillary services along with their associated definitions (in functional, performance based terms) that can be used to meet the operational needs of Hawaii and other bulk power systems.
- Technologies (generation, transmission, storage, and demand response (DR)) will be assessed for their ability to support the respective ancillary services to maximize the diversity and optionality for ancillary service acquisition and delivery.
- Identify the physical requirements of the ancillary services needed for each Hawaiian island (Oahu, Maui, Big Island)
- Outline considerations for specifying / acquiring ancillary services for the Hawaii grids that protect reliability, incent renewable generation, and minimize production costs.

Introduction

Ancillary services & additional functions required for power system operation

- **Ancillary services*** are those functions performed by the equipment and people that generate, control, transmit, and distribute electricity to support the basic services of generating capacity, energy supply, and power delivery. They are required to maintain reliable operations of the electric power system.
- In addition to ancillary services, other **interconnection requirements** are placed on resources to ensure reliable operation of the grid
- These ancillary services and interconnection requirements enable the system operator to meet the required operations **reliability standards** set by NERC.
- The ancillary services, interconnection requirements, and reliability standards are related to the characteristics of a power system.

** FERC defined ancillary services as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."*

Key Terminology

Key Terminology

The following definitions are relevant throughout the content of this presentation and should be interpreted as described below:

Area Control Error (ACE): The instantaneous difference between a Balancing Authority's net actual and scheduled interchange, taking into account the effects of Frequency Bias and correction for meter error. *NERC Glossary (2008)*

Conventionally, $ACE = (NIA - NIS) - 10B (FA - FS) - IME$, where:

- **NIA** is the algebraic sum of actual flows on all tie lines.
- **NIS** is the algebraic sum of scheduled flows on all tie lines.
- **B** is the Frequency Bias Setting (MW/0.1 Hz) for the Balancing Authority. The constant factor 10 converts the frequency setting to MW/Hz.
- **FA** is the actual frequency.
- **FS** is the scheduled frequency. FS is normally 60 Hz but may be offset to effect manual time error corrections.
- **IME** is the meter error correction factor typically estimated from the difference between the integrated hourly average of the net tie line flows (NIA) and the hourly net interchange demand measurement.

Due to a lack of inter-area power flows, the definition of ACE has been modified for Hawaii. Specifically, for Hawaii, $ACE = - 10B (FA - FS) - IME$. This modified definition of ACE is still applicable for Hawaii as it correctly represents the fact that 100% of difference between supply and demand will manifest itself as a frequency error. *Revised definition per Hawaii RSWG Glossary.*

Key Terminology (cont'd)

The following definitions are relevant throughout the content of this presentation and are intended to provide clarification on their intended interpretation:

Automatic Generation Control (AGC): Equipment that automatically adjusts generation, storage devices, and/or responsive load in a Balancing Authority Area from a central location to maintain the Balancing Authority's interchange schedule plus Frequency Bias (i.e. ACE). *NERC Glossary (2008) with modifications to accommodate additional resource types such as load and storage devices.*

Although AGC was originally conceived as a means to provide fast (3-6 second signals) to generators, the concept of leveraging AGC to provide "MW raise/lower" commands to demand-side and storage resources is equally applicable and is in practice in some locations.

Key Terminology (cont'd)

The following definitions are relevant throughout the content of this presentation and are intended to provide clarification on their intended interpretation:

Droop Control / Governor: Droop speed control is near instantaneous means of using frequency deviations to distribute load set-point adjustments to a system of resources in a stable manner.

The magnitude of a given resource's response is proportional to the frequency deviation and typically characterized by "x%" droop. For example, a resource with operating range available will provide 100% additional output per "x%" change in system frequency. Response is typically a percentage of the resource's full-capability.⁽³⁾

Droop response can be provided by any frequency-sensitive resource.

Resource: A resource may consist of any generation, storage, load (i.e. demand-side), or transmission technology.

Spinning / Non-Spinning: Historically, the terms "spinning" and "non-spinning" have referred to the rotational nature of synchronized generators. Over time, this terminology has migrated to imply the "relative state of readiness and responsiveness" as it relates to the ability for a resource to fulfill its ancillary obligation. In an effort to leverage contemporary industry vernacular, this latter interpretation was adopted for use in this presentation.

Study Results

Task 1: Scope & Deliverables

Identification & definition of ancillary services

Objectives:

- Provide a standardized set of ancillary services along with their associated definitions (in functional terms).
 - Highlight emerging ancillary services and the entities pursuing them
 - **Scope added by GE: Discussion on interconnection requirements due to inter-relationship w/ ancillary services**
- Explain how each ancillary service is used for grid operation
 - Incorporate perspective during normal and contingency conditions
- Identify “Hawaii-specific” differences relative to the standardized definitions
 - Consider how ancillary functionality is currently provided
 - Adjust standardized definitions for Hawaii (finalize during Tasks 3 & 4)

Ancillary Services & Interconnection Requirements

Emphasis on **Ancillary Services** that provide direct support for the reliable and economic operation of the power system:

Real-Power Energy Balancing Services

- Frequency Responsive Reserve/Primary Frequency Response
- Regulation
- Load Following
- Spinning Reserve
- Non-Spinning Reserve
- Replacement Reserves

Additional Services

- Black Start
- Reactive Power/ Voltage Support

Generation requirements that are specified via **Interconnection Requirements** are:

Interconnection Requirements

- Power Factor & Voltage Control
- Voltage and Frequency Ride Through
- Ramp Rate Limits and Control
- Over and Under Frequency Controls
- Inertia

Other Considerations

Real-Power Energy Balancing Services

Operational Time Frames

Relationship during Normal Operating Conditions

Operational Time Frames (Normal Conditions)

Scheduling / Unit Commitment:

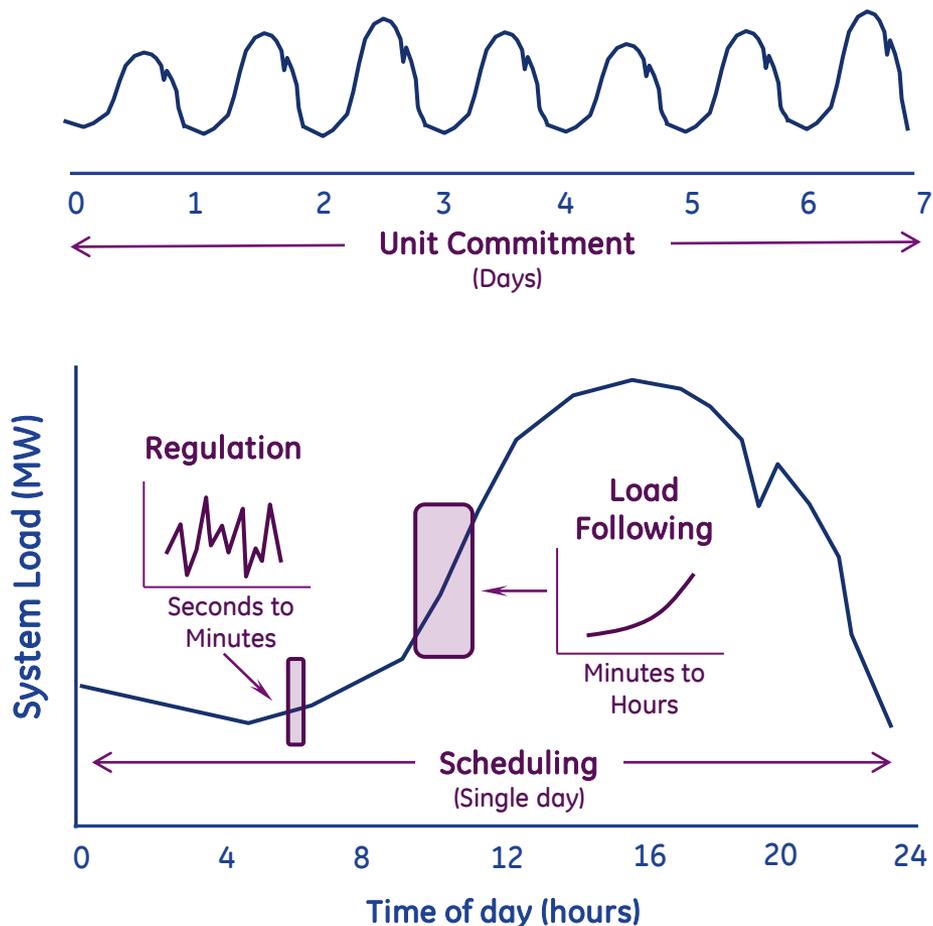
- Several hours to several days
- Ensures that appropriate generation is available to meet forecasted demand, reserve, and interchange requirements⁽²⁾.
- Critical to economic / reliable system operation⁽²⁾

Load Following:

- Several minutes to several hours
- Follows general trending pattern within the day⁽³⁾
- Usually performed by economic dispatch⁽³⁾
- Focuses on rate of change in generation and consumption⁽²⁾

Regulation:

- Several seconds to minutes
- Balances fast (sec-to-sec and min-to-min) random variation in supply-demand balance⁽³⁾
- Automatic response (typically via AGC) to adjust output (or responsive load)



Illustrations based on NREL: National Renewable Energy Laboratory, Renewable Electricity Futures Study (Vol. 4 of 4), Bulk Electric Power Systems: Operations and Transmission Planning, 2012

Operational Time Frames

Relationship during Contingency Operating Conditions

Operational Time Frames (Contingency Conditions)

Inertial Response:

- Arrests the frequency change
- Generators and loads adjust speed and transfer kinetic (or stored) energy to electrical energy⁽³⁾

Frequency Responsive Reserve:

- Frequency-sensitive droop response from generators with headroom (or responsive loads)⁽³⁾
- Stabilize frequency at or below nominal levels

Regulation:

- Commanded "MW" adjustment thru AGC
- Assists freq. recovery toward nominal levels⁽³⁾

Contingency Reserves:

- Spinning & Non-Spinning reserves
- Restore frequency to nominal levels⁽³⁾

Replacement Reserves:

- Relieve the Contingency Reserves⁽³⁾
- Protect against a follow-on event

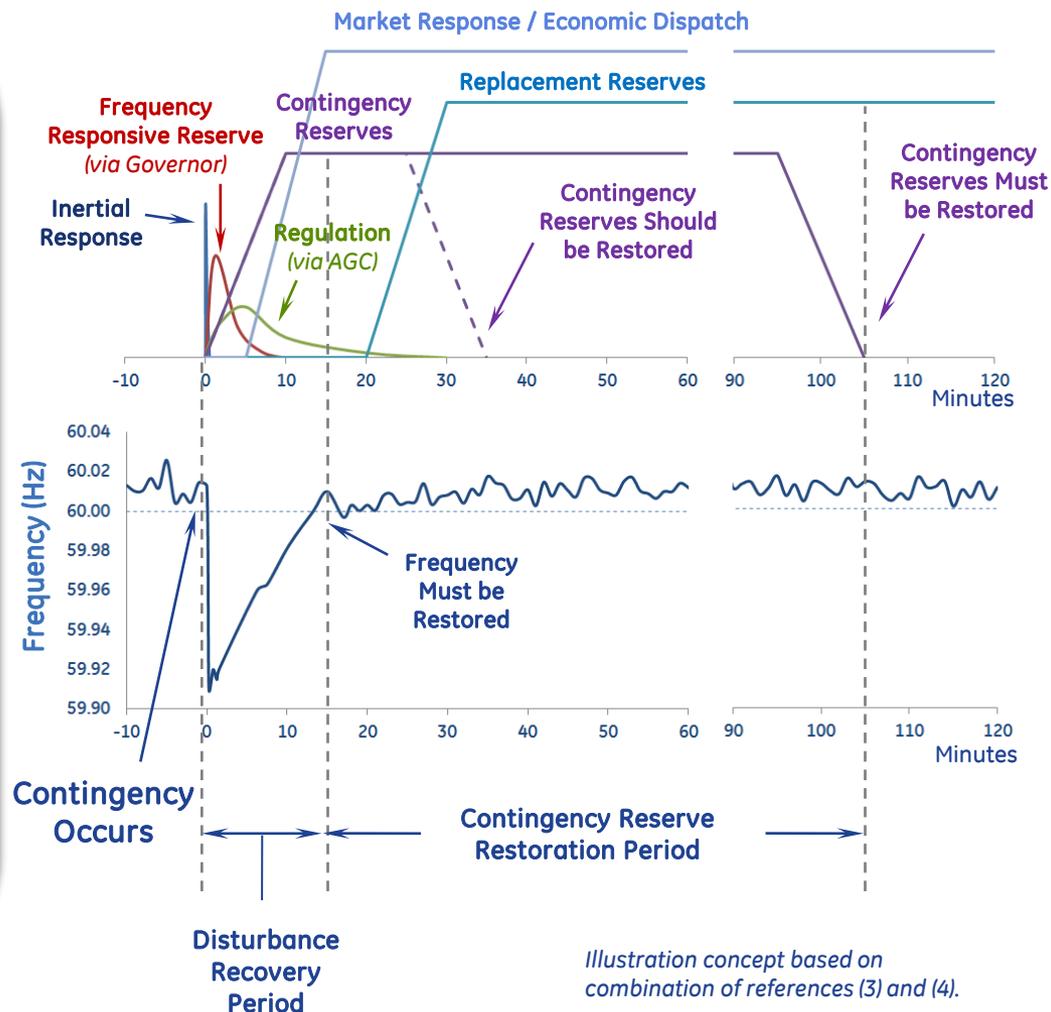


Illustration concept based on combination of references (3) and (4).

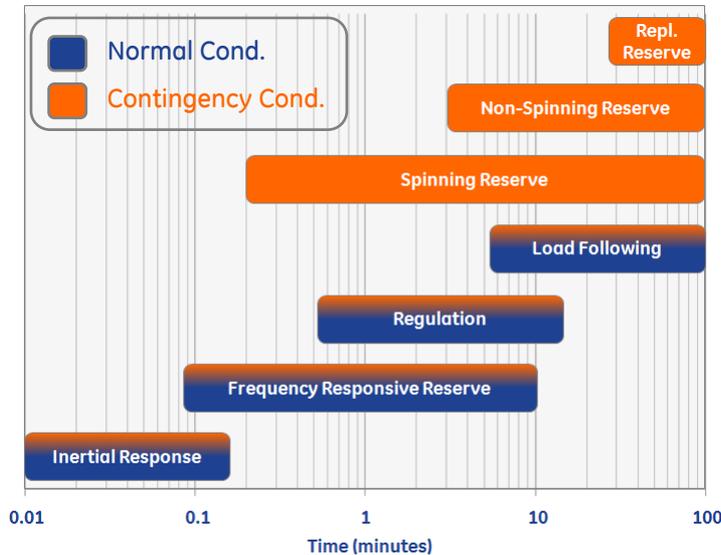
Continuous Spectrum of Protection

Progressive series of inter-related responses to ensure system reliability

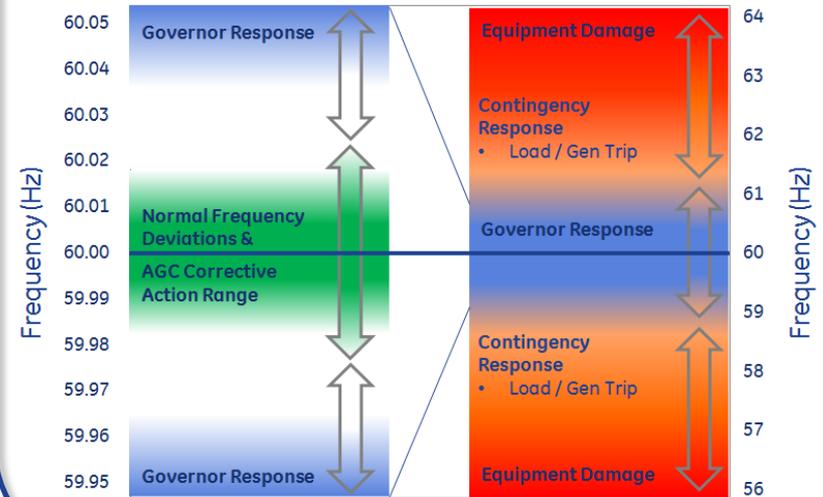
Combination of automated and manual actions link Normal and Contingency Conditions

- Inertial Response provided autonomously from synchronized generation (or synthesized via power electronics)
- Frequency Responsive Reserve/ Primary Frequency Response automatically driven by frequency deviations (droop governor response, etc.)
- Regulation drives automatic output adjustments thru Automatic Generation Control (AGC), precipitated by changes in Area Control Error (ACE)
- Automatic and Manually deployed reserves (Spinning / Non-Spinning / Replacement)

Response Times and Durations⁽⁵⁾



Progression from Normal to Contingency Conditions⁽⁵⁾



Ancillary Service Definitions

Ancillary Services

Functions Required to Maintain System Flexibility & Reliability

- Normal Cond.
- Contingency Cond.
- Additional Services

Frequency Responsive Reserve/ Primary Frequency Response

Automatic response triggered by frequency swings. Typically deployed during contingency events. Arrests and helps to recover the frequency fall-off.

Regulation

Used continuously during normal operations to correct short-term imbalances between supply and demand. Deployed via AGC signals.

Load Following

Slower than "Regulation" and used primarily during normal operations. Typically deployed via economic dispatch to correct an imbalance that will occur in the future.

Spinning Reserve

Type of contingency reserve that consists of resources which are connected to the power system and poised, ready to respond immediately.

Non-Spinning Reserve

Type of contingency reserve that consists of resources which are capable of providing full response within a specified time; however, the response does not need be immediate.

Replacement Reserve

Deployed following a contingency event. Intended to replenish contingency reserves; response does not need to begin immediately.

Black Start

Provided by resources capable of starting themselves quickly without support of an external electricity source. Used to restore a power system following a major blackout.

Reactive Power/ Voltage Support

Provided by resources capable of injecting/consuming reactive power which is required to maintain voltages within acceptable limits throughout the power system.

Inertial Response

- **Definition:** Inertial response is the autonomous and immediate⁽³⁾:
 - (1) Transfer of kinetic (or stored) energy into electrical energy during a frequency reduction
 - (2) Transfer of electrical energy into kinetic (or stored) energy during a frequency increase

Inertial response is not obtained as an ancillary service. Rather, Inertial response is provided by synchronized resources and variable generation (VG) resources with power converters that can provide synthesized inertia⁽⁴⁾. These inertial response requirements for VGs are addressed through the interconnection requirements. The immediate injection/consumption of real power reduces the rate of change of frequency (ROCOF) and assists in stabilizing the frequency of the power system.
- **Reaction Speed:** Inertial response is initiated and fully deployed within seconds⁽²⁾.
- **Response Duration:** Response is only effective during the first few seconds following a disturbance and, *with the exception of power converters*, is not directly controlled / purposefully sustained.
- **Frequency of Use:** For synchronous resources, the inertial response is continuously active and providing stability to the power system. Resources connected with power electronics may utilize a dead-band to withhold the response during normal operation and deploy only during major disturbances.
- **Magnitude of Response:** Resources will autonomously consume/inject until they reach their respective over/under-frequency trip set-points OR until system frequency stabilizes.

Frequency Responsive Reserve/ Primary Frequency Response

- **Definition**: Frequency responsive reserve is the immediate and automatic increase/decrease in real power output provided by frequency-sensitive resources^{(3),(4)}.
- **Reaction Speed**: Response should begin immediately and is typically fully deployed within a few seconds.
- **Response Duration**: Varies. Often defined as part of grid compliance / interconnection requirements and in-proportion to the magnitude of the frequency deviation. Typically, the response is less than 15 minutes* to ensure compliance with NERC BAL-002 which states that ACE must be returned to zero (or pre-disturbance level if originally negative) within 15-minutes* after the start of a reportable disturbance.
- **Frequency of Use**: For all resources which have upward/downward operating range available (relative to their current set-point), and are connected with governors, the frequency responsive reserve is continuously provided. In many cases, a small 10-50 mHz dead-band is applied so that small frequency deviations are ignored⁽³⁾.
- **Magnitude of Response**: Magnitude of the response is proportional to the frequency deviation and typically characterized by “x%” droop response. For example, a resource with operating range available will provide 100% additional output per “x%” change in system frequency. Response is typically a percentage of the resource’s full-capacity.⁽³⁾

* Represents the mainland and might be different for Hawaii

Regulation

Well-established
Ancillary Service

- **Definition**: Regulation service is the capability to adjust real power by resources capable of responding appropriately to a system operator's AGC signal in order to correct for actual or expected Area Control Error (ACE) needs. Regulation is distinguishable from Frequency Responsive Reserve. *Updated definition per FERC Order 755, but also recognized as an official ancillary service per FERC Order 888.*
- **Reaction Speed**: Regulation signal provided to participating resources must be updated at least every six (6) seconds (per NERC BAL-005, Requirement 8). Resources should begin to respond immediately with full response achieved in five (5) to ten (10) minutes for most locations (assuming a sustained AGC signal).
- **Response Duration**: Varies – full response typically required to be sustainable for a minimum of the economic dispatch interval (typically five (5) to ten (10) minutes).
- **Frequency of Use**: Continuous. Energy neutral service with up/down fluctuation balancing out in reasonably short-time.
- **Magnitude of Response**: Varies – typically distributed to participating resources in proportion to the size of the imbalance and the allocation of regulation MW's each resource is responsible for.

Note: NERC (per BAL-001) requires an amount of regulation required to satisfy control performance standards (CPS1 and CPS2). Lack of interconnection reduces CPS1 and CPS2 to statistical measures. May be appropriate to define statistical frequency control requirements (for each Hawaiian island) to provide basis for determining regulation amount – Kirby Proposed Ancillary Services (10/31/2011)

Load Following

- **Definition**: Load following is similar to Regulation, but on a slower time-scale.⁽⁴⁾ It focuses on the rate of change in supply and demand and is intended to correct for anticipated imbalances that will occur in the next several minutes to hours.⁽³⁾ Load following can be provided by any resource type capable of adjusting its real-power set-point in this time-frame.

Increased penetrations of VG can increase net-load ramping requirements. Load Following can be used to address sustained ramps and periods when preferred low-cost resources cannot ramp quickly enough. Can also use to bridge-gap between Regulation and Contingency Reserves.^{(3),(4),(5),(6)}

- **Reaction Speed**: Requirements for reaction speed, duration, accuracy measurement, and a mechanism for communicating set-points to participating resources would need to be established. It is anticipated that economic dispatch algorithms would be used to communicate set-points and resources would be remunerated for committing to more stringent response requirements.
- **Response Duration**: Similar to economic dispatch. Sustainable response at given set-point.
- **Frequency of Use**: Anticipated to be continuous, similar to economic dispatch.
- **Magnitude of Response**: Similar to economic dispatch and proportional to the anticipated future imbalance between supply and demand.

Spinning Reserve

Well-established
Ancillary Service

- **Definition**: Spinning Reserve is a type of contingency reserve and consists of resources that are connected to the power system and poised, ready to respond immediately.⁽²⁾ One of the officially recognized ancillary services per FERC Order 888.
- **Reaction Speed**: Spinning reserve begins to respond immediately and must achieve full response within ten (10) minutes.⁽²⁾ Per NERC BAL-002, ACE must be returned to zero (or pre-disturbance level if originally negative) within 15-minutes* after the start of a reportable disturbance.
- **Response Duration**: Varies. Per NERC Disturbance Control Standard (DCS) BAL-002, all contingency reserves must be fully restored (replenished) 90 minutes* after the end of the disturbance recovery period (or 105 minutes* after the start of a reportable disturbance).
- **Frequency of Use**: Intermittent, but typically deployed following a reportable disturbance.
- **Magnitude of Response**: Participating resources will be deployed up to their allocated MW level to ensure compliance with NERC Disturbance Control Standard (DCS) requirements.

* Represents the mainland and might be different for Hawaii

Non-Spinning Reserve

Well-established
Ancillary Service

- **Definition:** Non-Spinning Reserve is a type of contingency reserve and consists of resources that are capable of providing full response within a specified time; however, the response does not need to begin immediately.⁽²⁾ One of the officially recognized ancillary services per FERC Order 888 (referred to as Operating Reserve - Supplemental Reserve by FERC).
- **Reaction Speed:** Non-Spinning Reserve must achieve full response within ten (10) minutes. Per NERC BAL-002, ACE must be returned to zero (or pre-disturbance level if originally negative) within 15-minutes* after the start of a reportable disturbance.
- **Response Duration:** Varies. Per NERC Disturbance Control Standard BAL-002, all contingency reserves must be fully restored (replenished) 90 minutes* after the end of the disturbance recovery period (or 105 minutes* after the start of a reportable disturbance).
- **Frequency of Use:** Intermittent, but typically deployed following a reportable disturbance.
- **Magnitude of Response:** Participating resources will be deployed up to their allocated MW level to ensure compliance with NERC DCS requirements.

* Represents the mainland and might be different for Hawaii

Replacement Reserve

Well-established
Ancillary Service

- **Definition**: Replacement Reserve consists of resources that are capable of providing full response within a specified time; however, the response does not need to begin immediately. Replacement Reserve is not one of the officially recognized ancillary services per FERC Order 888.
- **Reaction Speed**: Replacement Reserve begins responding in thirty (30) to sixty (60) minutes and is intended to replenish contingency reserves in order to protect against a second event or reportable disturbance.^{(2),(3)} NERC BAL-002 does not explicitly require Replacement Reserves.
- **Response Duration**: Varies.
- **Frequency of Use**: Intermittent, but typically deployed to restore Contingency Reserves following a reportable disturbance.
- **Magnitude of Response**: Participating resources will be deployed up to their allocated MW level to ensure Contingency Reserves are replenished in accordance with NERC DCS requirements.

Black Start

Well-established
Ancillary Service

- **Definition**: Black start is an ancillary service acquired for the benefit of all loads provided by resources capable of starting themselves quickly without support of an external electricity source.^{(5),(7)} Black start resources must have sufficient real and reactive power capability to be able to energize transmission lines and restart other generators.⁽⁵⁾
- **Reaction Speed**: Resources must be available to begin re-energizing the power system immediately following a major blackout.
- **Response Duration**: Varies, but is required until the power system has been fully restored.
- **Frequency of Use**: Deployed following a major blackout of the power system.
- **Magnitude of Response**: Participating resources must be able to withstand off-nominal frequency and voltage during the restoration and have the ability to accept block-load increases on the order of 10% (or more) of the individual black start resource's full capacity.

Reactive Power/ Voltage Support

Well-established
Ancillary Service

- **Definition**: Voltage support is an ancillary service that is provided by resources capable of injecting/consuming reactive power which is required to maintain voltages within acceptable limits throughout the power system.⁽⁵⁾
- **Reaction Speed**: Reactive power can be adjusted very rapidly (seconds).
- **Response Duration**: Varies, but is typically provided continuously.
- **Frequency of Use**: Continuous.
- **Magnitude of Response**: Participating resources will typically be deployed to provide reactive power within a power factor range of 0.95 leading to 0.95 lagging.

Note: Interconnection requirements can be used as a mechanism for sourcing voltage support. Specifically, resources are often required to have a specified reactive power capability which is controlled by the power system operator.

Developments in Ancillary Services

Emerging Regulations, Services, and Requirements

Inertial Response (ERCOT):⁽³⁾

- Evaluating requirements for inertial response.
- Inertial Frequency Response Estimator Tool (IFRET) introduced in February 2010
 - Monitors system load, online conventional generation, spinning reserves and ratio of wind to total generation.
 - If insufficient inertial response available, system operator can adjust unit commitment

Frequency Responsive Reserve/ Primary Frequency Response (WECC):

- Frequency Responsive Reserve (FRR) procedure proposed by WECC in 2005⁽³⁾
- NERC BAL-002-WECC-1 (*Version 1: April 2008*) requires 50% of contingency reserves:
 - To be spinning **AND** able to “immediately and automatically respond proportionally to frequency deviations ... through the action of a governor or other control systems.”
- NERC BAL-012-WECC-2-CR (*Frequency Responsive Reserve Criterion, May 2013*)
 - Purpose: Ensure reliable operation during freq. deviation from a loss of generation
 - Applies to: WECC balancing authorities, Reserve Sharing Groups, and Reliability Coords.
 - Establishes minimum required FRR to prevent under-freq. load shed (UFLS) for simultaneous loss of two largest generators in WECC
 - Includes performance measurement criterion to gauge how generation adjusts to support the interconnection

Developments in Ancillary Services

Emerging Regulations, Services, and Requirements

Regulation Performance Compensation (FERC Order 755): Issued in October 2011

- Commission found “current methods for compensating resources for the provision of regulation are unduly discriminatory”.
- Require all RTOs and ISOs to modify their tariffs to provide for a two-part payment to regulation resources:
 - 1st Part: Payment for keeping a resource’s capacity in reserve in the event that it is needed to provide regulation.
 - 2nd Part: Payment shall be a performance payment that reflects the amount of work that each resource performs in real-time.

Secondary Frequency Response and Load Following (CAISO): Flexible Ramping Revised Draft Proposal – August 2012

- Stakeholder effort to develop market-based flexible ramping products
- CAISO currently deploys 10-min. Regulation service and 5-min. Real-time Dispatch (RTD)
- Flex-Ramping product addresses “lack of sufficient ramping and flexibility” to handle 5-minute supply/demand changes
- Increases in renewable penetration will drive need for increased ramping capability.
- Analogous to Load Following: Flexible ramping product addresses ramping issue before the binding real-time dispatch (RTD) ... Regulation addresses ramping issue after binding RTD.
- Purpose is to have resources poised to cover the variation and uncertainty in net system demand following the current RTD interval under consideration.



Developments in Ancillary Services

Emerging Regulations, Services, and Requirements

Secondary Frequency Response and Ramp Capability for Load Following (MISO): MISO white-paper - July 2011

- Investigating improved Load Following options
- Current practice: Use economic dispatch for “load following” ... coverage of any additional unexpected variation in net load is provided by residual resource flexibility.
- MISO recognizes variability of the net load will likely increase in the future (due to intermittent resources)
 - Strains the ramp response of controllable resources
 - Potential for increase in the frequency of short-term scarcity events ... due to ramping capacity shortage.
- Solution requires balance between increased op costs and avoided scarcity event cost
- Appear to be gravitating toward “market product” which prices for ramp capability:
 - Provides incentive to participate
 - Avoids “out of merit” dispatch which is not consistent w/ location-based marginal price
 - Load following product would be “cleared” based on resource opportunity cost and “paid-for” thru cost allocation similar to other ancillary products
- Several approaches proposed:
 - Single-interval: Ramp-capability would be considered for future 10-min. (2 RTD intervals)
 - Multi-interval: Similar to single-interval, but also identifies opportunities in future intervals to “pre-ramp” resources ... early interval adjustment for better future interval positioning.

Ancillary Service Allocations *(On the Mainland)*

Inertial Response

As implemented on the mainland

CAISO/NYISO:

- Inertial Response is not a stand-alone ancillary service product

ERCOT:

- ERCOT requirement that new wind plants supply primary frequency response for over-frequency events

PJM:

- Inertial Response is not a stand-alone ancillary service product

ISO-NE:

- Inertial Response is not a stand-alone ancillary service product

Frequency Responsive Reserve/ Primary Frequency Response

As implemented on the mainland

ERCOT:

- FRR is not a stand-alone ancillary service product
- All online generation resources must have governors in-service and unblocked

NYISO/IESO:

- FRR is not a stand-alone ancillary service product

PJM:

- FRR is not a stand-alone ancillary service product
- All resources providing spinning reserve must be synchronized to the grid and frequency responsive.

WECC:

- In process of developing FRR criteria [NERC BAL-012-WECC-2-CR - May 2009]
- Unclear if new criteria would replace spinning reserve or be a subset of spinning reserve
 - Current proposal is to base FRR criteria on NERC Category "C" event
- Criteria (as proposed) would share the total obligation among the respective balancing authorities (BA's) and would be proportional to BA's load and generation.

Regulation

As implemented on the mainland

ERCOT:

- Market-based and deployed via AGC
- MW requirement is a function of the month and daily hour number
 - Based on the amount historically deployed and amount of time it was exhausted
 - Considers additional wind penetration relative to the historically benchmarked levels
 - i.e. + “x” MW of additional regulation per 1000 MW of additional wind (also assessed monthly and hourly)
- All online generation resources must have governors in-service and unblocked

IESO:

- IESO contracts for regulation service.
- Terms / Conditions of the contract include:
 - Minimum of +/- 100 MW of regulation must be scheduled (system-level) at all-times
 - Minimum overall system ramp rate requirement is 50 MW / min

NYISO:

- Market-based product and deployed via AGC (every 6 seconds)
- MW requirement is a function of the month and daily hour number
- All resources providing spinning reserve must be synchronized to the grid and frequency responsive.

Regulation (cont'd)

As implemented on the mainland

MISO:

- Market-based and deployed via AGC (every 4 seconds)
- No fixed “MW” requirement; however, must carry sufficient reserve which is responsive to AGC to comply w/ NERC’s Control Performance Criteria

PJM:

- Regulation service is scheduled via two (2) methods:
 - Self-scheduled
 - PJM RTO Regulation Market
- Resources providing regulation receive two (2) signals:
 - AReg (Assigned Regulation): Assigned regulation for hour. Typically constant for the hour, but adjusted on a 10 second scan rate.
 - RegA (Real-time Instantaneous Target): +/- MW signal deployed via AGC every 2 sec.
- MW requirement determined for two (2) daily periods
 - On-Peak (0500 – 2359): 1% of the forecast peak load for the day
 - Off-Peak (000-0459): 1% of the forecast valley load for the day

SPP / WECC:

- Deployed via AGC.
- No fixed “MW” requirement; however, must carry sufficient reserve which is responsive to AGC to comply w/ NERC’s Control Performance Criteria

Spinning Reserve

As implemented on the mainland

ERCOT:

- Market-based 10-minute spinning reserve product
- Minimum “MW” requirement is 2300 MW (~3.5% peak demand) and can go up to 2800 MW (~4.3% peak demand).
- May be provided by:
 - Unloaded generation resources
 - Demand-side resources (up to 50% of the total spinning reserve MW)
 - Resources controlled by under-frequency relays
 - Direct Current (DC) tie-line response (must be fully deployed in 15 seconds)
- Load following / spin deployed as necessary to minimize use of 10-minute reserves

IESO:

- IESO has two market-based 10-minute products: (1) Spinning and (2) Non-spinning
- Spinning reserve must be provided by resources synchronized to the power system
- 10-min Spin/Non-Spin MW requirement is based on largest single contingency on the system
 - Minimum of 25% of the 10-minute reserve requirement must be spinning
 - Could be more based on historical ACE performance during contingency events

Spinning Reserve (cont'd)

As implemented on the mainland

Extracted from Reference [6] NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011

NYISO:

- Market-based 10-minute spinning reserve product
- 50% of the 10-minute contingency reserve requirement must be sourced from synchronized resources (including load reductions, curtailed resource capacity, or canceled off-system energy sales)
- Total 10-minute contingency reserve must be greater than the operating capacity loss caused by the most severe observed contingency OR the largest energy loss caused by the cancellation of an interruptible off-system energy purchase.

MISO:

- Market-based ancillary service product.
- Provided by synchronized generation resources which are capable of achieving response within the NERC Disturbance Recovery Period (15 min.)
- Residual regulating reserves (in excess of the requirement) may be applied to Spinning Reserve
- 40% of the contingency reserves must be spinning

SPP:

- Provided by frequency-sensitive synchronized resources
- 50% of the contingency reserve must be spinning reserve
- Spinning Reserve allocation (per resource) is limited to the increase in output associated w/ a frequency drop to 59.5 Hz. Under 5% droop, this is 16.7% of the individual resource capacity.

Spinning Reserve (cont'd)

As implemented on the mainland

Extracted from Reference [6] NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011

PJM:

- Market-based 10-minute ancillary product
- PJM consists of two (2) zones:

ReliabilityFirst Corporation (RFC) Reserve Zone:

- Consists of all PJM companies except for SERC-based companies
- Total contingency reserve must be able to cover the minimum imposed RFC requirement (150% largest generator) or largest contingency on the system.
- Per NERC BAL-002-RFC-02, at least 50% of the contingency reserves must be spinning and no more than 25% should be interruptible load.

Southern Reserve Zone:

- Consists of the Dominion load share of VACAR (NERC Sub-region: VA/NC/SC)
- Total contingency reserve req's for Southern Zone determined annually (~430 MW)
- Spinning reserves must be able to cover the largest contingency within the zone less the 15-minute quick-start capability in the zone.

WECC:

- Requires 50% of its contingency reserves to be spinning reserves; unloaded generation that can be loaded in 10-min. can be considered spinning reserve.
- Contingency reserves shall be sufficient meet the NERC Disturbance Control Standard (DCS) and be at least greater than:
 - Most severe single contingency
 - Sum of 5% of hydro generation load responsibility and 7% of thermal generation load responsibility

Non-Spinning Reserve

As implemented on the mainland

ERCOT:

- Market-based 30-minute ancillary service product
- Calculated for each hour of the day each month
- Can be provided by off-line generation resources or loads capable of being interrupted within 30-minutes for a duration of at least 1-hour.

NYISO

- Market-based 10-minute ancillary service product
- Represents the residual portion of the 10-minute contingency reserve (which is not covered by spinning reserve)
- Total 10-minute operating reserve must be greater than the operating capacity loss caused by the most severe observed contingency OR the largest energy loss caused by the cancellation of an interruptible off-system energy purchase.

MISO:

- Consists of off-line generation able to be loaded or interruptible load able to be removed within the NERC DCS period (15-minutes).

Non-Spinning Reserve (cont'd)

As implemented on the mainland

PJM:

- Not a formalized ancillary service product
- Consists of any resource capable of providing full response in 10-min (RFC Zone) or 15-min. (Southern Zone).
- Represents the residual portion of the 10-minute contingency reserve (which is not covered by spinning reserve)

SPP:

- Provided by any resource (which does not have to be connected to the network), but can be connected and applied to meet NERC DCS requirements (15-min.).

WECC:

- Represents 50% of the total contingency reserve obligation
- Consists of any resource capable of providing full response in 10-min, including:
 - Load which can be interrupted within 10 minutes
 - Interruptible exports
 - On-demand rights from other Balancing Areas (BA's)
 - Spinning Reserve in excess of requirement
 - Off-line generation that qualifies as non-spinning reserve

Replacement Reserve

As implemented on the mainland

IESO:

- Market-based 30-minute reserve product
- Replacement reserve addresses the residual portion of the largest single contingency plus half of the second largest contingency (typically, this is the loss of the two largest generators), which is not covered by 10-minute spinning and non-spinning reserves.

NYISO:

- Market-based 30-minute reserve product
- Equivalent to 50% of the total 10-minute contingency reserve (including both spinning and non-spinning resources)

PJM:

- Not a formalized ancillary service product
- Consists of any resource capable of providing full response within a 10 – 30 minute notification.

Reactive Power/ Voltage Support

As implemented on the mainland

CAISO:

- Maintains acceptable voltage levels and VAR flow on the Controlled Grid using all voltage control support equipment required to meet the operating criteria specified in the NERC and WECC Minimum Operating Reliability Criteria
- If notified of the loss of an automatic voltage regulator control (AVR), and the Scheduling Coordinator (SC) has not notified the PTO then notify the applicable PTO of the status of the device (the TO will direct the Generator Operator to maintain or change either its voltage Schedule or its Reactive Power Schedule as appropriate)

NYISO:

- Resource must be able to produce and absorb Reactive Power within its tested reactive capability range
- Resource must be able to automatically respond to voltage control signals; for a generator, a functioning Automatic Voltage Regulator (AVR) is required
- Resource must be under the operational control of the NYISO or a Transmission Owner

PJM:

- Not a formalized ancillary service product

ERCOT:

- As provided by ERCOT to the QSEs: The coordinated scheduling of voltage profiles at transmission busses to maintain transmission voltages on the ERCOT System in accordance with Operating Guides
- As provided by a QSE to ERCOT: The provision of Generation Resource capacity whose power factor and output voltage level can be scheduled by ERCOT to maintain transmission voltages within acceptable limits throughout the ERCOT System in accordance with Operating Guides

Black Start

As implemented on the mainland

CAISO:

- Cost of Service - units are identified for black start and their documented costs are then funded and rolled into a tariff for cost recovery

PJM/NYISO:

- Cost of Service - units are identified for black start and their documented costs are then funded and rolled into a tariff for cost recovery
- NYISO selects the generating resources with black start capability by considering the following operating characteristics: electrical location in the NYCA; startup time: from NYISO order to start to minimum output; maximum response rate (MW/minute) above minimum output; and maximum power output

ISO-NE:

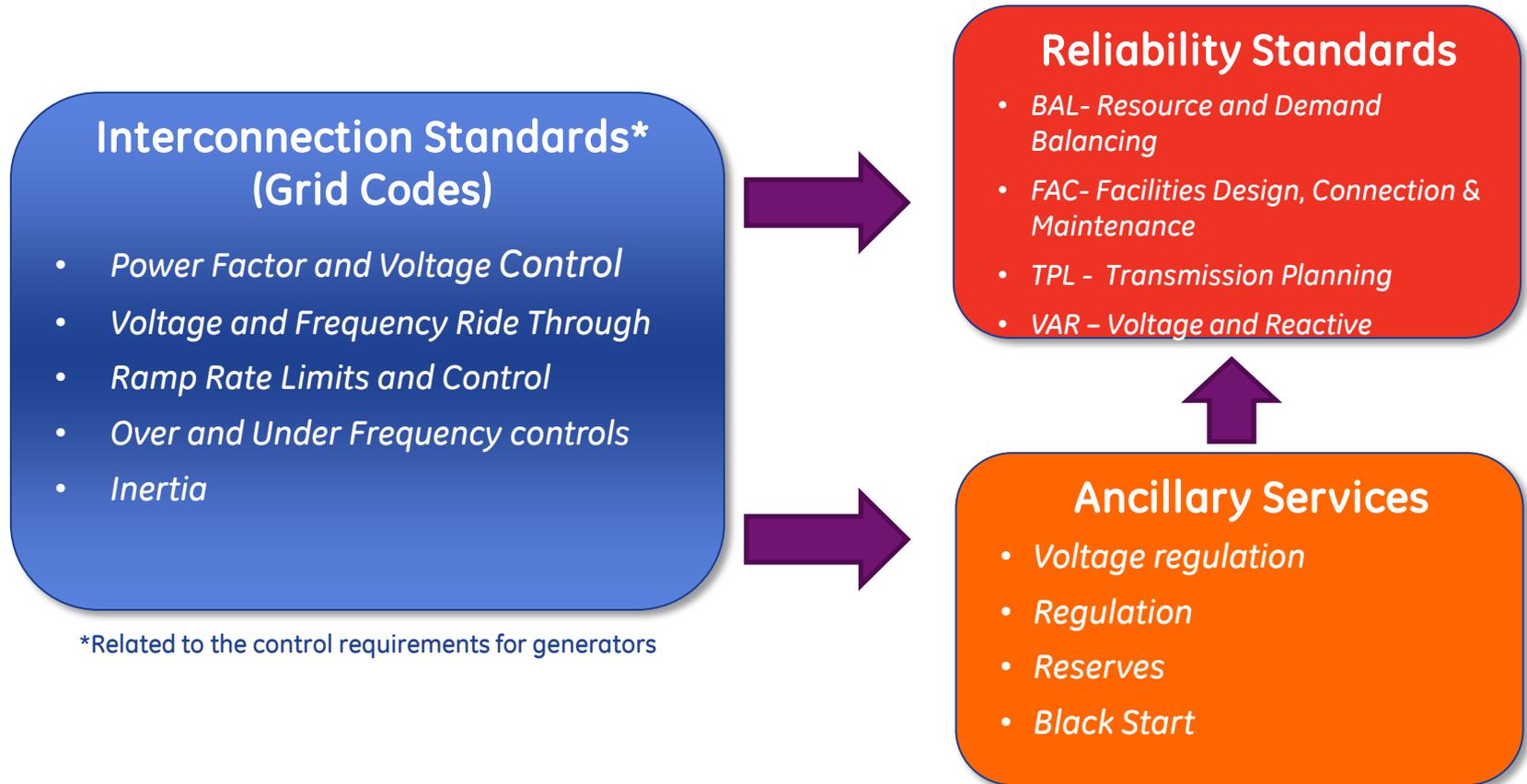
- Flat Rate Payment which increases black start remuneration to encourage provision - the monthly compensation paid to a generator is determined by multiplying a flat rate (in \$/KWyr and referred to as the \$Y value) by the unit's Monthly Claimed Capability for that month

ERCOT:

- Competitive Procurement - under this approach ERCOT runs a market for black start services and each black start unit must be able to demonstrate that it can startup another unit in close proximity to begin the islanding and synchronization of the grid
- As provided by ERCOT to QSEs: The procurement by ERCOT through Agreements, pursuant to emergency dispatch by ERCOT and emergency restoration plans of Resources which are capable of self-starting without support from the ERCOT System in the event of a blackout, in order to begin restoration of the ERCOT System to a secure operating state
- As provided by a Generator or a QSE to ERCOT: The provision of Resources under a Black Start Agreement, pursuant to emergency dispatch, which are capable of self-starting without support from the ERCOT System in the event of a blackout

Interconnection Requirements

Interconnection Requirements



Interconnection Standards enables the system to meet its reliability standards by requiring all generators:

- To have certain capabilities that directly helps with the system reliability
- To have certain capabilities that enables it to provide ancillary services that are required for system reliability

VER Interconnection Requirements

Existing Standards

Power Factor and Voltage Control

- *Several US & European Grid Codes including ERCOT (wind & solar), AESO (wind) required reactive power and voltage control*

Voltage and Frequency Ride Through

- *Many European and Canadian Grid Codes require voltage and frequency ride-through capabilities for all units. For example, IESO requires generator facilities to ride-through voltage and frequency deviations (between 58 to 61.5 HZ)*

Ramp Rate Limits and Control

- *Many operators are proposing ramp rate limits and controls for wind and solar plants. For example, Alberta has adopted a 10% MW rated capacity/minute upward ramp rate limit.*

Emerging Standards

Over and Under Frequency controls

- *Many ISOs require wind units to provide Over-frequency response similar to a thermal unit with a droop of 5%.*
- *Few grid operators (Nordic and ESBNG) require wind plants to be able to change the active power production as a function of the network frequency.*

Inertia

- *Hydro-Québec requires that wind plants be able to contribute to reducing frequency deviations similar to a synchronous generator whose inertia constant (H) equals 3.5s.*

Reactive Power & Voltage Control

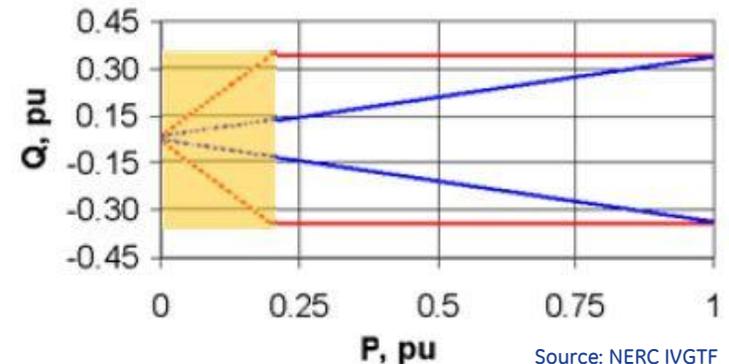
Capability to provide reactive power output within a certain power factor range and the capability to regulate voltage within this range

- Required for reliable operations
- Synchronous generators required to have 0.95 lead/0.90 lag capability. Automatic Voltage Regulator (AVR) required.
- Capable units participate in voltage support ancillary service
 - assumed to provide (and compensated)- NYISO
 - Only units that operate outside their PF range are paid opportunity cost - CAISO

Requirements for Wind and/or Solar Plants

- Order 661-A requires study by TO to justify the reactive capability requirement up to 0.95 lag to lead at POI
- ERCOT (wind & solar), AESO (wind), several European Grid Codes required reactive power and voltage control
- Typically, baseline capability of 0.95 lag to lead at full output (POI) and permissive reactive power range
- Some grid codes require a certain portion of the reactive power range be dynamic.

Reactive Power Capability Specification at the POI for 0.95 pf at Rated Output, Reduced Capability or Permissive Range Below 0.2 pu



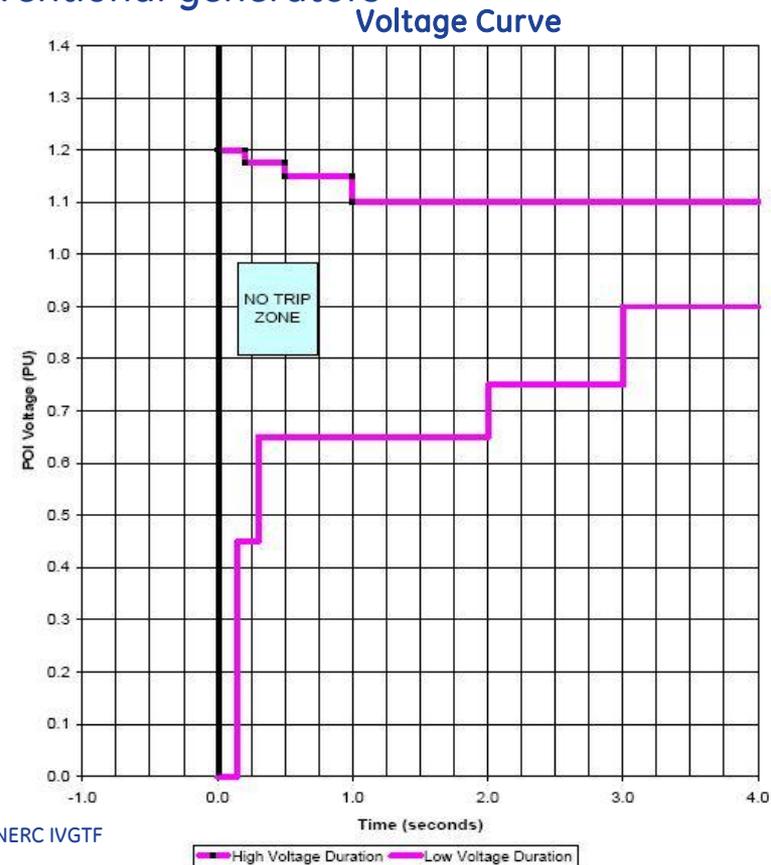
Fault Ride-through

Capability of the generator to ride-through (predetermined) temporary voltage and frequency deviations

- Inadvertent loss of generators after a fault compounds frequency and voltage problems
- No explicit ride through requirement specified for conventional generators

Requirements for Wind and Solar Plants

- FERC Order 661-A requires that wind plants remain connected for three phase faults with normal clearing
- NERC PRC-024-1 (draft) proposes voltage and frequency curves for all units
- Many European and Canadian Grid Codes require voltage and frequency ride-through capabilities for all units.
- For example, IESO requires generator facilities (10MW/50MW) to ride-through voltage and frequency deviations (between 58 to 61.5 HZ)
- In the U.S., most regions have voltage ride-through requirements for wind



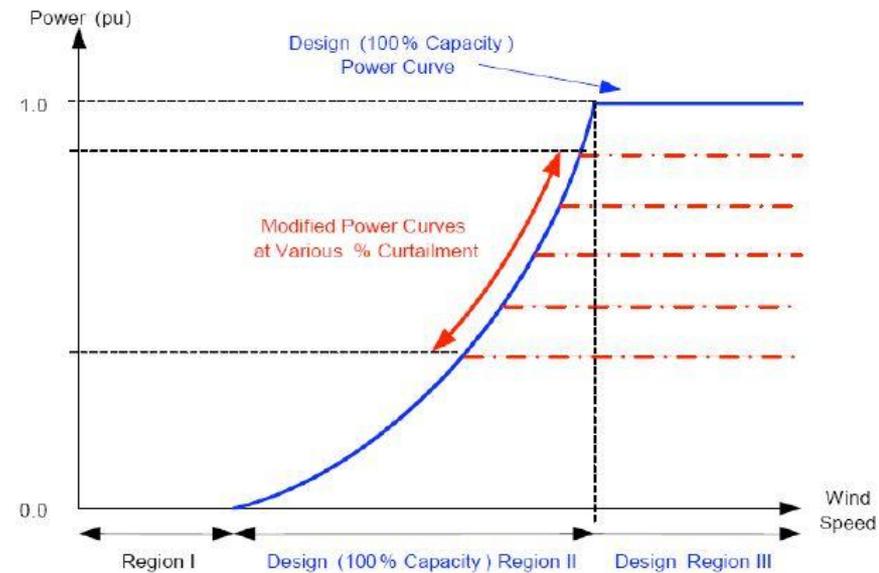
Ramp Rate Limits and Control

Capability to ramp the output of a generator under certain conditions

- Sudden changes in the output that are otherwise controllable may have a negative impact on system reliability
- No specific ramp rate and control requirements for synchronous generators ... conventional generator have “gradual” ramp rates

Requirements for Wind and Solar Plants

- Many operators are proposing ramp rate limits and controls for wind and solar plants
- Alberta ISO has adopted a 10% MW rated capacity/minute upward ramp rate limit.
- ERCOT and NYISO have the capability to dispatch wind generation



Source: NERC IVGTF

Over and Under Frequency Control

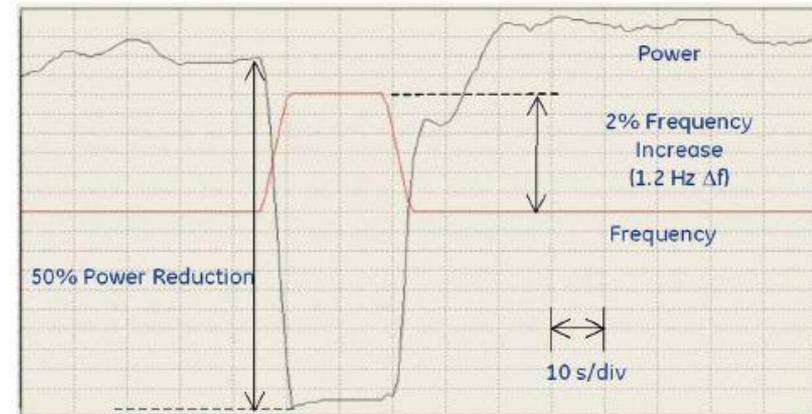
Capability to automatically increase and decrease (sustained) output under low and high frequency conditions respectively

- System frequency should be maintained around nominal value
- Synchronous generators are required to have governors with droop control
- Provide MWs in response to a drop in frequency... however, need “headroom”
- Reduce MWs in response to an increase in frequency... however, need to be operating above their minimum generation level

Requirements for Wind and Solar Plants

- Capable of providing over-frequency response (by pitch control or inverter control)
- Can provide under-frequency response... however, need to spill energy which has high opportunity cost
- Many ISOs require wind units to provide Over-frequency response in response to high system frequency similar to a thermal unit with a droop of 5%.
- Few grid operators (Nordic and ESBNG) require wind plants to be able to change the active power production as a function of the network frequency.

Over-frequency Response (test) of Wind Plant



Source: NERC IVGTF

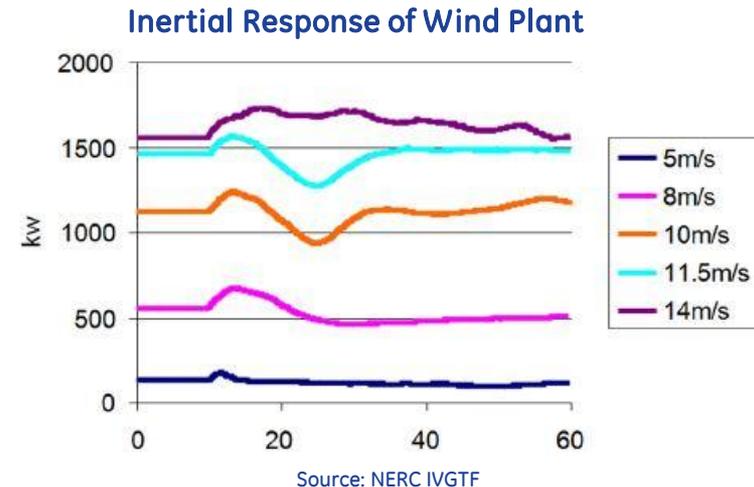
Inertia

Capability to provide an immediate response to a drop in system frequency

- Conventional generating units give up a portion of their stored kinetic energy as increased power output, which helps to retard the frequency decline after a fault.
- No specific inertia requirement for synchronous generators

Requirements for Wind and Solar Plants

- Stored kinetic energy from the turbine-generator rotors can be temporarily donated to the grid in the form of MWs
- Response depends on wind speed and is tunable
- For PV spilling is required to provide this response
- Hydro-Québec requires that wind plants be able to contribute to reducing large (> 0.5 Hz), short-term (< 10 s) frequency deviations on the power system, as does the inertial response of a conventional synchronous generator whose inertia constant (H) equals 3.5s.



Other Considerations

Items not addressed directly thru Ancillary Services or Interconnection Requirements

Reduced Minimum Generation Capability:

- Potential to avoid curtailment of renewable and economically preferred generating assets
- Enables more online reserve ... potential for more granular ancillary service participation
- Improved system-level load following capability
- Provides options for improved portfolio management ... hedge against uncertain conditions

Short-circuit Strength:

- Short-circuit levels may decrease if synchronous generators are replaced by renewables
- Synchronous generators may need to be online to maintain minimum short-circuit levels
- Additional studies are required

Load Shaping:

- Consider proactive movement of demand-side resources or non-dispatchable load to provide a more manageable daily load shape
 - i.e. incentivize / prohibit charging of PEV's at certain times of day
- "Load shaping" may provide an opportunity to reduce the amount of other ancillary services that are required.
- Anticipate that this would be a procedural implementation rather than ancillary-service based approach ... need to carefully consider how to monitor, incentivize, and enforce the targeted load adjustments.

Hawaii-Specific Differences / Additions

Ancillary Services – Hawaii

Unique characteristics of Hawaiian system warrant attention to ancillary services and interconnection requirements

- Relatively small island systems: HECO~1200 MW, MECO ~200MW, HELCO~195 MW peak load... challenge to maintain frequency
- No interconnections ... imbalance between load and generation affects frequency, a small frequency bias
- High Rate of Change of Frequency (ROCOF)... units are large compared to the size of the system
- High cost of energy and ancillary services due to high fuel import prices... lean operations
- Many must run/scheduled units... historical operations
- Small system with few units... single vertically integrated utility, multiple IPPs and third-party dispersed generation on each island with no centralized power markets

Ancillary Services – Hawaii (con't)

Unique characteristics of Hawaiian system warrant attention to ancillary services and interconnection requirements

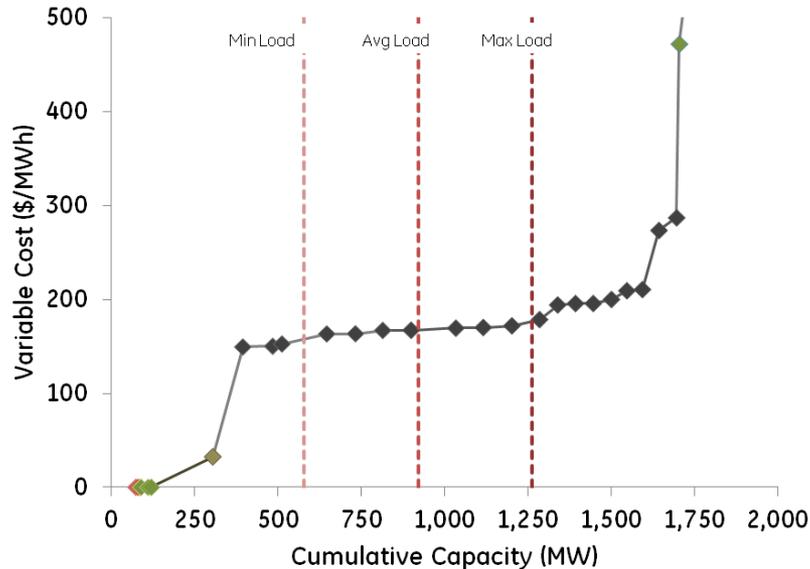
- While fewer opportunities for transaction “liquidity”, ancillary service value can be calculated/estimated to provide incentives/payments to providers of ancillary services - does not need to remain in bundled utility offering
- Large amounts of distributed generation
- Clean Energy Mandate includes RPS target of 40% and 4,300 GWH reduction for Energy Efficiency Portfolio Standards by 2030; high wind and solar generation potential in MECO, geothermal in HELCO
- Hawaii specific operating criteria to maintain system frequency and voltage and provide adequate reserves

Ancillary Services – Hawaii

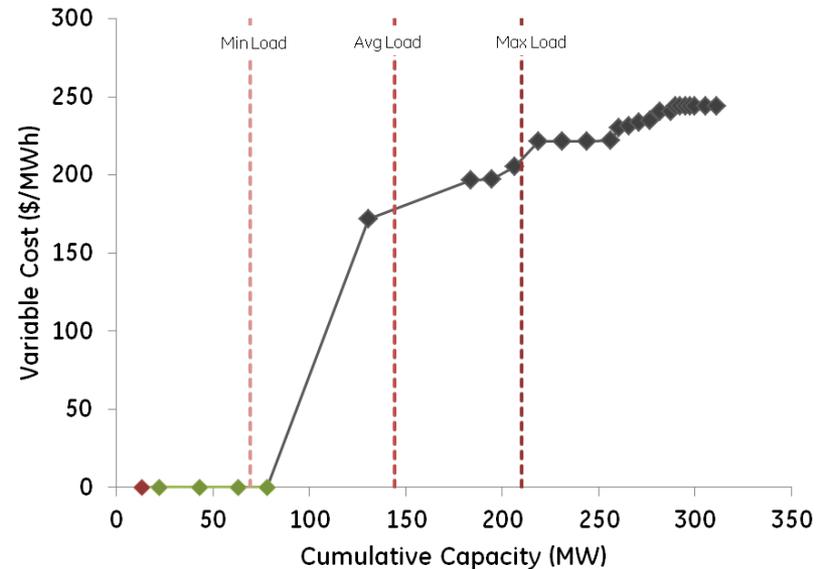
Characteristics of the Hawaii Grids

Size (MW) of power grids and resource size and mix result in limited options to serve demand and noticeable dispatch stack step changes

HECO (Oahu) Dispatch Stack



MECO (Maui) Dispatch Stack



* Renewable capacity is derated per ongoing Stage 2 interconnection study

System Operating Criteria

Hawaii specific operating criteria to maintain system frequency and voltage and provide adequate reserves

- A few criteria of note:
 - Under Frequency Load Shed is used to maintain frequency: instantaneous load shed occurs at 58.9 Hz, 58.7 Hz and 58.8 Hz for the three islands respectively. Both HECO and HELCO also have time delay blocks starting at 59 Hz and 59.3 Hz respectively
 - Each Island has several “must run” units for stability and contractual reasons
 - HECO carries spinning reserves for large single contingency while MECO and HELCO do not
- GE recognizes that understanding the current system operating criteria and practices is important to the study recommendations and therefore will confirm understanding while working through Tasks 3&4

Enabling Technologies

Task 2: Scope & Deliverables

Identification of technologies capable of providing each ancillary service

Objectives:

- Develop a summary table which identifies which technologies can supply each ancillary service. Consider:
 - Generation (including both conventional and variable renewable), storage, demand-response, and transmission technologies
 - Identify the approximate resource sizes
 - Include perspective on product attributes which can be used to assess ancillary compatibility
- Adhere to the following constraints:
 - Limit discussion to technologies in commercial or pilot applications today
 - Focus on current deployment costs – do not speculate about future costs
 - Avoid screening technologies based on cost-effectiveness
- Provide reference citations (as available) for each technology / ancillary match-up

Enabling Technologies

Aligning Technologies with Ancillary Service Capability

Approach:

- Spectrum of generation, transmission, storage, and demand-response technologies considered for their ability to support the defined ancillary services.
- Focus was placed on technologies in commercial or pilot applications today.
- Each resource-type was evaluated based on its capital cost, response capability, and degree of commercial penetration / experience providing each type of ancillary service.



Technology Capability Table

Screening Resources for their Ancillary Service Compatibility

| Technologies | Ancillary Services Compatibility | | | | | | | | |
|--|----------------------------------|------------------------------|------------|----------------|------------------|----------------------|---------------------|-----------------|-------------|
| | Inertial Response | Frequency Responsive Reserve | Regulation | Load Following | Spinning Reserve | Non-Spinning Reserve | Replacement Reserve | Voltage Support | Black Start |
| Generation | | | | | | | | | |
| Solar Thermal | A | T | T | T | T | --- | --- | A | T |
| Solar Photovoltaic (Transmission Connected) | T | T | T | T | T | T | T | A | --- |
| Wind (non-synchronized / power conversion) | A | A | A | A | A | T | T | A | --- |
| Wind (synchronized) | A | A | A | A | A | T | T | A | T |
| Hydropower | A | A | A | A | A | A | A | A | A |
| Geothermal | A | A | A | A | A | --- | --- | A | T |
| Biomass | A | A | A | A | A | --- | --- | A | --- |
| Cool | A | A | A | A | A | --- | --- | A | --- |
| Combined Cycle (Gas/Oil: Sm. HD/Aero) (1x1) | A | A | A | A | A | A | A | A | A |
| Combined Cycle (Gas/Oil: Heavy-duty) (1x1) | A | A | A | A | A | A | A | A | A |
| Simple Cycle (Gas/Oil: Small HD/Aero) | A | A | A | A | A | A | A | A | A |
| Simple Cycle (Gas/Oil: Heavy-duty) | A | A | A | A | A | A | A | A | A |
| Reciprocating Engines (Gas/Diesel/Bio) | A | A | A | A | A | A | A | A | A |
| Energy Storage | | | | | | | | | |
| Pumped Hydropower | A | A | A | A | A | A | A | A | A |
| CAES - Comp. Air Energy Storage | E | E | E | E | E | E | E | E | T |
| Solid Batteries | E | E | A | E | A | E | E | E | E |
| Flow Batteries (Redox) | T | T | T | T | T | T | T | T | T |
| Flywheels | E | E | A | --- | --- | --- | --- | T | --- |
| PEV | T | T | E | T | T | T | T | T | T |
| Fuel Cells (PEM) | T | T | T | T | T | T | T | T | T |
| Demand Response | | | | | | | | | |
| Fast Auto DR | T | A | A | T | A | A | A | --- | --- |
| Direct Load Control | T | A | E | T | A | A | A | --- | --- |
| Interruptible Load | T | A | T | T | A | A | A | --- | --- |
| Price Responsive Demand | T | T | T | T | A | A | A | --- | --- |
| Transmission | | | | | | | | | |
| Synch. Cond.: Large motor frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: Air-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: H2-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Shunt FACTS devices (STATCOM, SVCs)* | --- | --- | --- | --- | --- | --- | --- | A | --- |
| HVDC Transmission Technologies* | --- | --- | --- | --- | --- | --- | --- | A | A |
| Desirable Attributes / Retrofit Options | | | | | | | | | |
| Improved Turndown (MinGen) Capability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Elevated Ramp-rate Capability | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Faster Startup Capability | | | | | | ✓ | ✓ | | |

| | |
|---|---|
| A | Available commercially |
| E | Emerging capability in demonstration phase |
| T | Technically feasible, but not currently being pursued |



*Dynamic voltage support
imagination at work

Technology Capability Table (cont'd)

Screening Resources for their Ancillary Service Compatibility

| Technologies | Plant Size (MW) | | | | Cost Estimates | | Flexibility | | | |
|--|-----------------|-------------------|-------------------|---------|--|---|---------------------|---|---|---|
| | Minimum | Minimum (Typical) | Maximum (Typical) | Maximum | Total Overnight Cost in 2010 (2009 \$/kW) for stated size (MW) | Resource Size Assumed in Cost Estimate (MW) | Turndown Load Level | Ramp Rate Capability (thermally stable) | 10-Minute Output Available (from offline) | 30-Minute Output Available (from offline) |
| Generation | | | | | \$/kW | MW | %MW | %MW/min | %MW | %MW |
| Solar Thermal | 0.1 | 1 | 100 | 200 | \$4600 - 8100 | 200 | 12-15% | 3-7%* | 0% | 0% |
| Solar Photovoltaic (Transmission Connected) | 0.001 | 0.05 | 5 | 150 | \$2100 - 3900 | 10 | --- | Rapid* | 100% | 100% |
| Wind (non-synchronized / power conversion) | 0.001 | 1 | 100 | 450 | \$1500 - 2500 | 100 | < 10% | Rapid* | 100% | 100% |
| Wind (synchronized) | 0.001 | 1 | 100 | 450 | \$1500 - 2500 | 100 | < 10% | Rapid* | 100% | 100% |
| Hydropower | 0.001 | 0.5 | 50 | 650 | \$2200 - 4800 | 500 | 20-40% | 25-100% | 100% | 100% |
| Geothermal | 0.05 | 1 | 30 | 180 | \$2500 - 9900 | 50 | 12-15% | 3-7% | 0% | 0% |
| Biomass | 0.1 | 5 | 50 | 75 | \$2900 - 5800 | 50 | 35-40% | 3-7% | 0% | 0% |
| Coal | 0.1 | 10 | 400 | 1300 | \$1900 - 3900 | 600 | 35-40% | 3-7% | 0% | 0% |
| Combined Cycle (Gas/Oil: Sm. HD/Aero) (1x1) | 10 | 25 | 60 | 120 | \$1000 - \$1800 | 55 | 20-40% | 20-40% | 0-75% | 75-100% |
| Combined Cycle (Gas/Oil: Heavy-duty) (1x1) | 60 | 120 | 300 | 500 | \$900 - 1500 | 615 | 25-70% | 3-11% | 0-60% | 10-100% |
| Simple Cycle (Gas/Oil: Small HD/Aero) | 1 | 20 | 40 | 100 | \$800 - 1300 | 45 | 25-50% | 25-50% | 0-100% | 100% |
| Simple Cycle (Gas/Oil: Heavy-duty) | 40 | 80 | 200 | 330 | \$500 - 800 | 211 | 15-70% | 4-16% | 0-75% | 100% |
| Reciprocating Engines (Gas/Diesel/Bio) | 0.01 | 1 | 5 | 20 | \$700 - 1300 | 10 | 50% | 35% | 100% | 100% |
| Energy Storage | | | | | | | Resp. Time | %MW/min | %MW | %MW |
| Pumped Hydropower | --- | 100 | 1000 | --- | \$1000 - 3000 | 500 | 10s | 25-100% | 100% | 100% |
| CAES - Comp. Air Energy Storage | --- | 50 | 500 | --- | \$600 - 1600 | 260 | 1-10min | 4% | 100% | 100% |
| Solid Batteries | 0.1 | 1 | 20 | 50 | \$1000 - 4000 | 50 | 100ms | 500% | 100% | 100% |
| Flow Batteries (Redox) | --- | 0.1 | 20 | 50 | \$1700 - 4200 | 50 | 100ms | 500% | 100% | 100% |
| Flywheels | 0.1 | 1 | 20 | 40 | \$900 - 1100 | 20 | 1-4s | 1500% | --- | --- |
| PEV | --- | 0.02 | 0.05 | --- | --- | --- | 100ms | --- | --- | --- |
| Fuel Cells (PEM) | 1E-04 | 0.001 | 0.1 | 10 | \$3,000 | 1 | 10s | 500% | 100% | 100% |
| Demand Response | | | | | | | | | | |
| Fast Auto DR | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Direct Load Control | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Interruptible Load | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Price Responsive Demand | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Transmission | | | | | | | | | | |
| Synch. Cond.: Large motor frame | --- | 0 | 50 | --- | --- | --- | --- | --- | --- | --- |
| Synch. Cond.: Air-cooled generator frame | --- | 38 | 113 | --- | --- | --- | --- | --- | --- | --- |
| Synch. Cond.: H2-cooled generator frame | --- | 198 | 478 | --- | --- | --- | --- | --- | --- | --- |
| Shunt FACTS devices (STATCOM, SVCs) | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HVDC Transmission Technologies | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Desirable Attributes / Retrofit Options | | | | | | | | | | |
| Improved Turndown (MinGen) Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elevated Ramp-rate Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Faster Startup Capability | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |

Generation Technologies

Heavy-duty (HD) Gas Turbines / Combined Cycles:

- Well-positioned to provide all of the defined ancillary services
- Continued advancements in flexibility will enable greater penetration & reduce curtailment of renewable generation
 - Turndown, ramp-rates, part-load efficiency, hot-day output, daily cycling capability, etc.
- Much focus from both Aero and Heavy-duty GT/CC manufacturers on improved flexibility, reduced footprint, and lower startup/running emissions

Aero-derivative Gas Turbines / Combined Cycles:

- Similar ancillary capabilities as HD options; however, typically include more efficient simple cycle operation, minimal cycling penalties and improved quick-start / ramping capabilities.
- Reduced footprint, quick-delivery, and typically smaller block-sizes.

Reciprocating Engines:

- Able to provide 'full-spectrum' of ancillary services
- Effectiveness of inertial response (due to lower rotating mass) is less-than other conventional thermal generators
- Typically provide some of the fastest startup times and ramp-rates of all generation technologies.
 - Most offer full output (from offline) inside 10-minutes and more than 30% / min ramp rate
- Ideal for black start, particularly on smaller power systems

Generation Technologies

Coal / Biomass:

- Available to provide all “on-line” ancillary services
- ST-based generation ... operating range & ramping capability typically less-than GT/CC assets
- Not well-suited for applications which require startups inside 1-hr
 - Non-spinning reserve, Replacement reserves, Black start
- Excellent for inertial response

Geothermal:

- Similar ancillary capabilities as Coal / Biomass
- Improved operating range relative to coal / biomass (enabled by deeper turndown)
 - Lack of combustion process reduces limitations to ST aero / mechanical limits.
- Natural / continuously available fuel source enables potential for use as a black start resource
- Ancillary service potential not limited by fuel supply interruptions

Hydropower:

- Excellent resource-type for providing ancillary services ... used extensively on mainland.
- Superior operating range, ramp-rates, and startup times relative to other generation technologies
- Only restrictions would include release schedules (environmental / wildlife / recreational) and/or availability of water ... particularly for “run-of-river” applications

Generation Technologies

Solar Thermal⁽⁸⁾:

- Capable of providing inertial response similar to conventional steam generators
- Requires curtailment* to establish required headroom for services such as frequency responsive reserve, regulation, load following, and spinning reserve.
- Technically feasible to develop facilities capable of providing both black start and particularly voltage support services

Solar PV⁽⁸⁾:

- Not yet capable of providing inertial response, but feasible
 - Inverters likely possess the required response speed; however, on-site energy storage mechanism would be required.
- Curtailment* required for frequency responsive reserve, regulation, load following, and spinning reserve
- Response speed/accuracy better than most conventional generators can supply
- Voltage support services technically feasible

Wind⁽⁸⁾:

- Synthetic inertia from wind turbines is commercially available.
 - Energy extracted from the wind turbine rotor OR head-room provided by operation at curtailed output level.
- Curtailment* required for frequency responsive reserve, regulation, load following, and spinning reserve
- Response speed/accuracy better than most conventional generators can supply
- Voltage support services technically feasible

* Curtailment only required for upward movement. Downward movement can be provided without curtailment.

Emerging Req's / Opportunities

Specific to Variable Generation (VG)

CAISO:

- Exploring incentives to encourage greater participation in economic dispatch by wind and solar resources.⁽⁸⁾
- Considering reduction in the continuous energy requirements for ancillary services ... would benefit VG resources⁽⁸⁾
 - Spinning and Non-Spinning Reserve: From 2 hours down to 30 minutes
 - Regulation: 60 minutes for DAH and 30 minutes for RT

ERCOT:

- New requirements for wind generators – applicability based on the date of signing the Generation Interconnect Agreement ^{*(3)}
 - New generators required to provide “governor-like” response to frequency deviations⁽⁸⁾ : Requires adjustable dead-bands and droop response of 5%⁽³⁾
 - Includes Voltage Ride-Through (VRT) requirements⁽⁸⁾
- Wind generators must be capable of producing reactive power equal to ± 95 percent power factor (based on current load set-point) down to 10% of nameplate capacity.⁽⁸⁾
- Variable generation resources expected to respond to dispatch instructions⁽⁸⁾

* Required for all wind generators with standard generation interconnection agreements signed after January 1, 2010. Wind generation resources with interconnection agreements signed on or before January 1, 2010, shall have primary frequency response capabilities by December 1, 2010, if ERCOT believes this is physically practical.⁽³⁾

Emerging Req's / Opportunities

Specific to Variable Generation (VG)

NYISO:

- Wind scheduled / dispatched similar to other generation⁽⁸⁾
 - Bids a price-curve (based on operating costs only) ... required for RT and optional for DAH market
 - Must be able to accept electronic base-point signals ... penalties assessed for non-compliance
 - Equivalent to MW-deviation multiplied by regulation clearing price (3% tolerance allowed)
- VG allowed to provide reserves if all technical requirements are met⁽⁸⁾
 - Limited energy storage resources (LESR) allowed to provide regulation service. Rule change accepted by FERC to allow 15-minute continuous reserve (vs. 1-hour).⁽³⁾
 - Energy Management System (EMS) modified to monitor LESR energy levels & adjust regulating range to allow for charging (if required).⁽³⁾

Hydro Quebec:

- Wind plants larger than 10 MW must provide emulated inertial response similar to conventional synchronous generator (3.5s)⁽³⁾
- Demonstrations conducted with wind turbines supplying regulation service⁽⁸⁾

Desirable Attributes / Retrofit Options

Preferred Characteristics for New or Existing Generation Technologies

Improved Turndown (Minimum Generation) Capability:

- Enhances ability to provide all online ancillary services
 - Inertial Response, FRR, Regulation, Load Following, Spinning Reserve, Voltage Support
- Minimizes fuel cost during off-peak periods
- Potential to avoid curtailment of renewable and economically preferred resources

Elevated Ramp-Rate Capability:

- Increases the amount of available Regulation, Load Following and Spinning Reserve
- Potential to improve the quality of the response for smaller “MW” swings
- Aids in allowing offline reserves to contribute more quickly during contingency events

Faster Startup Capability:

- Enables Non-Spinning and Replacement Reserves to be delivered more quickly
- Opportunity to reduce fuel consumption thru replacement of some online reserves
- Typically accompanied by reduced startup emissions

Improved Cycling Capability:

- Ability to accommodate daily (and sometimes multi-daily) startups with minimal variable operation & maintenance penalties along w/ reduced minimum up/down time req's.
- Enables more options at the power system level and further limits required curtailments

Energy Storage – Flywheels

Technology Overview

- Mass rotating about an axis to store mechanical energy
- Mechanical energy converted to electrical energy via generator
- Practical for short charge-discharge cycles (less than 15 minutes)
- Flywheel energy storage provides >10 seconds of ride-through power to protect the load from that 99% of disturbances
- Backup gen-sets typically provides the other 1%

Energy Storage – Flywheels

Impact on Ancillary Services

- **Inertial Response:** Flywheels are coupled to the grid through a power electronic interface that should allow for emulation of inertial response
- **Regulation:** In regards to regulation, flywheels can use their power electronic front ends to accurately respond to automatic generation control (AGC) signals faster and more efficiently than traditional conventional generators, potentially reducing the total amount of comparable regulating reserve carried on traditional units
- **Load Following:** Some flywheel technology can apparently provide load following capability above the capacity rating of the distribution generation (DG) asset as well as voltage and reactive power support and control; For Combined Heat and Power (CHP) systems, this technology has the potential to facilitate the use of gas turbines as part of a CHP system, by improving these systems' ability to follow fast-changing loads
- **Spinning/Non-Spinning Reserve:** All energy storage technologies except for flywheels are well suited to provide spinning/non-spinning reserve; The only limiting factor for flywheels is the duration of the response required; However the introduction of energy storage can act to further reduce diesel fuel consumption by using the stored energy to provide both load following and supplying the occasional shortfall, while leaving the generator turned off - some flywheel energy storage technology could be ideal for this application due to its low maintenance, long design life, high cycling capability without any degradation in storage value, its ability to respond almost instantaneously (thus improving load following), and its ability to provide real and/or reactive power
- **Voltage Support:** All energy storage technologies are capable of providing voltage support

Energy Storage – Batteries

Technology Overview (applies to both Solid State and Flow types)

- A Battery Energy Storage System (BESS) system can cover a wide range making them suitable for almost all energy storage applications; One installation can be used for multiple applications such as spinning reserve and voltage & frequency control
- Lithium-Ion batteries are good for inertial/frequency response, regulation, reserves
- Energy batteries good for load following but could also be good for response
- Energy batteries (some sodium based batteries, flow batteries) can also provide power

Energy Storage – Batteries

Impact on Ancillary Services (applies to both Solid State and Flow types)

- **Inertial Response:** BESS do not include any rotating mass, but rather they interface to the grid through a power electronic front-end and the power electronic controls should be configurable to provide an emulation of inertial response over very short durations of up to a few seconds
- **Frequency Responsive Reserve:** The power electronics for battery energy storage can be controlled to provide frequency response
- **Regulation:** If BESS are used to provide regulation, then cycle life (number of charge/discharge cycles in the life of the battery), the round-trip energy efficiency and O&M costs will play a major role; On the other hand, these factors will be less important than the capital and replacement costs when BESS are used in black start applications - this is particularly true considering that these batteries will only be discharged and recharged when a major black out occurs and black start is required - shelf life, rather than cycle life will be important and round-trip efficiency will be of little or no concern
- **Load Following:** BESS can provide dispatched balance, with flow batteries potentially having the capability to provide the longer duration load following
- **Voltage Support:** All energy storage technologies are capable of providing voltage support

Energy Storage – PSH

Technology Overview (PSH - Pumped Storage Hydropower or Pumped Storage)

- Pumped Storage Hydropower (PSH) can quickly accommodate disturbances that occur on transmission grids – loss of generators, failure of transmission lines, instant demands (or cessation of demands) Low operating cost, reliable, long lifetime, can have large power ratings
- Fast response – can go from full load pumping to full load generation in minutes (as little as 10s). Additionally, a configuration with two penstocks could be deployed for pumping water and generating electricity simultaneously.
- Efficiency: >70-75% round trip (and may be upto 85%)

Energy Storage – PSH

Impact on Ancillary Services (PSH - Pumped Storage Hydropower or Pumped Storage)

- **Inertial Response:** PSH interface with the grid through a rotating machine that allows them to provide inertial response just like any conventional synchronous generator
- **Frequency Responsive Reserve:** PSH can provide primary frequency response and is available while the plant is generating but they must be designed with variable pumping control if they are to provide primary frequency response while pumping
- **Regulation:** In regards to regulation, PSH can respond to AGC Controls in the same manner as traditional hydro and gas turbine plants while generating and can provide regulation when pumping if they are initially designed to do
- **Load Following:** When it comes to load following, PSH can follow system operator dispatch commands to provide sub-hourly to multi-hour energy balancing in the generating mode; As with primary frequency response, pumped hydro plants can provide load following or ramping when pumping if they are initially designed to do so
- **Spinning Reserves:** PSH is well suited to provide spinning reserve; The amount of response available from a pumped storage plant while pumping depends on the plant design
- **Non-Spinning Reserves:** Because non-spinning reserves do not need to respond as quickly as spinning reserves, PSH is well suited to provide non-spinning reserve
- **Voltage Support:** All energy storage technologies are capable of providing voltage support

Energy Storage – CAES

Technology Overview (CAES – Compressed Air Energy Storage)

- Gas Turbine (GT) that uses 40% less fuel - 2/3 of GT fuel is used to compress air
- Air is pre-compressed (using off-peak energy) in an underground chamber
- The pre-compressed air supplements gas turbine
- Shorter construction time, greater site flexibility, lower capital costs than PSH
- Low operating costs, reliable, long lifetime, can have large power ratings
- Fast response – can go from full load pumping to full load generation in minutes
- Efficiency: >70-75% round trip

Energy Storage – CAES

Impact on Ancillary Services (CAES – Compressed Air Energy Storage)

- **Inertial Response:** CAES plants interface with the grid through a rotating machine that allows them to provide inertial response just like any conventional synchronous generator
- **Frequency Response:** CAES plants can provide primary frequency response and is available while the plant is generating
- **Regulation:** When it comes to regulation, CAES plants can respond to AGC Controls in the same manner as traditional hydro and gas turbine plants while generating
- **Load Following:** In regards to load following, CAES plants can follow system operator dispatch commands to provide sub-hourly to multi-hour energy balancing in the generating mode
- **Spinning Reserves:** CAES is well suited to provide spinning reserve - the fast response is easily met by CAES
- **Non-Spinning Reserves:** Because non-spinning reserves do not need to respond as quickly as spinning reserves, CAES is well suited to provide non-spinning reserve
- **Voltage Support:** All energy storage technologies are capable of providing voltage support

Plug-in Electric Vehicle (PEV)

Technology Overview

- Very low capital cost
- Very fast response
- High power/low energy (per vehicle)
- Capable of storing electricity from an intermittent generator such as PV or wind (wind is the cheapest, low-CO2 emissions energy source, but is intermittent)
- Potential to supply energy back to the grid on demand
- Day time opportunity charging could go really well with high PV penetration since the HSIS is showing daytime PV curtailment

Plug-in Electric Vehicle (PEV)

Impact on Ancillary Services

- **Inertial Response:** PEV chargers have the advantage that they can both increase and decrease consumption, providing the opportunity for full inertial response
- **Frequency Responsive Reserve:** The solid-state control capability of PEV chargers make providing primary frequency response feasible
- **Regulation:** PEV solid-state charger control potentially allows for the provision of regulation; Communications will be required to deliver the system operator's AGC signals to the PEV chargers every few seconds
- **Load Following:** PEV chargers can supply load following and ramping response well and are better suited for this service if the balancing requirements are more or less neutral and are not in one direction for a sustained period of time, such as when the load or variable generation forecast errs significantly
- **Spinning Reserves:** PEVs could provide spinning reserves and can respond immediately after receiving a control signal, particularly by reducing its charging though reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge
- **Non-Spinning Reserves:** PEVs can supply non-spinning reserves though reserve capabilities may be limited in certain circumstances such as in the final hours of the night to honor requirements to PEV owners of a full overnight charge
- **Voltage Support:** The interface of the PEVs to the power system is through inverters that have the ability to provide reactive power to the grid and support system voltage

Demand Response (DR)

Impact on Ancillary Services

- **Inertial Response:** Distributed resources' contributions to system inertial response needs is not anticipated to be significant
- **Frequency Responsive Reserve:** The potential contribution of DR to system primary frequency response has been low so far
- **Regulation:** Regulation is the most difficult ancillary service to provide (though fast DR can), requiring the load to adjust consumption every few seconds in response to the system operator's AGC commands; Responsive load is beginning to provide Regulation Reserve
- **Spinning Reserves:** Appropriately responsive load can provide any of the contingency reserves; Technically, demand can provide better reliability response than generation since full response is usually achieved immediately by tripping the load
- **Non-Spinning Reserves:** Appropriately responsive load can provide any of the contingency reserves, including non-spinning reserve; ERCOT's "Loads acting as a Resource" (LaaR) are capable of being interrupted within 30 minutes and are capable of running (or being interrupted) at a specified output level for at least 1 hour (small loads can be used for spin as well)
- **Supplemental Reserves:** Supplemental reserve is reserve capability that can be fully converted into energy or load that can be removed from the system within a 10-to-30 minute interval following the request of the an ISO dispatcher (i.e. PJM)
- **Voltage Support:** DR is not well suited for supporting system voltage or reactive needs; Reducing loads may have a small localized impact on system voltage, but the ability to supply reactive power to support bulk system voltages is limited

Demand Response (DR)

Available DR Programs Cross-referenced with Ancillary Service Potential

| <u>DR Programs</u> | <u>Ancillary Services</u> |
|--|--|
| Direct Load Control (DLC) | Frequency Resp. Reserve & Regulation (w/ enhanced communication and control), Spinning Reserve, Non-Spinning Reserve |
| Interruptible Load | Spinning reserve, Non-Spinning Reserve |
| Load as a Capacity Resource | Non-Spinning Reserve |
| Demand-side Spinning Reserves | Spinning Reserve |
| Demand-side Non-Spinning Reserves | Non-Spinning Reserve |
| Demand-side Regulation Service | Frequency Responsive Reserve, Regulation, Load Following |
| Peak Time Rebate (PTR) and also Critical Peak Rebate (CPR) | Spinning Reserve, Non-Spinning Reserve |
| Real-Time Pricing (RTP) | Not a traditional A/S function but can be used for "Load Leveling/Load Shifting" |
| Critical Peak Pricing (CPP) | Spinning reserve, Non-Spinning Reserve |
| Time of Use Pricing (TOU) | Not a traditional A/S function but can be used for "Load Leveling/Load Shifting" |
| Fast Auto-DR / Aggregated DR / Integrated DR | Frequency Responsive Reserve, Regulation, Load Following, Spinning Reserves, Non-Spinning Reserves |

Demand Response (DR)

Program Details

- **Direct Load Control (DLC):** In a DLC Program, the program sponsor remotely shuts down or cycles a customer's electrical equipment, e.g. air conditioner, water heater, lighting, on short notice; DLC programs are primarily offered to residential or small commercial customers
- **Interruptible Load:** In an interruptible load program, electric consumption is subject to curtailment or interruption under tariffs or contracts that provide a rate discount or bill credit for agreeing to reduce load during system contingencies; In some instances, the demand reduction may be effected by action of the system operator, called 'remote tripping', after notice to the customer in accordance with contractual provisions
- **Load as a Capacity Resource:** A Load as Capacity Resource commits to make pre-specified load reductions when system contingencies arise
- **Demand-side Spinning Reserves:** Spinning Reserves are demand-side resources synchronized and ready to provide solutions for energy supply and demand imbalance within the first few minutes of an emergency event
- **Demand-side Non-Spinning Reserves:** Non-Spinning Reserves are demand-side resources that may not be immediately available, but may provide solutions for energy supply and demand imbalance after a delay of ten minutes or more
- **Fast Auto-DR and also Aggregated DR/Integrated DR:** Aggregated and Integrated DR capable of managing load via high-speed, automated EMS that can deliver second-to-second and minute-to-minute variations in load under grid operator or load scheduler direction

Demand Response (DR)

Program Details (cont'd)

- **Demand-side Regulation Service:** Regulation Service is a type of demand response service in which a demand resource increases and decreases load in response to real-time signals from the system operator; Demand resources providing Regulation Service are subject to dispatch continuously during a commitment period; This service is usually responsive to Automatic Generation Control (AGC) to provide normal regulating margin; Also known as regulation or regulating reserves, up-regulation and down-regulation
- **Peak Time Rebate (PTR) and also Critical Peak Rebate (CPR):** Peak Time Rebates allow customers to earn a rebate by reducing energy use from a baseline during a specified number of hours on critical peak days; Like CPP, the number of critical peak days is usually capped for a calendar year and is linked to conditions such as system reliability concerns or very high supply prices
- **Real-Time Pricing (RTP):** In RTP rate and price structures, the retail price for electricity typically fluctuates hourly or more often to reflect changes in the wholesale price of electricity on either a day-ahead or hour-ahead basis
- **Critical Peak Pricing (CPP):** CPP is the rate and/or price structure designed to encourage reduced consumption during periods of high wholesale market prices or system contingencies by imposing a pre-specified high rate or price for a limited number of days or hours
- **Time-of-Use Pricing (TOU):** TOU Pricing is a rate where usage unit prices vary by time period, and where the time periods are typically longer than one hour within a 24-hour day; TOU rates reflect the average cost of generating and delivering power during those time periods

Demand Response (DR)

Available Resources and Processes that can be used for Demand Response

Residential/Small Comm. End-uses

- A/C Cycling & PCT
- Water Heating
- Space Heating
- Lighting
- Smart Appliances
- Refrigeration
- Fans
- Pumps (Fountain, Pool, Irrigation)
- Thermal Storage (Heat & Cool)
- Battery Storage
- Building Thermal Mass
- EV Charging

C&I Customer Type / Process Uses

- Water Utilities and Water Pumping
- Wastewater Treatment
- Pulp & Paper Product Making
- Fruit + Vegetable Preserving
- Evaporative Processes
- Water Desalination
- Bakeries + Food Manufacturing
- Chemical Manufacturing
- Batch Operations: Hammer Mills
- Air Liquefaction/Separation
- Dairy Product Manufacturing
- Fabricated Metal Product Manufacturing
- Beverage Manufacturing
- Cold Storage & Refrigerated Warehouses
- Arc Furnace & Induction Processes
- Electrolysis and Electroplating
- Oil Pipelines and Pump Stations
- Smelting Processes

Demand Response (DR)

Additional Comments

- All these end-use devices and processes can be aggregated into a larger DR grouping which with proper sizing and integration; With the required communication, command, and control systems, they can provide any of the needed A/S functions, as long as the system architecture and technical characteristics meet the A/S functionality requirements in terms of size, metering, speed and timing of response
- Virtual DR Plants with Energy Management System, Demand Response Management Systems, and Fast Auto-DR all could refer to such an aggregated and integrated system; Large loads can participate individually, but smaller loads are most likely to participate in an Aggregated DR system managed either by the utility or by third party DR aggregators; Suitability of the end-uses and processes would depend on the underlying DR program

Fuel Cells

Technology Overview

- Fuel cells are playing an increasing role in energy storage
- PEM Fuel Cells are currently common for storage but Solid Oxide Fuel Cells (SOFCs), which use natural gas as a fuel and would be viewed more as power generation as opposed to storage, are being researched and tested - there currently is not sufficient information at the system level for this technology but some are targeting 1-10MW at <\$2000/kW – baseload
- The Naval Air Warfare Center in China Lake, California, is developing a system that will use solar power to create hydrogen for use in a fuel cell during periods with insufficient sunlight
- In Canada, a partnership between the federal government, BC Hydro, Powertech, and General Electric is converting excess off-peak electricity into hydrogen, reducing diesel consumption by an estimated 200,000 liters per year and greenhouse gas (GHG) emissions by an estimated 600 tons per year
- Germany's Enertrag AG, one of the world's largest wind power companies, is building a facility to use excess wind energy to produce hydrogen for energy storage and for transport applications

Transmission Technologies

- The following data applies to new 60 Hz GE synchronous condensers* only

| Frame | Rotor | + MVARs | H Range |
|---------------------------------|-------------------------------|--------------|----------------|
| Large motor frame | 4 or 6 poles (salient design) | Up to +50 | ~1.50 to ~2.0 |
| Air-cooled generator frame | Round rotor | +38 to +113 | ~3.0 to ~2.3 |
| Hydrogen-cooled generator frame | Round rotor | +198 to +478 | ~1.28 to ~0.88 |

*-inertia is relatively low for these machines

HVDC and Shunt FACTS for Grid Support

- HVDC technology can be a more economically feasible option for integration of off-island wind power.
 - There are two types of technologies: (1). Conventional line commutated converter (LCC) HVDC, and (2). Voltage-source converter (VSC) technology
 - Voltage source converter technology is capable of providing dynamic voltage support to the grid and is flexible to connect with weak AC systems
 - World's first Ultra high voltage DC solution: Southern power grid China, Conventional LCC HVDC project 5000 MW +/- 800 kV, 1418 km
 - World's first off-shore VSC HVDC: North Sea, 88MW (in 2005) being expanded to additional 100 MW in 2015, 66kV, 70 km,
- Shunt FACTS devices (such as SVC's, STATCOMS) have been deployed worldwide to provide voltage support to the grid.
 - These devices are capable of providing dynamic reactive VAR and voltage support
 - Typical STATCOM ratings for grid applications: 10's – 100's of MVA
 - Energy storage can also be coupled with such devices to provide dynamic real power compensation

References

References

- (1) NREL: National Renewable Energy Laboratory, Renewable Electricity Futures Study (Vol. 4 of 4), Bulk Electric Power Systems: Operations and Transmission Planning, 2012
- (2) NERC: North American Electric Reliability Corporation, Special Report: Potential Reliability Impacts of Emerging Flexible Resources, November 2010
- (3) NREL: National Renewable Energy Laboratory, Operating Reserves and Variable Generation, August 2010
- (4) Kirby, B., Proposed Ancillary Services, October 31, 2011
- (5) Kirby, B., Ancillary Services: Technical and Commercial Insights, July 2007
- (6) NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011
- (7) Hawaii Reliability Standards Working Group, Glossary of Terms, Version 1 – 2012, Docket No. 2011-0206
- (8) NERC: North American Electric Reliability Corporation, NERC IVGTF Task 2.4 Report: Operating Practices, Procedures, and Tools, March 2011
- (9) Black & Veatch, Cost and Performance Data for Power Generation Technologies, February 2012
- (10) US Energy Information Administration (EIA), Annual Energy Outlook (AEO), Energy Market Module (EMM), 2011
- (11) Gas Turbine World (GTW), Performance Specifications, 2012 Edition, Volume 42
- (12) Bechtel Corporation, Concentrated Solar Thermal Plants Downstream of the Solar Field – Design/Optimization of the Associated Power Generation Cycle

References

- (13) Power Engineering, Hydroelectricity: The Versatile Renewable, June 1, 2009
- (14) GE Energy, Western Wind and Solar Integration Study, Prepared for National Renewable Energy Laboratory, May 2010
- (15) Oak Ridge National Laboratory, National Hydropower Association, Hydropower Research Foundation, Summary Report on a Summit Meeting: Pumped Storage Hydropower, September 2010
- (16) Renewable Northwest Project, Summary Report on Coal Plant Dynamic Performance Capability, August 2010
- (17) GE Energy (Miller, N., Leonardi, Bruno), New York Independent System Operator, Feasibility Evaluation of Energy Storage for Black Start Services on the NYISO System, December 16 2011
- (18) Milligan, M., Kirby, B., Utilizing Load Response for Wind and Solar Integration and Power System Reliability, Presented at WindPower 2010, Dallas, Texas, May 23–26 2010
- (19) Hawaii Renewable Energy Development Venture Technology Assessment - Grid Energy Storage Systems (<http://www.hawaiirenewable.com/wp-content/uploads/2009/12/16.-Energy-Storage.pdf>)
- (20) Pratt, Rob (Pacific Northwest National Laboratory), Najewicz, Dave (GE Appliances), Opportunities for Mass Market Demand Response to Provide Ancillary Services, October 2011
- (21) Raslter, Dan (EPRI), Akhil, Abbas (ERPI), Gauntlett, Dave (AECOM), Cutter, Eric (E3), Energy Storage System Costs 2011 Update Executive Summary - Presented to Storage System Suppliers, February 22 2012
- (22) Freund, Sebastian (GE GRC), Shu, Mark (GE Energy), Stoffer, Bart (GE Energy), 2010 insights: Grid-base energy storage, January 19 2011

References

- (23) Young, Russell (GE Energy), Manz, Devon (GE Energy): Utility Energy Storage, 2010
- (24) Federal Energy Regulatory Commission, Assessment of Demand Response & Advance Metering, Staff Report, February 2011
- (25) http://www.ercot.com/content/gridinfo/etts/flywheel/presentations/PSWG_meeting_082410.pdf
- (26) http://www.beaconpower.com/files/Beacon_Power_presentation_ESA%206_7_11_FINAL.pdf
- (27) DOE, Office of Energy Efficiency and Renewable Energy: 2010 FUEL CELL TECHNOLOGIES MARKET REPORT, June 2011

Ancillary Services Definitions and Capability Study

Part 2, Tasks 3-4, Final Report For Hawaii Natural Energy Institute

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imagination at work

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Foreword

This report was prepared by General Electric International, Inc. acting through its Energy Consulting group based in Schenectady, NY through the support of the Hawaii Natural Energy Institute and under a contract with the Research Corporation of the University of Hawaii.

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1 Study Background and Objectives

The purpose of this study is to identify, define and quantify ancillary services necessary to integrate new generation resources, including renewable generation, for bulk power systems and particularly the Hawaiian Islands. The results of this study may be: incorporated into the Hawaii Reliability Standards Working Group's proposals for new reliability standards; used to develop recommendations for revised generation interconnection technical requirements; provided to the Hawaii Public Utility Commission for consideration and adoption; and used to inform the Hawaii utilities' Integrated Resource Planning process.

The GE team has been deeply involved in analyzing the impact of renewable generation on the HECO systems and has performed 9 system-level studies over the past 5 years. The power output from Variable Generators (VG) such as wind and solar plants, by definition is variable. Also, there is a certain amount of uncertainty associated with this generation in the hours preceding actual operations. The generation from VGs is not only variable within the hour and is also variable on a longer timeframe such as daily, weekly and monthly time frame. The variability of VGs within the hour (along with the variability associated with the load) is handled by the system operator through the use of regulation and load-following (spinning) reserves. This study will leverage the findings of the renewable impact studies performed by GE.

The project focuses on four tasks¹:

- Task 1: Define a standardized set of ancillary services along with their associated definitions (in functional, technology-neutral, performance based terms) that can be used to meet the operational needs of Hawaii and other bulk power systems, and provide for the integration of variable generation technologies.
- Task 2: Assess resource technologies (generation, transmission, storage, and demand response (DR)) for their ability to support the respective ancillary services, to maximize the diversity and optionality for ancillary service acquisition and delivery.
- Task 3: Identify the physical requirements of the ancillary services needed for each Hawaiian island (Oahu, Maui, Big Island).
- Task 4: Outline considerations for specifying / acquiring ancillary services for the Hawaii grids that protect reliability, incent renewable generation, and minimize production costs.

This report presents the results of Tasks 3 and 4 of the study. The results of Tasks 1 and 2 were presented in a separate report, GEA30441 Hawaii Ancillary Services Study PART 1 REPORT and PRESENTATION_12192912r1.pdf.

¹ After the study commenced, it was decided that Task 1 should be generic and address all ancillary services that are in service or under development in the U.S., as well as internationally, regardless of their applicability to the Hawaii system. The applicability of the ancillary services to the Hawaii system was included as a portion of Task 3 of the study. Therefore, in Task 1, the difficulty in adopting some of the researched ancillary services for the Hawaii system was acknowledged, but not discussed in detail.

2 Summary of Results

Ancillary services are required to maintain reliable operations of the electric power system. With Hawaii Natural Energy Institute (HNEI), in cooperation with the Hawaii Reliability Standards Working Group (RSWG), GE has worked to identify, define and quantify ancillary services necessary to integrate new generation resources, including renewable generation, for the Hawaiian Islands. This written summary report for Tasks 3-4 and the attached PowerPoint slides documenting Tasks 3-4, comprise the Part 2 final report from GE for use by HNEI and the Hawaii RSWG.

The purpose of a companion report on Part 1 of the study was to define a standardized set of ancillary services along with their associated definitions that can be used to meet the operational needs of any bulk power systems, and provide for the integration of variable generation technologies. Part 1 also provided an assessment of resource technologies (generation, transmission, storage, and demand response (DR)) for their ability to support the respective ancillary services, to maximize the diversity and optionality for ancillary service acquisition and delivery.

The purpose of the Part 2 study was to identify the physical requirements of the ancillary services needed for each Hawaiian island and to outline considerations for specifying / acquiring ancillary services for the Hawaii grids that protect reliability, incent renewable generation, and minimize production costs². The Part 2 study was performed under two tasks – Task 3 and Task 4.

The primary focus of Task 3 was to investigate the need for additional ancillary services and interconnection requirements under a couple of different renewable generation scenarios for the three Hawaii electric power systems. The results of past renewable integration studies performed for the Hawaii utilities, where available, were used to understand the impact of renewables on operations under the different scenarios. This information along with the lessons learnt from Part 1 on the best practices in the industry was used to determine the additional ancillary services and interconnection requirements for Hawaii. The unique characteristics of the Hawaii systems were taken into account in determining these additional ancillary services and interconnection requirements. Another important deliverable of Task 3 was to develop a process for evaluating various resource options that were summarized in the technology section (Part 1 - Task 2) for providing the ancillary services required under future system conditions.

The purpose of Task 4 of the report was to outline considerations for promoting a least-cost portfolio of resources that can supply ancillary services and interconnection requirements that attempt to protect reliability, maximize renewable output and minimize energy costs.

The major recommendations related to ancillary services and interconnection requirements are given below.

² Production costs include all costs associated with the operation of a power system. These costs include (but are not limited to): fuel costs, variable O&M costs, fixed O&M costs, startup/shutdown & cycling costs, impact of transmission losses, environmental compliance costs, and any explicit compensation which is paid to resources. Production costs do not include capital expenditure associated with the initial purchase of a resource or associated upgrades costs. Consumer cost is highly correlated with Production cost; however, the primary differentiator is that that Consumer cost includes the impact of capital expenditure on the price rate-payers are exposed to. In addition, consumer cost also includes other distribution-related expenses which are not typically included in the production cost.

- Require synthetic inertia capability for future utility-scale wind plants. The parameters for synthetic inertia (deadband, active power contribution, duration of response, maximum generation reduction etc.) should be designed to meet the Hawaii system requirements.
- Require droop control to be a part of the interconnection requirements for future utility-scale wind and solar plants in addition to the requirement for dispatchable generators.
- Variable Generation (VG) should be compensated for providing up reserves if their generation is curtailed for the explicit purpose of providing reserves. Recommend the development of tools to reliably calculate the amount of reserves that VG can provide.
- VG should be required to provide down reserves without any explicit compensation similar to other dispatchable units in the system. Need to design and employ forecasting methodology/tool to calculate the amount of down reserves that VGs can reliably provide based on actual and forecasted generation from VGs.
- VG should be required to provide up reserves without any explicit compensation when they are curtailed for reasons other than providing up reserves since their opportunity cost is zero when they are already curtailed.
- Recommend AGC (ability of wind plant to directly accept and act on a maximum dispatch signal delivered by AGC) capability to be a part of the interconnection requirements for all future utility-scale generators including wind and solar plants.
- Recommend that VG be compensated for providing up regulation if their generation is curtailed for the explicit purpose of providing regulation.
- In general, storage and demand response should be allowed to provide regulation and reserves as long as they are economical.

As mentioned before, another important deliverable of Task 3 was to develop a process for evaluating various resource options. A methodology that can be exercised during a resource planning process to evaluate and assist with the selection of a future technology mix that is compatible with the system-level interconnection and ancillary service requirements was developed. Specifically, the methodology focuses on minimizing the overall production cost and capital expenditure required to obtain a “least-cost” portfolio while observing system reliability needs. Additional consideration is given to parameters which are more difficult to quantify economically, such as propensity for a given portfolio to improve future renewables penetration and/or reduce risk exposure. There are 10 specific steps included in the body of the report and corresponding presentation material.

The objective of Task 3 was also to evaluate methods for procuring the recommended ancillary services. Four potential approaches for obtaining, compensating, and incentivizing ancillary services were included the report. The details of each approach along with their respective pros/cons are discussed further in the report body and corresponding presentation material. Specifically, the four approaches are:

1. Market Clearing Price

2. Reimbursement of Offer Price
3. "Make-whole" Compensation
4. Condition of Interconnection

On Hawaii, ancillary services are presently obtained from dispatchable resources through a method which is similar to the previously mentioned "Condition of Interconnection" approach. Specifically, the utilities have the ability to dispatch resources to provide ancillary services without explicit compensation to the respective resources. Going-forward, there will be a continued desire to increase the penetration of renewable resources on the Hawaiian system which has the potential to increase the system-level ancillary service requirements. As the system-need for ancillary services increases, it may be necessary to incentivize new resources to provide (or existing resources to expand upon) their ancillary service capability. This incentive could likely come in the form of explicit financial compensation and include aspects of either the "make-whole compensation" or "reimbursement of offer price" methods. However, it should be noted the use of these methods has the potential to increase the overall production cost as a result of the explicit compensation for [some of/all of] the ancillary services. Careful consideration is required before introducing such remuneration methods or unbundling the ancillary services.

As outlined in the technology table (Part I, Task 2), renewable resources (i.e. wind/solar) are capable of providing many ancillary services. The use of these resources for providing A/S may help to facilitate their increased penetration and potentially reduce production costs as it introduces another degree of freedom for commitment & dispatch. Current RFP's and draft PPA's are seeking to leverage this capability from VG resources. Relative to the current environment, in which dispatchable resources are not explicitly compensated for fulfilling the system-level ancillary obligations, requiring the wind/solar to provide ancillary services via the "Condition of Interconnection" approach would certainly be considered as an equitable option. Due to the fact that wind/solar resources are presently compensated based on their energy contract price, which likely includes some fixed and capital cost recovery, there are periods when wind/solar are more expensive to operate than some non-renewable resources on the system (i.e. periods where the energy contract price is higher than the marginal system cost). During these periods, it may result in a system level production cost savings to curtail wind/solar to provide ancillary services. However, the existing wind/solar contracts have provisions which preclude the curtailment of these resources for economic reasons. Therefore, during periods where wind/solar are curtailed exclusively for the purposes of providing ancillary services (i.e. up-reserves), the use of "Make-whole Compensation", to explicitly compensate for costs (including opportunity costs) associated with providing ancillary services, would be recommended. It should be noted that the existing wind/solar contracts purposefully prevented curtailment for economic reasons in an effort to maximize renewable penetration.³ Therefore, to adopt the previous recommendation, an adjustment to the existing contracts would be required.

Energy storage devices have the potential to enhance penetration of renewable resources and/or lower the overall production cost. The process for "Evaluating and Selecting a Potential Resource

³ The provisions which preclude economic curtailment of renewable VG have not been extended to dispatchable renewables such as hydropower or biomass.

Mix” developed in Task 3 and discussed earlier, could be leveraged to help quantify these potential benefits. Due to the fact that energy storage resources are energy-neutral and operate exclusively for the purposes of providing ancillary services, the use of “make-whole compensation” is not applicable (i.e. storage resources have no opportunity costs). Therefore, an explicit remuneration method, such as “Reimbursement of Offer Price” may be required to incentivize the development & participation of energy storage resources to supply ancillary services. To obtain a value for the ancillary services offered by the energy storage resources, it is likely that the previously mentioned “system-level” use of a production cost simulation would be required. Specifically, the simulation could be exercised by individually enabling / disabling the respective ancillary service capability for each resource under consideration. The resulting benefit (i.e. “reduction”) in the overall annual production cost could be used as a basis for assessing the ancillary service offer price.

Ancillary service participation from DR, transmission, and retrofit options has the potential to reduce production costs, improve renewables penetration, and avoid/defer/attenuate major capital expenditure. Similar to energy storage resources, an explicit compensation method would likely be required to incentivize participation from DR and/or transmission-related technologies. To incentivize the modification (i.e. retrofit) of existing resources to provide, or expand upon, their ancillary service capability, further use of explicit compensation may be required to cover upgrade costs.

It should be noted that some resources have the potential to increase (or decrease) the required amount of ancillary services on the system. Further, some resources have the potential to provide more ancillary capability than other resource types. In some cases, such as wind/solar, an individual resource has the potential to increase the required amount of ancillary services on the system. However, these resources also have [typically] low variable operating cost and have the potential to reduce the overall production cost for the system. As a result, it is not recommended that individual resources, which induce additional ancillary obligations on the system, be additionally penalized. Instead, it is recommended that the impact on overall consumer cost (including total ancillary services costs), coupled with other policy-related directives such as renewable penetration targets, be used as the metric to assess the viability of a particular resource.

2.1 Key Terminology

The following definitions for key terminology are relevant throughout the content of this study and should be interpreted as described below.

Area Control Error (ACE):

The instantaneous difference between a Balancing Authority's net actual and scheduled interchange, taking into account the effects of Frequency Bias and correction for meter error. Source - NERC Glossary (2008)

Conventionally, **ACE = (NIA – NIS) – 10B (FA – FS) – IME**, where:

NIA is the algebraic sum of actual flows on all tie lines.

NIS is the algebraic sum of scheduled flows on all tie lines.

B is the Frequency Bias Setting (MW/0.1 Hz) for the Balancing Authority. The constant factor 10 converts the frequency setting to MW/Hz.

FA is the actual frequency.

FS is the scheduled frequency. FS is normally 60 Hz but may be offset to effect manual time error corrections.

IME is the meter error correction factor typically estimated from the difference between the integrated hourly average of the net tie line flows (NIA) and the hourly net interchange demand measurement.

Due to a lack of inter-area power flows, the definition of ACE has been modified for Hawaii. Specifically, for **Hawaii, ACE = – 10B (FA – FS)**. This modified definition of ACE is still applicable for Hawaii as it correctly represents the fact that 100% of difference between supply and demand will manifest itself as a frequency error. Source - Revised definition per Hawaii RSWG Glossary

Automatic Generation Control (AGC):

Equipment that automatically adjusts generation, storage devices, and/or responsive load in a Balancing Authority Area from a central location to maintain the Balancing Authority's interchange schedule, plus the Frequency Bias (i.e. ACE). Source - NERC Glossary (2008) with modifications to accommodate additional resource types such as load and storage devices

Although AGC was originally conceived as a means to provide fast (3-6 second signals) to generators, the concept of leveraging AGC to provide "MW raise/lower" commands to demand-side and storage resources is equally applicable and is in practice in some locations.

Droop Response:

Droop response is a near instantaneous means of proportionally adjusting a resource's real-power to resist a change in frequency; allowing a system of resources to operate in a stable manner.

The magnitude of a given resource's response is proportional to the frequency deviation and typically characterized by "x%" droop. For example, a resource with operating range available will provide

100% additional output per “x%” change in system frequency. Response is typically a percentage of the resource’s full-capability.

Droop response can be provided by any frequency-sensitive resource.

Resource:

A resource may consist of any generation, storage, load (i.e. demand-side), or transmission technology.

Spinning / Non-Spinning:

Historically, the terms “spinning” and “non-spinning” have referred to the rotational nature of synchronized generators. Over time, this terminology has migrated to imply the “relative state of readiness and responsiveness” as it relates to the ability for a resource to fulfill its ancillary obligation. In an effort to leverage contemporary industry vernacular, this latter interpretation was adopted for use in this presentation.

3 Study Results

3.1 Task 3: Identify the physical requirements of ancillary services needed for each Hawaiian island.

The objective of this task was to answer the following questions:

1. How much additional quantity of existing ancillary services (example, additional MWs of spinning reserves) may be required in the future under high renewable generation scenarios?
2. What new ancillary services and interconnection requirements may be needed in the future under high renewable generation scenarios?
3. What is the process to determine a cost-effective way of using existing as well as new technology to meet the additional ancillary service requirements?

Drawing on recent Hawaii renewables integration studies conducted by GE, the project teams' expertise from these and similar large scale renewable integration studies, and other sources, GE and the HPUC and HECO companies hypothesized the following scenarios of renewables development for the three utilities.

Table 3.1 Scenarios of renewable development

| | HECO (Oahu) | MECO (Maui) | HELCO (Big Island) |
|--|---|--|---|
| Most Recent IRP | HECO IRP 2009-2028 (Sep 2008) | MECO IRP 2007-2026 (April 2007) | HELCO IRP 2007-2026 (May 2007) |
| Resource Planning Study to support future IRP | ? | Available from MECO | HELCO Resource Planning Study (June 2012) |
| Other renewable integration studies | OWIST & HSIS (Available from GE) | HSIS (Available from GE) | |
| Load Forecast | From OWIST and HSIS | Base Line From HSIS | Base Line From Resource Planning Study |
| Scenario 1: Moderate penetration Renewables or mix definition | HSIS Scenario 4A 360 MW Dist Solar PV 400 MW Cent Solar PV 100 MW On-shore Wind No Off-Shore Wind | HSIS Base Line (2012 system) 15 MW Dist Solar PV 0 MW Cent Solar PV 72 MW On-shore Wind | HELCO 100% renewables intermittent - heavy 22 MW Biomass 100 MW Wind (centralized) 100 MW PV (centralized or distributed) 50 MW Geothermal |
| Scenario 2: High penetration Renewables or mix definition | HSIS Scenario 4B 160 MW Dist Solar PV 200 MW Cent Solar PV 100 MW On-shore Wind 200 Off-Shore Wind (same solar & wind MWH as 4A) | HSIS Scenario 3 30 MW Dist Solar PV 15 MW Cent Solar PV 72 MW On-shore Wind Scenario 3: Heavy Intermittent Renewables 22 MW Biomass 100 MW Wind, 100 MW PV 50 MW Geothermal | HELCO 100% renewables geothermal/ dispatchable - heavy 42 MW Biomass 50 MW Wind (centralized) 50 MW PV (centralized or distributed) 100 MW Geothermal |

Details regarding existing interconnection requirements and ancillary services were gathered and summarized by GE using various sources such as typical design criteria for new units, model PPAs etc. GE also reviewed pertinent documents from HPUC and Hawaii utilities such as Docket 2008-0273 Feed-in Tariff ("FIT") and the updates to the information contained in the docket provided by the HECO utilities.

The attached workbooks⁴ include the details regarding existing interconnection requirements and ancillary services for all three HECO utilities as well as forecasted ancillary services (primarily increase in MWs of operating reserves) for the chosen scenarios where available. To the extent that the scenarios had been previously studied by the GE teams as part of the renewable integration studies, the additional reserve requirements (HECO and MECO Scenarios 1&2) were available. For MECO Scenario 3 and HELCO Scenarios 1&2, more detailed studies would need to be performed to determine the additional reserve requirements. The process for determining the additional reserve requirements is included in Appendix A (Methodology for Determining Operating Reserves). For the purposes of this study, GE worked with the MECO and HELCO to try and define the directional change and magnitude of ancillary services for those scenarios. Where practical, GE estimated the amount of ancillary services required based on studies performed in Hawaii and the mainland.

The results from the primary frequency response simulations were available for some of the selected scenarios from the HSIS and OWIS study performed by GE. These simulations were also used in the determination of the need for new ancillary services.



4

HECO Workbook: HECO Ancillary Services for Scenarios_DRAFT_Rev7.xlsx
MECO Workbook: MECO Ancillary Services for Scenarios_DRAFT_rev6.xlsx
HELCO Workbook: HELCO Ancillary Services for Scenarios_DRAFT_Rev4.xlsx

3.1.1 Additional Quantities of Existing Ancillary Services Required Under Study Scenarios

This section discusses the additional quantities of existing ancillary services required under the study scenarios for each HECO utility, where available.

3.1.1.1 HECO

The following two scenarios were studied:

Scenario 1 - HSIS Scenario 4A

360 MW Dist. Solar PV

400 MW Cent Solar PV

100 MW On-shore Wind

No Off-Shore Wind

Scenario 2HSIS-Scenario 4B

160 MW Dist. Solar PV

200 MW Cent Solar PV

100 MW On-shore Wind

200 Off-Shore Wind

(same solar & wind MWH as 4A)

Inertia and Primary Frequency Response

Results of HSIS study show that 1) enforcing no trip of Distributed PV on under-frequency excursion helped to reduce the frequency drop by 2.2-3.4 Hz (if UFLS is not active), 2) use of frequency responsive load (50MW @ 59.5 Hz trip), and synthetic inertia from off-shore wind plants can support the system during loss of generation contingency by reducing the frequency drop (raising the nadir) by up to 0.3 Hz, in cases where synchronous generators are displaced by renewables. Please see figures.

Figure 3.1 HECO Scenario 4A – Loss of AES (with frequency ride through of Dist PV)

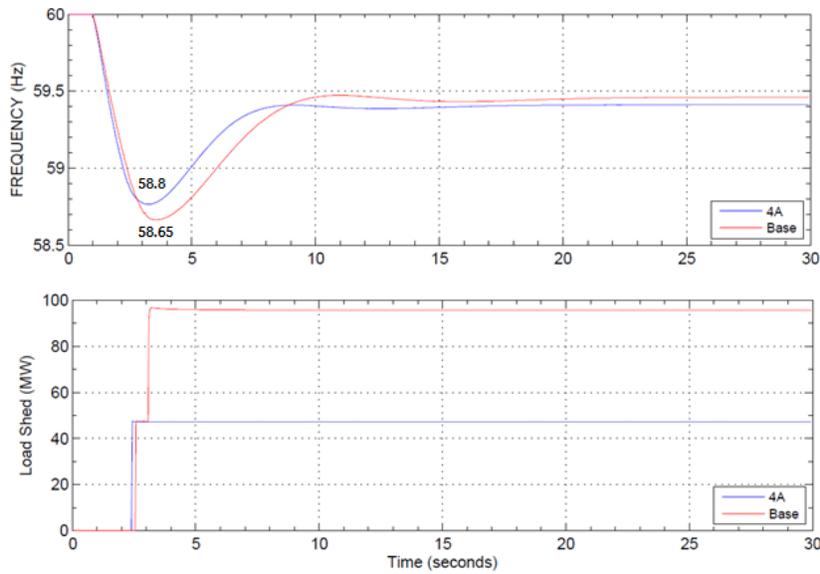


Figure 3.2 HECO Scenario 4A – Loss of AES (without frequency ride through of Dist PV)

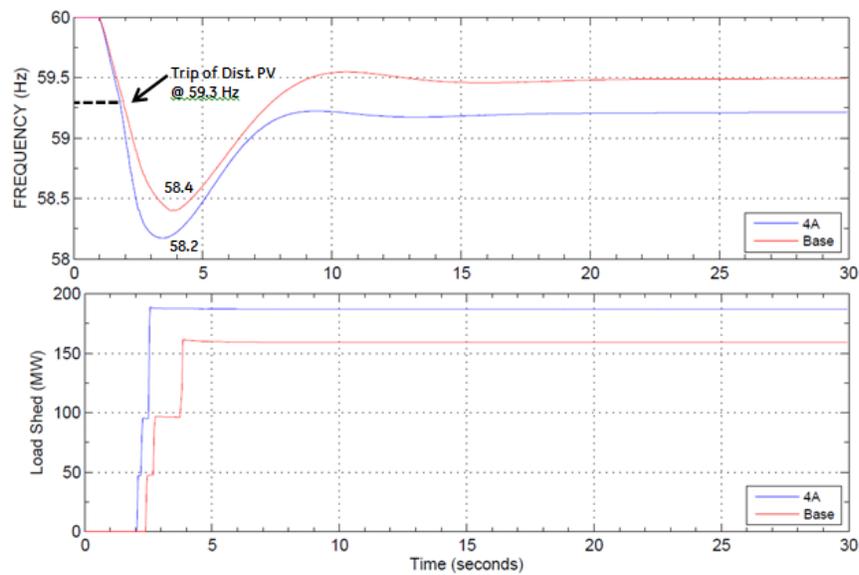
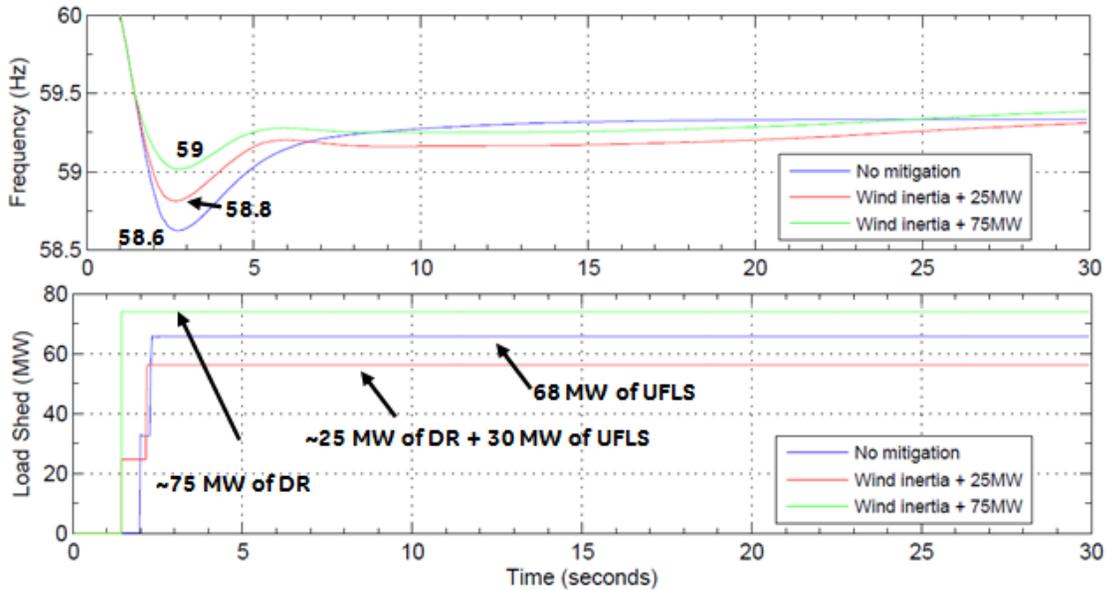
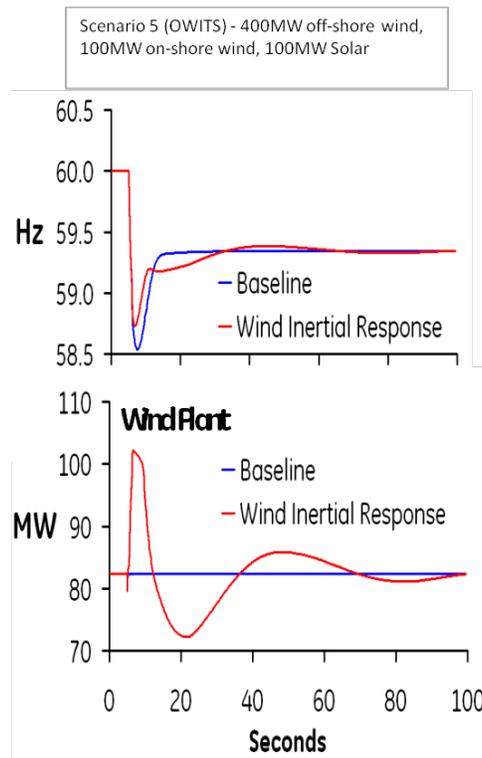


Figure 3.3 HECO Scenario 4B - Synthetic Inertia from Online Wind Plants & Frequency Responsive Load Reserves



Preventing distributed PV trips has the most beneficial effect on the frequency response. The frequency nadir without distributed PV trip is 58.1 Hz, 0.9 below the first stage of UFLS. For a safe margin, other recommendations (i.e., synthetic inertia and frequency responsive load) should also be implemented.

Figure 3.4 HECO Scenario 5 - Synthetic Inertia from Online Wind Plants



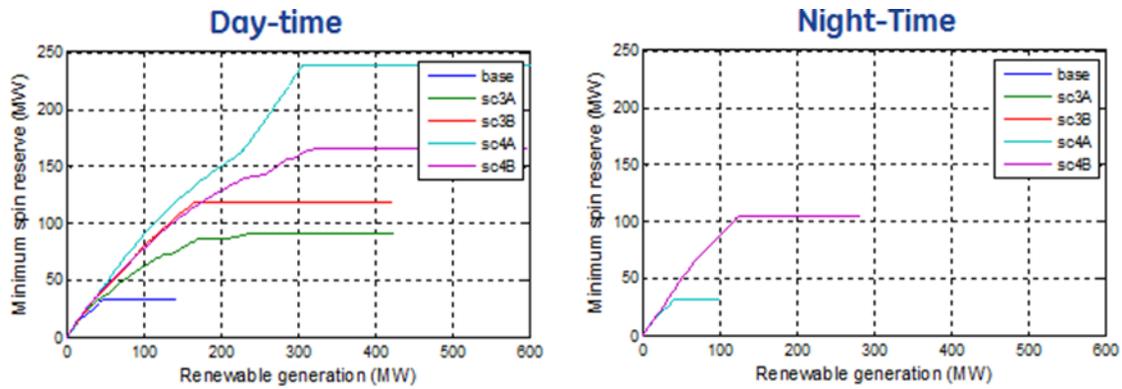
Regulation

The additional regulation reserves required to accommodate variability in wind and solar generation is given below.

Scenario 1 - HSIS Scenario 4A: Max Day-time (6am-8pm) = 239MW; Night-time (8pm-6am) = 32MW.

Scenario 2HSIS-Scenario 4B: Day-time (max) = 166MW; Night-time (max) = 104MW

Figure 3.5 HECO Spinning Reserve Requirement as a Function of Online Renewable Generation



Inter-hour results from the simulation of these scenarios confirm that the operating reserves requirement helps the system (in Scenarios 4A and 4B) to carry enough reserves to sustain the worst sub-hourly event in each hour of the year as well as to ride the system through forecast error/uncertainty. Further analysis is required to determine the economics of the existing capacity meeting the additional reserve requirement. If the existing capacity is insufficient or uneconomic, then other means of obtaining spinning reserves (for example, from battery storage and DR) should be explored. This is further discussed in the next section on the methodology to estimate technology mix.

3.1.1.2 MECO

The following two scenarios were studied:

Scenario 1 – Maui Baseline

- 15 MW Dist Solar PV
- 0 MW Cent Solar PV
- 72 MW On-shore Wind

Scenario 2- Maui Scenario 3

- 30 MW Dist Solar PV
- 15 MW Cent Solar PV
- 72 MW On-shore Wind

Scenario 3- Heavy Intermittent Renewables Scenario

- 22 MW Biomass
- 100 MW Wind
- 100 MW PV
- 50 MW Geothermal

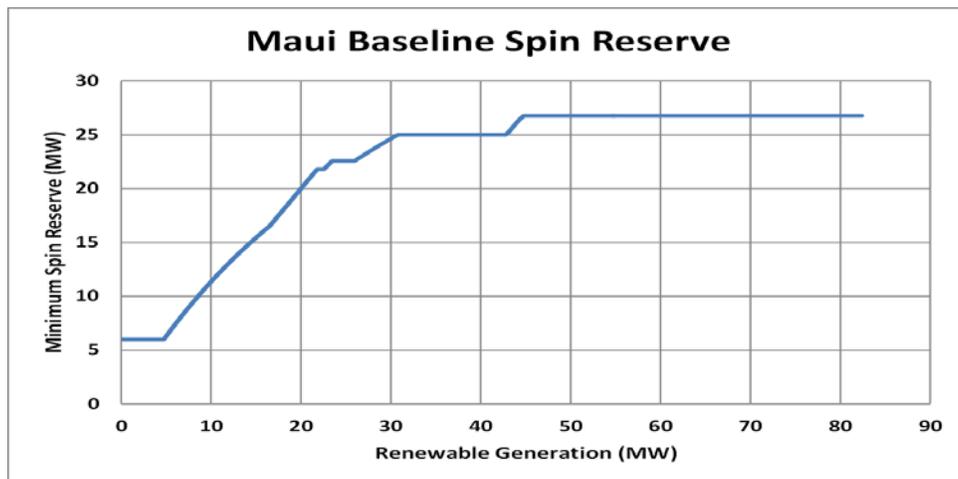
Inertia and Primary Frequency Response

Regulation

Scenario 1 & 2: As a function of forecast of wind+solar power. Max Reserves approximately 27 MW as shown in the figure.

Scenario 3: As a function of forecast of wind+solar power. Max Reserves estimated to be approximately 50 MW.

Figure 3.6 MECO Spinning Reserve Requirement as a Function of Online Renewable Generation



3.1.1.3 HELCO

The following two scenarios were studied:

Scenario 1 – Heavy Intermittent

Geothermal - 50MW

ROR Hydro - 16.85MW

Wind - 100MW

Distributed PV - 12MW

Central/Dist PV - 88MW

Biomass - 22MW

Scenario 2- Heavy Dispatchable

Geothermal - 100MW

ROR Hydro - 16.85MW

Wind - 50MW

Distributed PV - 12MW

Central/Dist PV - 38MW

Biomass - 42MW

Inertia and Primary Frequency Response

(No data available)

Regulation

(No data available)

3.1.2 Recommendations for New Ancillary Services and Interconnection Requirements

Task 1 (Part 1 study) researched the ancillary services and interconnection requirements that are currently being employed or under consideration globally. The ancillary services are as follows:

- Frequency Responsive Reserve/Primary Frequency Response
- Regulation
- Load Following
- Spinning Reserve
- Non-Spinning Reserve
- Replacement Reserves

The emerging interconnection requirements fall in the categories below:

- Power Factor and Voltage Control
- Voltage and Frequency Ride Through
- Ramp Rate Limits and Control
- Over and Under Frequency controls
- AGC Response Capability
- Inertia

It should be noted that the above-mentioned ancillary services and interconnection requirements have been employed in various parts of the world and may or may not be applicable to the Hawaii system. These ancillary services and interconnection requirements were discussed in detail in the Part 1 report. The information presented in Section 3.1.1 along with the lessons learnt from the Part 1 study on the best practices in the industry were used to determine the additional ancillary services and interconnection requirements for Hawaii. The unique characteristics of the Hawaii systems were taken into account in determining these additional ancillary services and interconnection requirements. Below is a list of the recommendations.

3.1.2.1 Inertial Response

Inertial response is very important for the Hawaii utilities since they are small islanded systems with relatively high Rate-of-Change-of-Frequency (ROCOF) due to system events. Currently, the desired inertial response from dispatchable synchronous renewable generation (RE) resources such as geothermal plants is obtained as a condition of contract. There is no synthetic inertia requirement in the interconnection requirements for Variable Generation (VG) resources such as wind and solar plants. However, recent PPAs for renewable generation have included inertia requirement.

Based on the information gathered in Part 1, it can be concluded that, at present, there is no ancillary service or market associated with inertial response anywhere in the world. Where implemented, the inertial response requirements have been through interconnection requirements. For example, Hydro Quebec⁵ requires wind power to provide an emulated inertial response. Based on the Part 1 study, we have also determined that with the current technology, it is possible for wind plants to provide synthetic inertial response, which if designed properly can help the system ride through

⁵ Hydro-Québec requires that wind plants be able to contribute to reducing large (> 0.5 Hz), short-term (< 10 s) frequency deviations on the power system, as does the inertial response of a conventional synchronous generator whose inertia constant (H) equals 3.5s

frequency events. Therefore, we recommend synthetic inertia capability for future utility-scale wind plants. The parameters for synthetic inertia (deadband, active power contribution, duration of response, maximum generation reduction etc.) should be designed to meet the Hawaii system requirements. The utilities should also perform offline studies to determine the impact of synthetic inertia on inertial and primary frequency response and how it impacts inertia requirements from other (future) interconnecting resources, Under Frequency Load Shedding (UFLS) practices, and spinning reserve requirements. The offline studies should be used to guide for determining combinations of resources that need to be online.

3.1.2.2 Primary Frequency Response

Primary frequency control involves the autonomous, automatic, and rapid action (i.e., within seconds) of a generator to change its output to oppose large changes in frequency. Primary frequency control actions are especially important during the period following the sudden loss of generation to prevent the frequency from collapsing. Primary frequency response is provided by units that are selected to provide spinning reserves.

HECO uses spinning reserves to cover 100% of its largest single contingency (185MW). The units providing spinning reserves are on governor and AGC control. In addition, HECO also carries spinning reserves to meet the variations in load and renewable energy within the hour. These units are also on governor and AGC control and provide frequency response.

In MECO, no separate spinning reserves are carried for contingencies. The units that provide regulation are on governor and AGC control and also provide frequency response and provide spinning reserves for contingencies. The regulating reserves are a function of forecast of wind and solar generation - minimum of 6MW and a maximum of 50MW in the up direction and up to 9 MW in the down direction. Under Frequency Load Shedding (ULFS) is used to prevent the frequency from collapsing. Fast-starting offline resources are used to restore shed load.

In HELCO, the units that provide regulation are on governor and AGC control and also provide frequency response and spinning reserve. The regulating reserves are a function of forecast of wind and solar generation with a minimum of 6 MW plus up to 15 MW to account for the wind regulation. ULFS is used to prevent the frequency from collapsing. Fast-starting offline resources are used to restore shed load.

Currently, the interconnection requirements for HECO utilities require all dispatchable generators (conventional, as well as synchronous RE) to have a 4% droop that is adjustable. HECO utilities also have the capability to dispatch units to provide reserves as needed. As such, the HECO utilities currently obtain primary frequency response as a condition of interconnection.

Based on our research in the Part 1 study, Primary Frequency Response ancillary service is an emerging ancillary service that is being investigated in the U.S. mainland systems⁶. FRR (Frequency

⁶ All systems carry contingency reserves (spinning and non-spinning) to help bring the frequency to its original value after the loss of a generator or transmission line. However, having sufficient contingency reserves in itself does not guarantee adequate primary frequency response. Currently, NERC is investigating the need for Frequency Responsive Reserves to ensure adequate primary frequency response. This is because the speed of response of resources that can provide

Responsive Reserves) is already being used in the markets in Australia⁷. However, in Hawaii all the dispatchable generators are on both governor and AGC control and are already required to have fast response (100% response within 30 seconds) in emergency situations. This fact needs to be considered in determining if there is a need for an additional primary frequency response ancillary service. Also, how such an ancillary service would work in a non-market environment should be investigated.

Based on the research performed on technical capabilities of resources in the Part 1 study, wind and solar plants are capable of providing primary frequency response improving the reliability of the grid.

Our recommendations with respect to primary frequency response are as follows:

- We recommend droop control to be a part of the interconnection requirements for future utility-scale wind and solar plants in addition to this requirement for dispatchable generators.
- We also recommend that VG be compensated for providing up reserves if their generation is curtailed for the explicit purpose of providing reserves. The payment mechanism will be discussed later in the section on ancillary service procurement. We also recommend the development of tools to reliably calculate the amount of reserves that VG can provide.
- VG should be required to provide down reserves without any explicit compensation similar to other dispatchable units in the system. In many instances, using VG to provide reserves also reduces their curtailment. For example, using wind generation to provide down reserves (instead of carrying the down reserves by dispatching up a thermal generator) reduces the curtailment of wind generation. Tools to determine the amount of down reserves that VGs can reliably provide should be developed.
- VG should be required to provide up reserves without any explicit compensation when they are curtailed for reasons other than providing up reserves since their opportunity cost is zero when they are curtailed.

contingency reserve is driven by NERC standard BAL-002 requirement R4 requires that the ACE be returned to zero (or to its pre-disturbance level if its pre-disturbance level is originally negative) within 15 minutes. In FERC Order 693, FERC ordered NERC to revise its standard so that it “defines the necessary amount of Frequency Response needed for Reliable Operation for each Balancing Authority with methods of obtaining and measuring that the frequency response is achieved.” NERC is pursuing a frequency response initiative that is looking at what types of requirements are needed. A frequency responsive reserve (FRR) procedure has been proposed in a WECC whitepaper. The proposal suggests a FRR amount for all of WECC that is based on the largest credible contingency the system is prepared to deal with without activating UFLS (a 3200 MW Category C double generator contingency) allocated to each balancing authority based on peak load.

⁷ In Australia, the NEM has 6 FCAS (Frequency Control Ancillary Services) related to primary frequency response

- Fast Raise (6 Second Raise)
- Fast Lower (6 Second Lower)
- Slow Raise (60 Second Raise)
- Slow Lower (60 Second Lower)
- Delayed Raise (5 Minute Raise)
- Delayed Lower (5 Minute Lower)

- Allowing VG to provide primary frequency response as suggested above can help reduce the production cost of the system, improve the reliability and lower curtailment. It should also be noted that the above provisions are similar to those used in the ERCOT⁸ market.

3.1.2.3 Frequency Regulation Ancillary Service (Secondary Frequency Response)

Regulation is very important for Hawaii utilities unlike the mainland where shortages may only result in CPS violations and do not show up in the system frequency. This ancillary service is required to follow the changes in load, as well as renewable generation. Regulation is not only required under normal operations, but also after an event to restore the frequency after primary frequency response has been provided.

- Currently, HECO does not quantify up regulation but it is carried as part of its spinning reserve requirement. The generators selected for providing primary frequency response (that are also on AGC) provide up regulation.
- The amount of up regulation carried by MECO is a function of forecast of wind and solar generation, with a minimum of 6MW and a maximum of 50MW. 6-8 MW of down regulation is also held depending on number of CTs online.
- In HELCO, the regulating reserve requirement is determined by the anticipated near-term balancing needs, which the system operator determines by observing the variability of apparent demand (due to wind variability, solar PV) and forecasted customer demand. HELCO also carries sufficient down regulating reserve to cover largest off-peak load loss due to a single contingency.
- Currently, the interconnection requirements require all dispatchable generators (conventional, as well as synchronous RE) to be on AGC. All the existing wind contracts also include active power control (APC) provision to enable automatic curtailment.
- In Hawaii, the AGC signal is sent to generators every 4 seconds. There are two components to a generator signal: a regulation component, and an economic component. The regulation component has larger gains and more aggressive time of implementation and therefore will override the economic signals when frequency is off-normal (HELCO).

Based on the findings in the Part 1 study, markets such as California ISO are looking into a separate load-following ancillary service product to handle changes in variable generation that are sustained. However, this is an artifact of the CAISO (and other) markets where regulation is only used to handle variations in net load within the dispatch interval, typically 5 minutes. In Hawaii, regulating reserves are maintained to manage anticipated variability within the hour in the apparent demand, which includes forecast changes in load and the imbalances caused by changes in variable generation⁹. Therefore, there is no need for a separate load-following

⁸ The wind generation plants should have adjustable dead bands to match those of other conventional resources or that which is provided in the operating guides, and a similar droop to the other resources of 5%. In ERCOT, wind generators are required to provide down response all the time and up response when curtailed.

⁹ Regulating reserves are designed to meet the inter-hour variability of wind and solar. The nature of the fleet is such that there are abundant up-reserves to sustain forecast uncertainty (in load and renewables). Also, load variability in shorter time scales is smaller than the renewable variability and in the high penetration scenarios it is not at all visible. With

reserve in Hawaii. However, higher amounts of regulation reserves will be required to integrate higher amounts of variable generation as shown later through the scenarios. Variable generation resources and other emerging technologies should be allowed to provide regulation. Based on the research performed in the Part 1 study, wind plants have the capability¹⁰ to provide regulation.

Our recommendations with respect to secondary frequency response are as follows:

- We recommend AGC (ability of wind plant to directly accept and act on a maximum dispatch signal delivered by AGC) capability to be a part of the interconnection requirements for all future utility-scale generators including wind and solar plants.
- We recommend that VG be compensated for providing up regulation if their generation is curtailed for the explicit purpose of providing regulation. The payment mechanism will be discussed later. We also recommend the development of tools to reliably calculate the amount of regulation that VG can provide.
- VG should be required to provide down regulation without any explicit compensation similar to other dispatchable units in the system. Need tools to determine the amount of down regulation that VGs can reliably provide.
- VG should be required to provide up regulation without any explicit compensation when they are curtailed for reasons other than providing up regulation since their opportunity cost is zero when they are curtailed.
- Allowing VG to provide regulation as suggested above can help reduce the production cost of the system, improve the reliability and lower curtailment.

3.1.2.4 Non-Spinning Reserves

Non-spinning reserves in the form of quick start resources serve a number of purposes. Following an outage or unexpected loss of generation, diesels are initially used (offline contingency reserves) to replace lost generation and/or UFLS restoration; following this intermediate and/or more efficient generation is started to replace the diesels. Quick start units are also used to offset regulating requirements within the hour. All three utilities carry varying amounts of QS resources. No changes to non-spinning reserves ancillary services are proposed. However, faster/more contribution from non-spinning assets may help to reduce the spinning regulation reserves requirement and should be evaluated.

3.1.2.5 Black Start Service

All three utilities have a number of units with black start capability. No changes to black start service proposed.

changes to the operating practices or in baseload fleet, it maybe required to assess reserves requirement for forecast uncertainty (in net load).

¹⁰ Grid codes in Ireland and Denmark require Active Power Control (APC) for wind farms which give them the capability of responding to operator power set-point commands (equivalent to AGC)

3.1.3 Storage and Demand Response

In general, storage and demand response should be allowed to provide regulation and reserves as long as they are economical. However, the following need to be considered:

- Need to consider the interaction between DR response and UFLS since UFLS uses 75-80% of all load. The interaction of UFLS and DR must be developed and coordinated to ensure adequate protection for the UFLS system.
- The modification of PV to being required to trip on lower frequency set-points than standard IEEE 1547 trip settings, which are higher than UFLS trip settings, to mitigate loss of PV during a system low-frequency events was completed by the recent modification to Hi Rule 14h. However, there are still legacy installations that trip in accordance with IEEE 1547 and will compound the impact of unit trips. HECO uses 57.3 Hz for low frequency trip of distributed PV (not sure about other utilities). Legacy PV trips at 59.3 Hz and still must be considered in all studies. Since the 1547 standard and, similarly, Rule 14H specify in terms of a must-trip instead of ride-through, confirmation that the existing change results in the desired ride-through is important - a future change to a ride-through requirement may be necessary.
- Need to consider feeder net load for UFLS system as distributed PV increases and feeder net load decreases during some hours.

3.1.4 Changes to Interconnection Requirements

Below are the suggested changes to the interconnection requirements.

3.1.4.1 *Reactive Power and Voltage Regulation*

- Hawaii utilities have voltage regulation and control requirements for dispatchable and variable generation. No changes proposed.

3.1.4.2 *Voltage and Frequency Ride-thru*

- Hawaii utilities have voltage and frequency ride-thru requirements for dispatchable and variable generation. Utilities should develop requirements for unbalanced ride thru requirements. Unbalanced voltage capability is required in weak systems and is currently a much larger issue than LVRT since turbine manufacturers do not currently have a standard to meet and the current technology of WTG is much less than conventional generation.

3.1.4.3 *Ramp Rate Limits and Control*

- Hawaii utilities have ramp rate limits in the up direction for variable generation. Ramping requirements in the up and down direction are included as requirements for dispatchable generation. No changes proposed.

3.1.4.4 *Over and Under Frequency Controls*

- Per recommendation before, require wind and solar plants to have primary frequency response capabilities.

3.1.4.5 Inertia

- Per recommendation before, require wind plants to have inertial response capabilities.

3.1.4.6 AGC Capability

- Per recommendations before, require all generators including wind and solar plants to have the ability to accept and respond to AGC commands. Active power set-point is a current requirement for VG to enable curtailment. This would require modifications to the AGC program.

3.1.5 Fundamentals of Power System Operation

This section is intended to serve as a primer which provides a common foundation for the general terminology and concepts that will be referred to throughout the balance of this report. In addition, it is intended to provide insight into the processes and considerations that are required to leverage available power system resources to “serve the load” in the most cost effective and reliable manner. Downstream sections of this report will contain more Hawaii-specific discussion, considerations, and where possible, recommendations which reference these concepts. The “fundamentals” are outlined here and in the PowerPoint presentation for Tasks 3&4 in Appendix A.

In a power system, resources are committed and dispatched based on their ability to:

1. Directly provide energy
2. Support the reliable delivery of energy

Often, the same resource may serve both functions. The degree to which this occurs depends upon the attributes of the individual resource, resource mix, and the respective needs of the power system. To supply “energy”, a resource is primarily evaluated based on its variable cost structure:

- Startup Cost: Typically on a “\$/startup” basis. Represents the cost incurred for bringing a resource to a state where it is available for dispatch.
- Minimum Generation Cost: Typically on a “\$/hr” basis. Represents the variable cost required to sustain operation at the minimum permissible “real-power” operating level.
- Incremental Variable Cost: Typically on a “\$/MWh” basis. This represents the cost for the next incremental adjustment in the real-power set-point.

To support the “reliable delivery of energy”, a resource is considered based on additional attributes that characterize its flexibility. Examples include, but are not limited to:

- Inertial Response: Typically measured by a resource’s inertial constant “H” (in seconds). This is a normalized value that relates a resource’s kinetic energy to its respective capacity.
- Ramp-rate: Typically on a “MW/min” basis. Characterizes the rate at which a resource is able to adjust it’s real-power set-point. This rate can be set “tuned” differently dependent upon whether the need is for frequency response (i.e. FRR), regulation, (i.e. AGC), load following, spinning reserve, and/or startup periods.
- Quick-start capability: Typically on a “minutes or hours” basis. Characterizes the time-delay required for a unit that is offline or disconnected from the power system to become available for the purposes of providing energy or supporting the reliable delivery of energy.
- Operating Range: Characterized on a “real-power” and “reactive power” basis.
- Real-power range: Characterizes the range over which a resource is able to inject or consume actual “MW” to support the load on the power system.

- Reactive-power range: Characterizes the range over which a resource is able to provide “MVAR” to assist with maintaining system voltage levels.
- Minimum Operating Period:
- Minimum up-time: The minimum time for which the unit needs to be online once started
- Minimum down-time: The minimum time for which the unit needs to be offline once shutdown
- Black-start capability: Ability to start a unit without support from the grid

Determining the balance between using a resource for its “energy” vs. its ability to support the “reliable delivery of energy” often requires sophisticated algorithms. Typically, this balance is achieved through “security-constrained unit-commitment (SCUC)” and “security-constrained economic dispatch (SCED)” algorithms. For long-term power system planning, a production cost model is often leveraged to execute the SCUC and SCED algorithms. For day-to-day and week-to-week operations, similar algorithms are used in energy management system (EMS) software. The objective of the algorithms is to ensure that sufficient resources will be online (i.e. committed) to meet the anticipated load forecast (including variability) and satisfy reserve requirements in the most economical manner (i.e. lowest system cost) while observing reliability constraints. Emphasis is placed on leveraging assets with the lowest variable operating costs. More expensive resources are only selected if their flexibility is required to ensure reliable delivery of the energy, relieve system constraints, or they benefit increased renewables penetration, etc.

Once a resource is “committed”, the “security-constrained economic-dispatch” algorithms are then utilized to obtain a resource’s load set-point (i.e. “dispatch-point”). To achieve a solution, these algorithms attempt to “park” all committed resources at the same incremental variable cost (additional details in following slides). Typically, the “most-economical” manner for operating the system is for all committed resources to be dispatched to the same “incremental variable cost” (provided the resource is not at the extremes of its operating range). This is referred to as “economic dispatch”. The resource which will provide the “next most economical MW” is referred to as the marginal unit. And, at that instant, the “system marginal cost” is equivalent to the incremental variable cost of that resource. Often, there are multiple units “on or near the margin”.

To satisfy the reliability needs of the power system, it is often necessary to adjust the dispatch of the resources away from their economic optimum set-point. This movement creates additional “headroom/legroom” and increases the available reserves to satisfy system requirements. To ensure that these adjustments are made in the most economical manner, a process referred to as “co-optimization” is often deployed. This process assists in identifying which resources to adjust, and by how much. Specifically, it attempts to minimize the “opportunity costs” associated with moving a resource away from its economic optimum to meet the reliability needs of the system.

The concept of using opportunity costs to rank/prioritize resources and make system-level trade-offs between energy vs. ancillary capability is still applicable regardless of whether an explicit payment is made to the resources for their ancillary participation.

Typically, ancillary service needs are “best-served” by marginal resources. This is driven by the fact that they often have the lowest opportunity cost for providing the service. For example, a wind farm¹¹ typically has a very low variable operating cost. Curtailing the wind for the specific purpose of providing an ancillary service would [typically] result in very high opportunity cost (for both the plant and the power system). However, during periods where renewables are curtailed, due to must-run resources and/or corresponding over-supply, allocation of ancillary services to the renewables would likely be very cost-effective. In situation where renewables are not curtailed, selecting a combustion turbine or storage device¹² would likely result in lower opportunity cost and lower system cost.

¹¹ In Hawaii, during off-peak periods, wind energy contract prices can be higher than the variable cost of other thermal generation. For these circumstances (and while wind contracts do not separate fixed & variable costs), curtailing wind for the purposes of providing ancillary services may be recommended.

¹² Storage devices are unique. Such resources are often “energy-neutral” (i.e. zero net-output on a nominal basis). As a result, storage devices do not have an “opportunity cost” per se. The variable cost to provide ancillary services from a storage device is typically driven by the cost to initiate the device's operation (i.e. startup) and the corresponding variable O&M during operation. As a result of their energy-neutral / zero-opportunity cost, storage devices are typically prioritized ahead of other resources for providing ancillary services.

The following illustrations are intended to provide further clarification on some of the key tools and concepts that were discussed in this section. Specifically, Figure 3-7 and Figure 3-8 illustrate the calculations for opportunity costs and co-optimization. The accompanying PowerPoint presentation in Appendix A has additional details on production cost modeling, average vs. incremental variable cost, and economic dispatch.

Opportunity Cost

(Example shown for a Generating Resource)

- Economic Dispatch would indicate "Unit 1" should be providing 100 MW (full-output).
- Consider "Unit 1" for 20 MW of upward regulation service.
- The opportunity cost of moving 20 MW from providing "energy" to serve the "ancillary" needs is characterized as:

| | |
|-------------------|-----------|
| Providing 100 MW: | \$8000/hr |
| Providing 80 MW: | \$5600/hr |
| Difference: | \$2400/hr |
- Normalizing the \$2400/hr by the 20 MW, results in an opportunity cost of **\$120/MWh**.
- Resources with the "lowest opportunity cost" should be the 1st resources selected to migrate from providing energy to serve the ancillary needs of the system.
- In many locations, the opportunity cost of the "last resource" required to provide the ancillary service will set the "ancillary clearing price".

Providing 100 MW (Energy-only):

- Revenue (proxy) = (\$200/MWh) * (100 MW) = \$20000/hr
- Cost = (\$120/MWh) * (100 MW) = \$12000/hr
- Profit (proxy) = \$8000/hr

Providing 80 MW (Energy + 20 MW Regulation "stand-by")

- Revenue (proxy) = (\$200/MWh) * (80 MW) = \$16000/hr
- Cost = (\$130/MWh) * (80 MW) = \$10400/hr
- Profit (proxy) = \$5600/hr

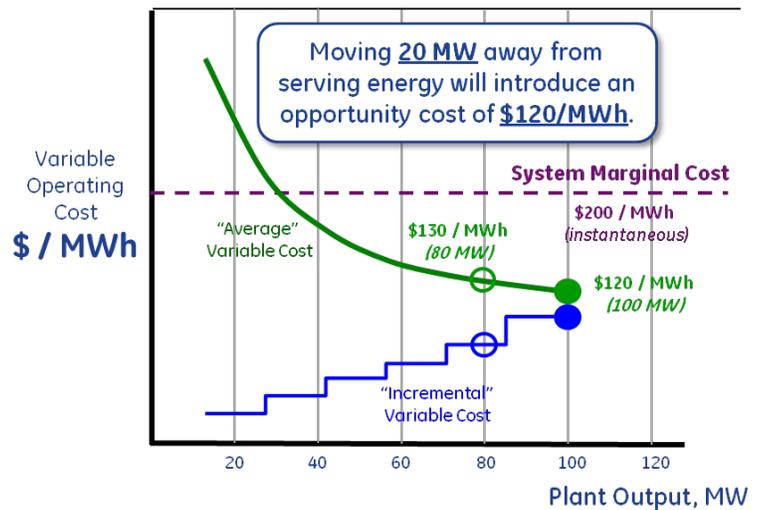


Figure 3.7 Opportunity Cost illustration

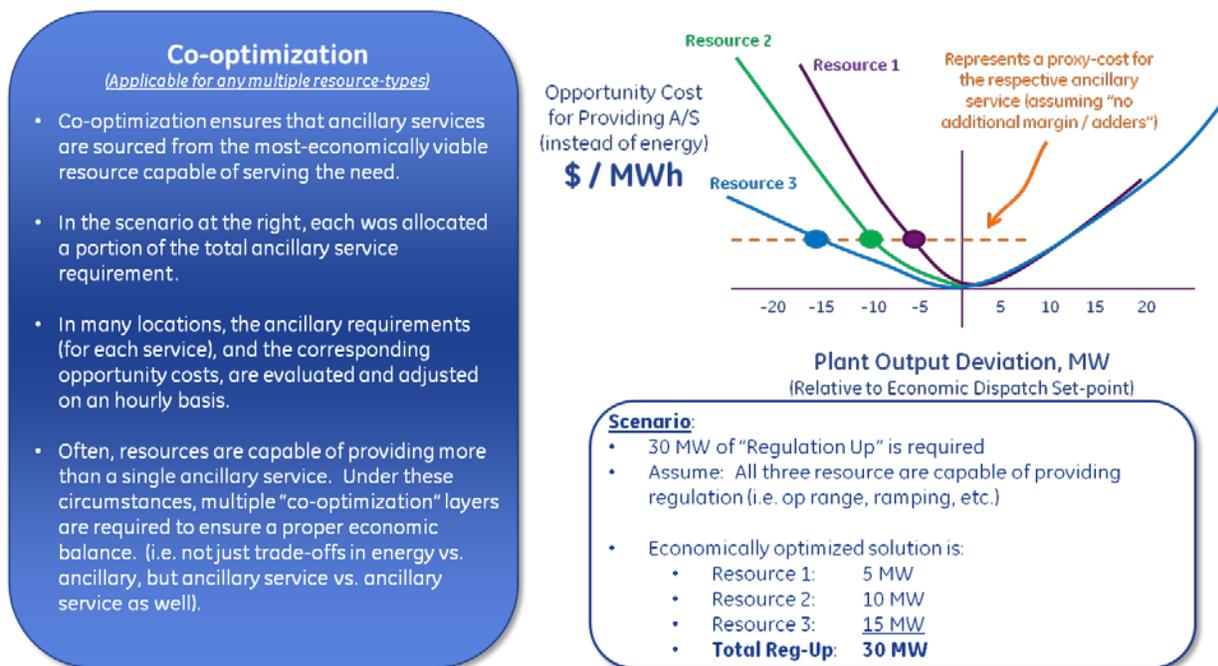


Figure 3.8 Co-optimization illustration

In an effort to place the preceding material in context, the accompanying PowerPoint presentation provides some HECO-specific perspective on the opportunity cost associated with migrating a resource away from providing energy and into ancillary participation. For the following example, which is an excerpt from the PowerPoint in Appendix A, we'll be assuming an instantaneous marginal system level cost of \$190 / MWh.

Figure 3.9 shows the instantaneous opportunity cost for ancillary service for HECO based on the data available in the HSIS study. Figure 3.10 shows the Opportunity cost as the deviation from the economic dispatch set-point is increased for the HECO units.

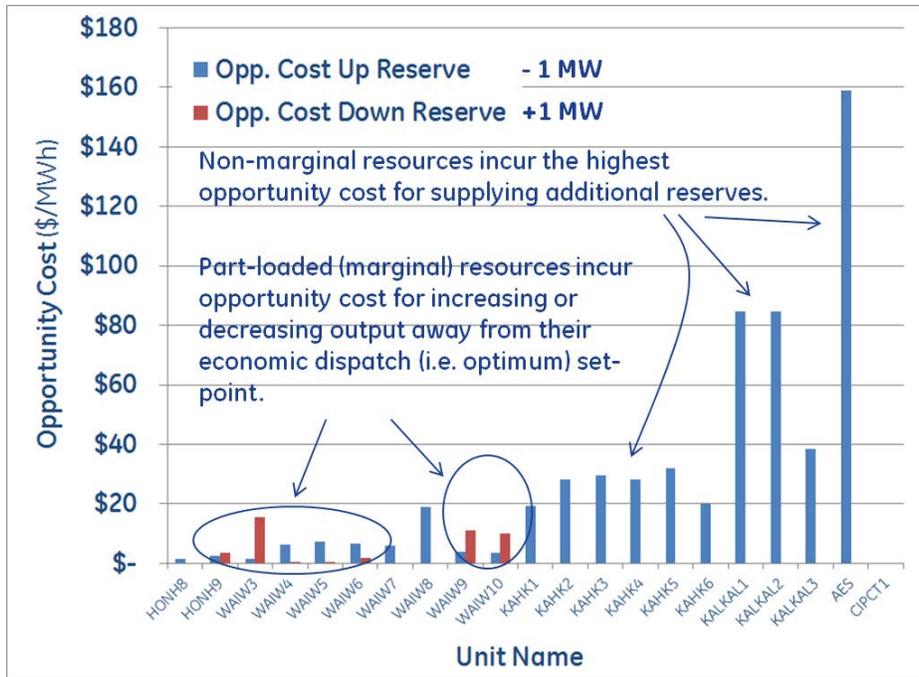


Figure 3.9 Instantaneous opportunity cost for shifting capability from energy to A/S

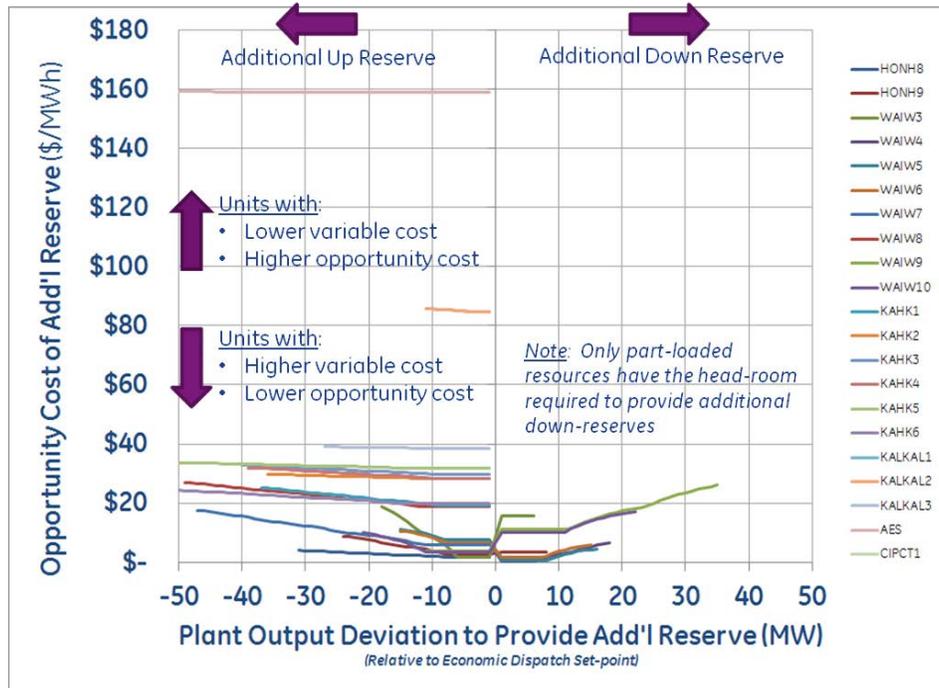


Figure 3.9 Opportunity cost as the deviation from the economic dispatch increases

3.1.6 Process for Evaluating and Selecting a Potential Future Technology Mix

This section outlines a methodology that can be exercised during a resource planning process to evaluate and assist with the selection of a future technology mix that is compatible with the system-level interconnection and ancillary service requirements. Specifically, the methodology focuses on minimizing the overall production cost and capital expenditure required to obtain a “least-cost” portfolio while observing system reliability needs. Additional consideration is given to parameters which are more difficult to quantify economically, such as propensity for a given portfolio to improve future renewables penetration and/or reduce risk exposure.

Using HECO Scenario 4A (as an example), each of the steps outlined in the above-mentioned process will be placed in context (see PowerPoint in Appendix A). It should be noted that many options are available to fulfill any observed ancillary service deficiencies, such as: new generation, energy storage, demand response programs, transmission technologies, and existing generation modifications/retrofits. To ensure that an optimal (economic, risk, environmental) solution is achieved, it is recommended that a series of options be developed and analyzed via the following process.

Due to the complexity of the simulations required to generate the data that would be required to perform this analysis, the following process will not be able to be demonstrated in its entirety. A separate study would be required to calibrate a suitable simulation and fully execute the process.

The process is outlined here and in the PowerPoint presentation for Tasks 3&4 in Appendix A.

1. **Identify Current or Future Scenario:** Begin with an established current or future scenario. It is assumed that the resource-specific variable cost characteristics (i.e. heat rate curves, variable O&M cost, startup costs), min-up/down times, ramp-rates, storage capacity, DR availability/activation thresholds, and system-level future economic scenario (i.e. fuel cost/availability, system load forecast, etc.) are known values.

To provide a comprehensive evaluation, it may be necessary to perform an uncertainty analysis of the key parameters which influence the characterization of a given future scenario.¹³ The results of the uncertainty analysis would yield the relevant bounds for each key parameter. With the uncertainty bounds understood, a matrix of the desired evaluation conditions for a parametric sensitivity analysis could be established. This process would be executed for each evaluation condition to ensure a robust analysis of the potential resource mix.

¹³ A contemporary example of why the up-front uncertainty analysis would be beneficial is the increased adoption of distributed solar PV on the Hawaiian islands. The increase in the use of distributed solar PV has a tendency to change the system load forecast (i.e. net-load shape) which will be served by the centralized resource technologies targeted by this report. Without an uncertainty analysis, an inaccurate representation of the load forecast could result; this would have the potential to drive a sub-optimal resource mix.

Similar uncertainty analysis of the resource-specific variable cost characteristics, operability constraints, storage/DR characteristics, fuel cost/availability, etc. may be required to develop a robust evaluation matrix to guide the sensitivity analysis.

2. **Obtain Production Cost Simulation:** Obtain a production cost simulation that is capable of performing security constrained unit commitment (SCUC) and security constrained economic dispatch (SCED)
 - a. The production cost simulation (or post-processing algorithms) should be capable of analyzing intra-hour behavior to fully evaluate the ancillary service performance.
 - b. Simulation needs to be able to “co-optimize” the energy and ancillary services.
3. **Estimate required “system-level” amounts for each ancillary service:** Assess/anticipate the required amount (and minimal level of acceptable responsiveness) that is required for each ancillary service. Provide these ancillary requirements to the production cost simulation and corresponding post-processing algorithms. These ancillary requirements will be interpreted as constraints by the simulation so that it can reserve the respective ancillary capability from each of the available resources. Note: Iteration will be required to optimize.
4. **Identify “resource-level” ancillary service capability:** Identify the amount of each ancillary service that can be performed by each resource. This establishes the subset of the respective resource’s capability that could be allocated to the given ancillary service. Items such as operating range, startup times, ramp-rates, min-up/down times, inertial response, black start capability, etc. are key considerations.
5. **Execute the Production Cost Simulation:** Execute the production cost simulation for the respective scenario. Review the hourly (and sub-hourly data as applicable) to ensure that all ancillary services requirements (plus other relevant system constraints) were observed. i.e. sufficient system-level regulation, spinning reserve, etc. was reserved.
6. **Identify Trends in the Results:** If the ancillary service requirements were not successfully achieved, or it appears that excess ancillary capability is available, consider the trends in the deficiencies (or excess):
 - a. Are the deficiencies (or excess) driven by inadequate responsiveness from the available resources?
 - b. Are the deficiencies (or excess) driven by inadequate operating range?
 - c. Are the deficiencies (or excess) present in all hours or only some hours?

7. **Consider potential solutions to alleviate deficiencies and improve system efficiency.** To assist in identifying solutions, consider the trends in the deficiencies (or excess):

Adjustments to operating procedures:

- Adjusted minimum run-times
- Relaxed qualifications/requirements for respective A/S participation
- Activation thresholds for DR,
- storage device charging procedures
- Relaxed “must-run” rules

Retrofits of existing resources:

- Increased plant output
- Improved turndown on thermal units
- Elevated ramp-rates
- Reduced start times
- Synthetic inertia & governor response from renewables

New resources:

- Fossil
- Storage
- Demand response
- Renewable assets
- Inter-island connectivity

8. **Evaluate the economic viability of each potential solution:**

- a. Consider/evaluate the change in total cost required to serve the anticipated system load profile.
- b. Potential for the respective solution to facilitate the desired trajectory of renewables penetration over-time.

9. **Perform a cost-benefit analysis:** This analysis evaluates the year-over-year (YOY) system-level benefit (typically in the form of reduced production cost) of the proposed solution relative to the capital cost required to achieve the respective solution. Rank the solutions according to their economic viability (i.e. NPV, IRR, etc.)
10. **Evaluate the risks associated of each potential solution:** A comprehensive risk assessment of the potential options should also be conducted and weighted against to the economic viability to ensure that the selected solution is robust and reliable:

Potential Risks to consider (not limited to the following):

- Inadequate response from renewables due to instantaneous availability
- Available down-reserves and stable operating region of thermal units during loss of load events
- Voltage/VAR support sufficiency
- Reductions in inertial response capability
- Unfavorable impacts to “system-level” variable cost of operation
- Impact to existing utility / IPP contracts may require modifications to accommodate schedule changes
- Challenges associated with monitoring / controlling DR participation on a centralized basis

3.2 Task 4: Outline considerations for specifying and acquiring A/S

3.2.1 Procuring Ancillary Services – Overview of Approaches for Obtaining, Compensating, and Incentivizing

This section puts forth some potential approaches and mechanisms which can be used to obtain, compensate, and incentivize resources for providing ancillary services. The following four approaches will be highlighted in this section:

1. Market Clearing Price
2. Reimbursement of Offer Price
3. “Make-whole” Compensation
4. Condition of Interconnection

The above listing is not intended to be exhaustive; however, the GE team believes that it contains a representative subset of the most viable techniques which could be considered. Further, it should be noted that each option is not mutually exclusive and may incorporate aspects of the surrounding approaches.

Method #1: Market Clearing Price

The Marketing Clearing Price approach is leveraged primarily by wholesale power markets. For this method, each resource submits (or is assigned) an offer price for the respective ancillary service. Most often, resources submit offer prices that are based on their opportunity cost to reserve the headroom or legroom required to provide the service. Some resources, such as storage devices, do not have an opportunity cost because they do not directly provide energy. Instead, their offer price may be based on startup, variable O&M, charging costs, or other expenses associated with providing the respective A/S.

In addition to the cost to provide the service, many markets allow resources to include “additional margin” in their offer price. In some cases, the resource may use to the additional margin to hedge against increased variable O&M costs (i.e. cycling wear & tear). In other cases, the resources may simply leverage the additional margin to cover “cost uncertainty” and/or attempt to enhance their ancillary profitability.

In some markets, the offer price is capped. The cap is often derived by calculating the cost for a unit to provide the service and adding [up to] a maximum allowable margin. The lesser of the submitted price and the capped price is then used as the offer price in the market clearing algorithms.

The “market clearing price” for the ancillary service is driven by the offer price of the last rank-ordered¹⁴ resource required to satisfy the system-level ancillary requirement (for the respective ancillary service). For this approach, all participating resources will receive the “same price” for the

¹⁴ A “low to high” ranking of the offer prices for each participating resource.

given period (typically 1-hour increments).¹⁵ To incentivize “no risk” participation, some markets will compensate for “actual incurred” costs which are larger than the revenues derived from the ancillary market clearing price via “make-whole” payments. This ensures that resources are “no worse off” for having provided ancillary services.

Due to the fact that all participating resources receive the same price for a given ancillary service, it is important to note that most resources, with the exception of the marginal ancillary resource, will earn a financial benefit (i.e. profit) for providing the respective A/S.

Method #2: Reimbursement of Offer Price

The Reimbursement of Offer Price is an alternative that could potentially be leveraged between two contracting parties seeking to enter into a bilateral agreement for A/S. It is a logical compromise between the “market clearing price” and “make-whole compensation” approach. Instead of a “clearing price” for the ancillary service, each resource is compensated on an individual basis for providing the service. The offer price for each resource would likely be derived in a similar fashion to the Market Clearing Price methodology. Specifically, the resource’s “cost to provide + margin” (including opportunity costs) would serve as a rational basis for the offer price. If the agreement is between a utility and IPP, the offer price could be based on the anticipated production cost savings for the utility. The final ancillary service price would be based on a negotiated value between the respective parties.

The period for which this contractually agreed to price is valid could be varied (i.e. hourly, daily, monthly, annually, or simply set at a constant rate for contract period, etc.). Similar to the Market Clearing Price approach, it is recommended that the Reimbursement of Offer Price incentivize participation by providing a “no-risk” contract architecture through the reimbursement of “actual incurred” costs (i.e. if incurred costs are higher than the compensation that would be derived via the offer-price).

Due to the fact that resources are compensated on an individual basis, profitability (for the resource providing the service) is limited to the margin included in the offer price.

Method #3: Make-whole Compensation

The Make-whole Compensation approach is another alternative that could potentially be leveraged between two contracting parties seeking to enter into a bilateral agreement for A/S. Most wholesale markets include “make-whole compensation” provisions in their architecture. This method extracts the “spirit & intent” of those provisions. At its core, the rationale for “Make-whole Compensation” is to explicitly compensate participating resources for their costs (including opportunity costs) associated with providing A/S. This method is designed to make the participating resource indifferent toward providing ancillary services. Instead of negotiating an offer-price, the resource-specific cost

¹⁵ In many wholesale markets, there exists both a day-ahead clearing price and a real-time (or supplemental) clearing price (as-required) to ensure sufficient ancillary availability.

structure would be shared between the contracting parties so that an accurate assessment of incurred costs could be obtained.

Due to the fact that resources are compensated on an individual basis, and only for their cost to provide the service, there is no additional profitability potential for participating in A/S. For the three approaches discussed thus far, this method will typically result in the lowest overall production cost to reliably serve the load. It is important to note that while this approach adequately and explicitly compensates resources for their A/S participation, it does not incentivize that participation.

Method #4: Condition of Interconnection

It is important to note that all power systems (historical, existing, and future) require the use of certain interconnection requirements and ancillary services to ensure the system reliability is maintained. In many cases, such as with regulated utilities, the explicit compensation of resources for ancillary participation has not been required to maintain a reliable system. For this reason, the Condition of Interconnection approach was included in this list of options. The “Condition of Interconnection” approach would simply require ancillary service capability and participation from interconnecting resources. Resources would not be explicitly remunerated for providing ancillary service capability or for the associated costs incurred.

The incentive for resources to provide ancillary service capability would be driven by the accompanying right to participate in selling energy. For this type of agreement, it is implied that the participating resources would derive financial benefit from the sale of energy alone that was sufficiently large enough to cover both the cost to provide energy and the cost to provide A/S. Due to the lack of explicit compensation, the “Condition of Interconnection” approach has the potential to offer the lowest production cost of the four methods described.

3.2.2 Forward Planning Approach to Derive Rational Ancillary Service Contract Prices

Much attention has been focused on obtaining ancillary services from resources with the lowest offer price and/or lowest “cost to provide” (including opportunity costs).

One potential method for assessing the basis of a “rational” ancillary service offer price would be to leverage a production cost simulation with the capability to co-optimize energy and ancillary services. For a given future scenario, with a known resource mix, the simulation could be exercised and evaluated at both a resource-level and a system-level to draw conclusions about a rational offer price for the respective resource:

- At a **resource-level**, the results of the simulation could be interrogated to identify the perceived cost (including opportunity cost) for each resource to provide a given ancillary service. To develop an offer price, the hourly observations for each resource could then be aggregated and averaged over a period that aligned w/ the desired contractual period.

- At a **system-level**, the simulation could be exercised by individually enabling / disabling the respective ancillary service capability for each resource under consideration. The resulting benefit (i.e. “reduction”) in the overall annual production cost could be used as a basis for assessing the ancillary service offer price for each particular resource.

To adequately bound the offer price, it is recommended that both the resource-level and system-level assessments be conducted.

3.2.3 Hawaii-specific Ancillary Service Procurement

On Hawaii, ancillary services are presently obtained from dispatchable resources through a method which is similar to the previously mentioned “Condition of Interconnection” approach. Specifically, the utilities have the ability to dispatch resources to provide ancillary services without explicit compensation to the respective resources. Going-forward, there will be a continued desire to increase the penetration of renewable resources on the Hawaiian system which has the potential to increase the system-level ancillary service requirements. As the system-need for ancillary services increases, it may be necessary to incentivize new resources to provide (or existing resources to expand upon) their ancillary service capability. This incentive could likely come in the form of explicit financial compensation and include aspects of either the “make-whole compensation” or “reimbursement of offer price” methods. However, it should be noted the use of these methods has the potential to increase the overall production cost as a result of the explicit compensation for [some of/all of] the ancillary services. Careful consideration is required before introducing such remuneration methods or unbundling the ancillary services.

As outlined in the technology table (Part I, Task 2), renewable resources (i.e. wind/solar) are capable of providing many ancillary services. The use of these resources for providing A/S may help to facilitate their increased penetration and potentially reduce production costs as it introduces another degree of freedom for commitment & dispatch. Current RFP’s and draft PPA’s are seeking to leverage this capability from VG resources. Relative to the current environment, in which dispatchable resources are not explicitly compensated for fulfilling the system-level ancillary obligations, requiring the wind/solar to provide ancillary services via the “Condition of Interconnection” approach would certainly be considered as an equitable option. Due to the fact that wind/solar resources are presently compensated based on their energy contract price, which likely includes some fixed and capital cost recovery, there are periods when wind/solar are more expensive to operate than some non-renewable resources on the system (i.e. periods where the energy contract price is higher than the marginal system cost). During these periods, it may result in a system level production cost savings to curtail wind/solar to provide ancillary services. However, the existing wind/solar contracts have provisions which preclude the curtailment of these resources for economic reasons. Therefore, during periods where wind/solar are curtailed exclusively for the purposes of providing ancillary services (i.e. up-reserves), the use of “Make-whole Compensation”, to explicitly compensate for costs (including opportunity costs) associated with providing ancillary services, would be recommended. It should be noted that the existing wind/solar contracts purposefully prevented curtailment for economic reasons in an effort to maximize renewable penetration. Therefore, to adopt the previous recommendation, an adjustment to the existing contracts would likely be required.

Energy storage devices have the potential to enhance penetration of renewable resources and/or lower the overall production cost. The process for “Evaluating and Selecting a Potential Resource Mix” developed in Task 3 and discussed earlier, could be leveraged to help quantify these potential benefits. Due to the fact that energy storage resources are energy-neutral and operate exclusively for the purposes of providing ancillary services, the use of “make-whole compensation” is not applicable (i.e. storage resources have no opportunity costs). Therefore, an explicit remuneration method, such as “Reimbursement of Offer Price” may be required to incentivize the development & participation of energy storage resources to supply ancillary services. To obtain a value for the ancillary services offered by the energy storage resources, it is likely that the previously mentioned “system-level” use of a production cost simulation would be required. Specifically, the simulation could be exercised by individually enabling / disabling the respective ancillary service capability for each resource under consideration. The resulting benefit (i.e. “reduction”) in the overall annual production cost could be used as a basis for assessing the ancillary service offer price.

Ancillary service participation from DR, transmission, and retrofit options have the potential to reduce production costs, improve renewables penetration, and avoid/defer/attenuate major capital expenditure. Similar to energy storage resources, an explicit compensation method would likely be required to incentivize participation from DR and/or transmission-related technologies. To incentivize the modification (i.e. retrofit) of existing resources to provide, or expand upon, their ancillary service capability, further use of explicit compensation may be required to cover upgrade costs.

It should be noted that some resources have the potential to increase (or decrease) the required amount of ancillary services on the system. Further, some resources have the potential to provide more ancillary capability than other resource types. In some cases, such as wind/solar, an individual resource has the potential to increase the required amount of ancillary services on the system. However, these resources also have [typically] low variable operating cost and have the potential to reduce the overall production cost for the system. As a result, it is not recommended that individual resources, which induce additional ancillary obligations on the system, be additionally penalized. Instead, it is recommended that the impact on overall consumer cost (including total ancillary services costs), coupled with other policy-related directives such as renewable penetration targets, be used as the metric to assess the viability of a particular resource.

3.2.4 Risk Considerations

The process and methodologies developed in this study can help promote a least-cost portfolio of resources to supply ancillary services and interconnection requirements that attempt to protect reliability, maximize renewable output and minimize energy costs. The process to specify technologies for ancillary resources is outlined in Task 3. The technology combination is not unique.

For each scenario, the risks associated with the recommended ancillary services and potential technology mix may include:

- Hawaii specific resource costs and economics should be considered in any least cost planning exercises. Task 3 outlines the system operation cost considerations and the capital costs can be accounted for in resource planning and/or competitive resource solicitations.
- New/emerging technology availability such as batteries should be considered in future plans to account for potential difference in time of ancillary server requirements and technology implementation timeline.
- Ability to uprate/upgrade existing resources to provide additional capacity, energy and/or ancillary services must be considered. For instance, an existing resource may not have physical space to uprate or may not be able to permit increased capabilities.
- Fuel availability and fuel infrastructure will dictate the ability to get certain fuels to the resources. While build out of the fuel delivery systems should be considered in the total system planning to accommodate increased need due to load growth or change in purpose, potential for interruptions in emergency situations should also be considered along with the ability to provide ancillary services. Production and delivery of biofuels may also need to be considered along with more traditional oil and natural gas.
- Wind and solar forecasting should be implemented in system operations to more accurately predict when these resources will be available. And in the case of wind, energy production must be available to provide frequency response and down regulation.
- Interconnection costs of the resources should be considered if new resources are being added to provide ancillary services.
- Inter-Island transmission connections, if in place, can be used to provide ancillary services between islands, but must be monitored for flow and outages to ensure that service is not interrupted. A minimum amount of certain ancillary services should be specified locally, as is the case is in other island/peninsular systems such as Long Island, in case the inter-island transmission connection is lost.
- Demand-side participation and programs can be used to provide certain ancillary services, like operating reserves, but the grid operator needs to have control over those resources on a centralized basis. Preferably via physical control such as demand response switches.
- Load shaping programs such as electric vehicle charging schedules, may be implemented to help shape the system load and thereby make planning for ancillary service deployment easier.
- Inadequate response from renewables due to instantaneous availability
- Available down-reserves and stable operating region of thermal units during loss of load events
- Voltage/VAR support sufficiency
- Reductions in inertial response capability
- Unfavorable impacts to “system-level” variable cost of operation
- Impact to existing utility / IPP contracts may require modifications to accommodate schedule changes such as with must run units

Additional details on the individual “technology-specific” risks are included in the PowerPoint Presentation in Appendix A which accompanies this report.

4 References

- [1] NREL: National Renewable Energy Laboratory, Renewable Electricity Futures Study (Vol. 4 of 4), Bulk Electric Power Systems: Operations and Transmission Planning, 2012
- [2] NERC: North American Electric Reliability Corporation, Special Report: Potential Reliability Impacts of Emerging Flexible Resources, November 2010
- [3] NREL: National Renewable Energy Laboratory, Operating Reserves and Variable Generation, August 2010
- [4] Kirby, B., Proposed Ancillary Services, October 31, 2011
- [5] Kirby, B., Ancillary Services: Technical and Commercial Insights, July 2007
- [6] NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011
- [7] Hawaii Reliability Standards Working Group, Glossary of Terms, Version 1 – 2012, Docket No. 2011-0206
- [8] NERC: North American Electric Reliability Corporation, NERC IVGTF Task 2.4 Report: Operating Practices, Procedures, and Tools, March 2011
- [9] Black & Veatch, Cost and Performance Data for Power Generation Technologies, February 2012
- [10] US Energy Information Administration (EIA), Annual Energy Outlook (AEO), Energy Market Module (EMM), 2011
- [11] Gas Turbine World (GTW), Performance Specifications, 2012 Edition, Volume 42
- [12] Bechtel Corporation, Concentrated Solar Thermal Plants Downstream of the Solar Field – Design/Optimization of the Associated Power Generation Cycle
- [13] Power Engineering, Hydroelectricity: The Versatile Renewable, June 1, 2009
- [14] GE Energy, Western Wind and Solar Integration Study, Prepared for National Renewable Energy Laboratory, May 2010
- [15] Oak Ridge National Laboratory, National Hydropower Association, Hydropower Research Foundation, Summary Report on a Summit Meeting: Pumped Storage Hydropower, September 2010
- [16] Renewable Northwest Project, Summary Report on Coal Plant Dynamic Performance Capability, August 2010
- [17] GE Energy (Miller, N., Leonardi, Bruno), New York Independent System Operator, Feasibility Evaluation of Energy Storage for Black Start Services on the NYISO System, December 16 2011
- [18] Milligan, M., Kirby, B., Utilizing Load Response for Wind and Solar Integration and Power System Reliability, Presented at WindPower 2010, Dallas, Texas, May 23–26 2010
- [19] Hawaii Renewable Energy Development Venture Technology Assessment - Grid Energy Storage Systems (<http://www.hawaiiirenewable.com/wp-content/uploads/2009/12/16.-Energy-Storage.pdf>)
- [20] Pratt, Rob (Pacific Northwest National Laboratory), Najewicz, Dave (GE Appliances), Opportunities for Mass Market Demand Response to Provide Ancillary Services, October 2011
- [21] Raslter, Dan (EPRI), Akhil, Abbas (ERPI), Gauntlett, Dave (AECOM), Cutter, Eric (E3), Energy Storage System Costs 2011 Update Executive Summary - Presented to Storage System Suppliers, February 22 2012
- [22] Freund, Sebastian (GE GRC), Shu, Mark (GE Energy), Stoffer, Bart (GE Energy), 2010 insights: Grid-base energy storage, January 19 2011
- [23] Young, Russell (GE Energy), Manz, Devon (GE Energy): Utility Energy Storage, 2010

- [24] Federal Energy Regulatory Commission, Assessment of Demand Response & Advance Metering, Staff Report, February 2011
- [25] http://www.ercot.com/content/gridinfo/etts/flywheel/presentations/PSWG_meeting_082410.pdf
- [26] [http://www.beaconpower.com/files/Beacon Power presentation ESA%206_7_11_FINAL.pdf](http://www.beaconpower.com/files/Beacon_Power_presentation_ESA%206_7_11_FINAL.pdf)
- [27] DOE, Office of Energy Efficiency and Renewable Energy: 2010 FUEL CELL TECHNOLOGIES MARKET REPORT, June 2011

5 Appendix A: Power Point Presentation

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Ancillary Services Definitions & Capability Study Part 2, Task 3-4, Final Report

December 19, 2012

Prepared by: GE Energy Consulting

Prepared for: Hawaii Natural Energy Institute (HNEI) and Hawaii Reliability Standards Working Group (RSWG)



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Study Background and Objectives

Ancillary Services Def. & Cap. Study

Overview of Study

Purpose:

Study sponsored by HNEI with support and guidance from Hawaii RSWG to identify, define, and quantify ancillary services required to support new generation (including renewable generation) for bulk power systems and particularly the Hawaiian islands.

Objectives:

- Define a standardized set of ancillary services along with their associated definitions (in functional, performance based terms) that can be used to meet the operational needs of Hawaii and other bulk power systems.
- Technologies (generation, transmission, storage, and demand response (DR)) will be assessed for their ability to support the respective ancillary services to maximize the diversity and optionality for ancillary service acquisition and delivery.
- Identify the physical requirements of the ancillary services needed for each Hawaiian island (Oahu, Maui, Big Island)
- Outline considerations for specifying / acquiring ancillary services for the Hawaii grids that protect reliability, incent renewable generation, and minimize production costs.

Introduction

Ancillary services & additional functions required for power system operation

- **Ancillary services*** are those functions performed by the equipment and people that generate, control, transmit, and distribute electricity to support the basic services of generating capacity, energy supply, and power delivery. They are required to maintain reliable operations of the electric power system.
- In addition to ancillary services, other **interconnection requirements** are placed on resources to ensure reliable operation of the grid
- These ancillary services and interconnection requirements enable the system operator to meet the required operations **reliability standards** set by NERC.
- The ancillary services, interconnection requirements, and reliability standards are dependent on the characteristics of a power system.

** FERC defined ancillary services as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."*

Key Terminology

Key Terminology

The following definitions are relevant throughout the content of this presentation and should be interpreted as described below:

Area Control Error (ACE): The instantaneous difference between a Balancing Authority's net actual and scheduled interchange, taking into account the effects of Frequency Bias and correction for meter error. *NERC Glossary (2008)*

Conventionally, $ACE = (NIA - NIS) - 10B (FA - FS) - IME$, where:

- **NIA** is the algebraic sum of actual flows on all tie lines.
- **NIS** is the algebraic sum of scheduled flows on all tie lines.
- **B** is the Frequency Bias Setting (MW/0.1 Hz) for the Balancing Authority. The constant factor 10 converts the frequency setting to MW/Hz.
- **FA** is the actual frequency.
- **FS** is the scheduled frequency. FS is normally 60 Hz but may be offset to effect manual time error corrections.
- **IME** is the meter error correction factor typically estimated from the difference between the integrated hourly average of the net tie line flows (NIA) and the hourly net interchange demand measurement.

Due to a lack of inter-area power flows, the definition of ACE has been modified for Hawaii. Specifically, for Hawaii, $ACE = -10B (FA - FS) - IME$. This modified definition of ACE is still applicable for Hawaii as it correctly represents the fact that 100% of difference between supply and demand will manifest itself as a frequency error. *Revised definition per Hawaii RSWG Glossary.*

Key Terminology (cont'd)

The following definitions are relevant throughout the content of this presentation and are intended to provide clarification on their intended interpretation:

Automatic Generation Control (AGC): Equipment that automatically adjusts generation, storage devices, and/or responsive load in a Balancing Authority Area from a central location to maintain the Balancing Authority's interchange schedule plus Frequency Bias (i.e. ACE). *NERC Glossary (2008) with modifications to accommodate additional resource types such as load and storage devices.*

Although AGC was originally conceived as a means to provide fast (3-6 second signals) to generators, the concept of leveraging AGC to provide "MW raise/lower" commands to demand-side and storage resources is equally applicable and is in practice in some locations.

Key Terminology (cont'd)

The following definitions are relevant throughout the content of this presentation and are intended to provide clarification on their intended interpretation:

Droop Control / Governor: Droop speed control is near instantaneous means of using frequency deviations to distribute load set-point adjustments to a system of resources in a stable manner.

The magnitude of a given resource's response is proportional to the frequency deviation and typically characterized by "x%" droop. For example, a resource with operating range available will provide 100% additional output per "x%" change in system frequency. Response is typically a percentage of the resource's full-capability.⁽³⁾

Droop response can be provided by any frequency-sensitive resource.

Resource: A resource may consist of any generation, storage, load (i.e. demand-side), or transmission technology.

Spinning / Non-Spinning: Historically, the terms "**spinning**" and "**non-spinning**" have referred to the rotational nature of synchronized generators. Over time, this terminology has migrated to imply the "relative state of readiness and responsiveness" as it relates to the ability for a resource to fulfill its ancillary obligation. In an effort to leverage contemporary industry vernacular, this latter interpretation was adopted for use in this presentation.

Study Results

Identify Physical Requirements of Ancillary Services

Task 3: Scope & Deliverables

Identify physical requirements of ancillary services

Objectives:

- From recent renewable integration and planning studies, develop two future scenarios
- With HPUC and Hawaiian utilities, specify basic level of required bulk power system reliability for each island (Oahu, Maui, Big Island) [Task 1 and Task 3]
- Propose methodology to estimate required ancillary services and interconnection requirements (under the future scenarios) while taking into account other system considerations
- Suggest a process to determine a set of technologies and associated features

Scenario Development

Approach:

- From recent renewable integration and planning studies, develop two future scenarios with HECO companies and HPUC

Observations:

- The HECO companies required to conduct a 20-year time horizon IRP study every three years.
- In May 2009, the HPUC proposed amendments to the framework for IRP based on the proposal of a new Clean Energy Scenario Planning (CESP) process.
- The revised goal of IRP is to develop an Action Plan that governs how the utility will meet energy objectives and customer energy needs consistent with state energy policies and goals, while providing safe and reliable utility service at reasonable cost, through the development of Resource Plans and Scenarios of possible futures that provide a broader long-term perspective.
- Some of the Hawaiian utilities (HELCO and MECO) have conducted resource planning studies. These studies are not intended to serve as IRPs. Rather, they seek to identify resource needs for Hawaii Island and identify resource options for consideration in a future IRP cycle.

Scenario Development

Sources for scenario planning

| | HECO (Oahu) | MECO (Maui) | HELCO (Big Island) |
|--|---|--|---|
| Most Recent IRP | HECO IRP 2009-2028 (Sep 2008) | MECO IRP 2007-2026 (April 2007) | HELCO IRP 2007-2026 (May 2007) |
| Resource Planning Study to support future IRP | ? | Available from MECO | HELCO Resource Planning Study (June 2012) |
| Other renewable integration studies | OWIST & HSIS (Available from GE) | HSIS (Available from GE) | |
| Load Forecast | From OWIST and HSIS | Base Line From HSIS | Base Line From Resource Planning Study |
| Scenario 1: Moderate penetration Renewables or mix definition | HSIS Scenario 4A 360 MW Dist Solar PV 400 MW Cent Solar PV 100 MW On-shore Wind No Off-Shore Wind | HSIS Base Line (2012 system) 15 MW Dist Solar PV 0 MW Cent Solar PV 72 MW On-shore Wind | HELCO 100% renewables intermittent – heavy 22 MW Biomass 100 MW Wind (centralized) 100 MW PV (centralized or distributed) 50 MW Geothermal |
| Scenario 2: High penetration Renewables or mix definition | HSIS Scenario 4B 160 MW Dist Solar PV 200 MW Cent Solar PV 100 MW On-shore Wind 200 Off-Shore Wind (same solar & wind MWH as 4A) | HSIS Scenario 3 30 MW Dist Solar PV 15 MW Cent Solar PV 72 MW On-shore Wind Scenario 3: Heavy Intermittent Renewables 22 MW Biomass 100 MW Wind, 100 MW PV 50 MW Geothermal | HELCO 100% renewables geothermal/ dispatchable – heavy 42 MW Biomass 50 MW Wind (centralized) 50 MW PV (centralized or distributed) 100 MW Geothermal |

Ancillary Services for Existing System and Future Scenarios

Level of Bulk Power System Reliability

Approach:

- Review pertinent documents from HPUC and Hawaii utilities to identify current specifications required for bulk power system reliability for each island (Oahu, Maui, Big Island) such as:
 - Docket 2008-0273 Feed-in Tariff ("FIT")
- Confirm findings and reliability levels to be used for this study with Hawaiian utilities and HPUC and identify any areas that may require further study beyond this project

Observations:

- The HECO Companies currently plan and operate their systems in accordance with reliability principles that are very much aligned with the NERC Reliability Standards
- FIT Reliability Standards were filed in Docket 2008-0273 Feed-in Tariff ("FIT") Proceeding HECO Companies Report on Reliability Standards per the direction of HPUC

Methodology to Determine A/S

Applied to future scenarios

Approach:

- Propose methodology to estimate required ancillary services and interconnection requirements (under the future scenarios) while taking into account other system considerations and using the basic level of bulk system reliability as the performance target
- Refer to renewable integration studies, both in Hawaii and on the mainland

Observations:

- The results from the simulation of the selected scenarios from the HSIS and OWIS study performed by GE were used to determine the need for additional ancillary services (for HECO and MECO).

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Inertial Response

- Currently, the desired inertial response from dispatchable synchronous renewable generation (RE) resources such as geothermal plants is obtained as a condition of contract. Currently, there is no synthetic inertia requirement in the interconnection requirements for Variable Generation (VG) resources such as wind and solar plants.
- With the current technology, it is possible for wind plants to provide synthetic inertial response, which if designed properly can help the system ride through frequency events.
- We recommend synthetic inertia capability for future utility-scale wind plants. The parameters for synthetic inertia (deadband, active power contribution, duration of response, maximum generation reduction etc.) should be designed to meet the Hawaii system requirements.
- The utilities should also perform offline studies to determine the impact of synthetic inertia on inertial and primary frequency response and how it impacts inertia requirements from other (future) interconnecting resources, UFLS practices, and spinning reserve requirements. The offline studies should be used to guide for determining combinations of resources that need to be online.

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Primary Frequency Response

- Currently, the interconnection requirements require all dispatchable generators (conventional, as well as synchronous RE) to have a 4% droop that is adjustable. HECO utilities also have the capability to dispatch units to provide reserves as needed. As such, the HECO utilities currently obtain primary frequency response as a condition of interconnection.
- Wind and solar plants are capable of providing primary frequency response improving the reliability of the grid. In many instances, using VG to provide reserves also reduces their curtailment. For example, using wind generation to provide down reserves (instead of carrying the down reserves by dispatching up a thermal generator) reduces the curtailment of wind generation.
- We recommend droop control to be a part of the interconnection requirements for future utility-scale wind and solar plants in addition to the requirement for dispatchable generators.
- We recommend that VG be compensated for providing up reserves if their generation is curtailed for the explicit purpose of providing reserves. The payment mechanism will be discussed later. We also recommend the development of tools to reliably calculate the amount of reserves that VG can provide.
- VG should be required to provide down reserves without any explicit compensation similar to other dispatchable units in the system. Need tools to amount of down reserves that VGs can reliably provide.
- VG should be required to provide up reserves without any explicit compensation when they are curtailed for reasons other than providing up reserves since their opportunity cost is zero when they are curtailed.
- The above provisions are similar to those used in the ERCOT market.

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Secondary Frequency Response

- Currently, the interconnection requirements require all dispatchable generators (conventional, as well as synchronous RE) to be on AGC.
- All the existing wind contracts also include active power control (APC) provision to enable automatic curtailment.
- We recommend AGC (ability of wind plant to directly accept and act on a maximum dispatch signal delivered by AGC) capability to be a part of the interconnection requirements for all future utility-scale generators including wind and solar plants.
- We recommend that VG be compensated for providing up regulation if their generation is curtailed for the explicit purpose of providing regulation. The payment mechanism will be discussed later. We also recommend the development of tools to reliably calculate the amount of regulation that VG can provide.
- VG should be required to provide down regulation without any explicit compensation similar to other dispatchable units in the system. Need tools to amount of down regulation that VGs can reliably provide.
- VG should be required to provide up regulation without any explicit compensation when they are curtailed for reasons other than providing up regulation since their opportunity cost is zero when they are curtailed.

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Storage and Demand Response

- In general, storage and demand response should be allowed to provide regulation and reserves as long as they are economical. However, the following need to be considered:
- Need to consider DR response and UFLS interaction. UFLS uses 75-80% of all load. The interaction of UFLS and DR must be developed and coordinated to ensure adequate protection for the UFLS system.
- The modification of PV to being required to trip on lower frequency set-points than standard IEEE 1547 trip settings, which are higher than UFLS trip settings, to mitigate loss of PV during a system low-frequency events was completed by the recent modification to Hi Rule 14h. However, there are still legacy installations that trip in accordance with IEEE 1547 and will compound the impact of unit trips. HECO uses 57.3 Hz for low frequency trip of distributed PV (not sure about other utilities). Legacy PV trips at 59.3 Hz and still must be considered in all studies. Since the 1547 standard and, similarly, Rule 14H specify in terms of a must-trip instead of ride-through, confirmation that the existing change results in the desired ride-through is important - a future change to a ride-through requirement may be necessary.
- Need to consider feeder net load for UFLS system as distributed PV increases and feeder net load during some hours reduces.

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Changes to Interconnection Requirements

Reactive Power and Voltage Regulation

Hawaii utilities have voltage regulation and control requirements for dispatchable and variable generation. No changes proposed.

Voltage and Frequency Ride-thru

Hawaii utilities have voltage and frequency ride-thru requirements for dispatchable and variable generation. Utilities should develop requirements for unbalanced ride thru requirements. Unbalanced voltage capability is required in weak systems and is currently a much larger issue than LVRT since turbine manufacturers do not currently have a standard to meet and the current technology of WTG is much less than conventional generation.

Ramp Rate Limits and Control

Hawaii utilities have ramp rate limits in the up direction for variable generation. Ramping requirements in the up and down direction are included as requirements for dispatchable generation. No changes proposed.

Over and Under Frequency Controls

Per recommendation before, require wind and solar plants to have primary frequency response capabilities.

Recommendations Regarding New Ancillary Services and Interconnection Requirements

Changes to Interconnection Requirements

Inertia

Per recommendation before, require wind plants to have inertial response capabilities. Inertia response should be defined by utility based on system needs.

AGC Capability

Per recommendations before, require all generators including wind and solar plants to have the ability to accept and respond to AGC commands. Active power set-point is a current requirement for VG to enable curtailment. This would require modifications to the AGC program.

Fundamentals of Power System Operation

Power System Operation

Identifying the balancing point between resource capability and system needs

This section is intended to serve as a primer which provides a common foundation for the general terminology and concepts that will be referred to throughout the balance of this report.

In addition, it is intended to provide insight into the processes and considerations that are required to leverage available power system resources to “serve the load” in the most cost effective and reliable manner.

Downstream sections of this report will contain more Hawaii-specific discussion, considerations, and where possible, recommendations which reference these concepts.

Power System Operation

Identifying the balancing point between resource capability and system needs

In a power system, resources are committed and dispatched based on their ability to:

1. Directly provide energy
 2. Support the reliable delivery of energy
- Often, the same resource may serve both functions. The degree to which this occurs depends upon the attributes of the individual resource, resource mix, and the respective needs of the power system.

To supply “energy”, a resource is *primarily* evaluated based on its variable cost structure:

Startup Cost:

- Typically on a “\$/startup” basis. Represents the cost incurred for bringing a resource to a state where it is available for dispatch.

Minimum Generation Cost:

- Typically on a “\$/hr” basis. Represents the variable cost required to sustain operation at the minimum permissible “real-power” operating level.

Incremental Variable Cost:

- Typically on a “\$/MWh” basis. This represents the cost for the next incremental adjustment in the real-power set-point.

Power System Operation (cont'd)

Identifying the balancing point between resource capability and system needs

To support the “reliable delivery of energy”, a resource is considered based on additional attributes that characterize its *flexibility*. Examples include, but are not limited to:

Inertial Response:

- Typically measured by a resource’s inertial constant “H” (in seconds). This is a normalized value that relates a resource’s kinetic energy to its respective capacity.

Ramp-rate:

- Typically on a “MW/min” basis. Characterizes the rate at which a resource is able to adjust it’s real-power set-point. This rate can be set “tuned” differently dependent upon whether the need is for frequency response (i.e. FRR), regulation, (i.e. AGC), load following, spinning reserve, and/or startup periods.

Quick-start capability:

- Typically on a “minutes or hours” basis. Characterizes the time-delay required for a unit that is offline or disconnected from the power system to become available for the purposes of providing energy or supporting the reliable delivery of energy.

Operating Range:

- Characterized on a “real-power” and “reactive power” basis.
- Real-power range: Characterizes the range over which a resource is able to inject or consume actual “MW” to support the load on the power system.
- Reactive-power range: Characterizes the range over which a resource is able to provide “MVAR” to assist with maintaining system voltage levels.

Power System Operation (cont'd)

Identifying the balancing point between resource capability and system needs

To support the “reliable delivery of energy”, a resource is considered based on additional attributes. Examples include, but are not limited to:

- Minimum Operating Period:
 - Minimum up-time: The minimum time for which the unit needs to be online once started
 - Minimum down-time: The minimum time for which the unit needs to be offline once shutdown
- Black-start capability:
 - Ability to start a unit without support from the grid

Power System Operation (cont'd)

Identifying the balancing point between resource capability and system needs

Determining the balance between using a resource for its “energy” vs. its ability to support the “reliable delivery of energy” often requires sophisticated algorithms. Typically, this balance is achieved through “*security-constrained unit-commitment (SCUC)*” and “*security-constrained economic dispatch (SCED)*” algorithms. For long-term power system planning, a ***production cost model*** is often leveraged to execute the SCUC and SCED algorithms. For day-to-day and week-to-week operations, similar algorithms are used in energy management system (EMS) software.

The objective of the algorithms is to ensure that sufficient resources will be online (i.e. committed) to meet the anticipated load forecast (including variability) and satisfy reserve requirements in the most economical manner (i.e. lowest system cost) while observing reliability constraints.

Emphasis is placed on leveraging assets with the lowest ***variable operating costs***. More expensive resources are only selected if their ***flexibility*** is required to ensure reliable delivery of the energy, relieve system constraints, or they benefit increased renewables penetration, etc.

Once a resource is “committed”, the “security-constrained economic-dispatch” algorithms are then utilized to obtain a resource’s load set-point (i.e. “dispatch-point”). To achieve a solution, these algorithms attempt to “park” all committed resources at the same incremental variable cost (*additional details in following slides*).

Power System Operation (cont'd)

Identifying the balancing point between resource capability and system needs

Typically, the “most-economical” manner for operating the system is for all committed resources to be dispatched to the same “incremental variable cost” (provided the resource is not at the extremes of its operating range). This is referred to as “economic dispatch”.

The resource which will provide the “next most economical MW” is referred to as the marginal unit. And, at that instant, the “system marginal cost” is equivalent to the incremental variable cost of that resource. Often, there are multiple units “on or near the margin”.

To satisfy the reliability needs of the power system, it is often necessary to adjust the dispatch of the resources away from their economic optimum set-point. This movement creates additional “headroom/legroom” and increases the available reserves to satisfy system req's.

To ensure that these adjustments are made in the most economical manner, a process referred to as “co-optimization” is often deployed. This process assists in identifying which resources to adjust, and by how much. Specifically, it attempts to minimize the “opportunity costs” associated with moving a resource away from its economic optimum to meet the reliability needs of the system.

The concept of using opportunity costs to rank/prioritize resources and make system-level trade-offs between energy vs. ancillary capability is still applicable regardless of whether an explicit payment is made to the resources for their ancillary participation.

Power System Operation (cont'd)

Identifying the balancing point between resource capability and system needs

Typically, ancillary service needs are “best-served” by marginal resources. This is driven by the fact that they often have the lowest opportunity cost for providing the service.

- For example, a wind farm* typically has a very low variable operating cost. Curtailing the wind for the specific purpose of providing an ancillary service would [typically] result in very high opportunity cost (for both the plant and the power system).
- However, during periods where renewables are curtailed (due to must-run resources and/or corresponding over-supply), allocation of ancillary services to the renewables would likely be very cost-effective.
- In situation where renewables are not curtailed, selecting a combustion turbine or storage device** would likely result in lower opportunity cost and lower system cost.

* *In Hawaii, during off-peak periods, wind energy contract prices can higher than the variable cost of other thermal generation. For these circumstances (and while wind contracts do not separate fixed & variable costs), curtailing wind for the purposes of providing ancillary services may be recommended.*

** *Storage devices are unique. Such resources are often “energy-neutral” (i.e. zero net-output on a nominal basis). As a result, storage devices do not have an “opportunity cost” per se. The variable cost to provide ancillary services from a storage device is typically driven by the cost to initiate the devices operation (i.e. startup) and the corresponding variable O&M during operation. As a result of their energy-neutral / zero-opportunity cost, storage devices are typically prioritized ahead of other resources for providing ancillary services.*

Power System Operation (cont'd)

Illustration of the key concepts & tools which facilitate the analysis

The illustrations on the following pages are intended to provide further clarification of some of the key tools & concepts that were discussed in the preceding slides:

- Production Cost Modeling
- Average vs. Incremental Variable Cost
- Economic Dispatch
- Opportunity Cost
- Co-optimization of Energy and Ancillary Services

Production Cost Modeling

Inputs



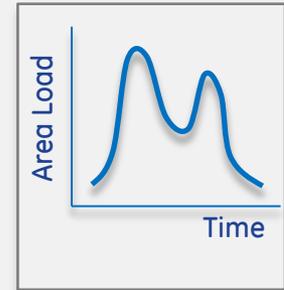
Resource Definition:

- Individual resource attrib.
- Variable cost structure
- Op Constraints & A/S Cap.
- Outage Schedules



Transmission Definition:

- Defines the electrical infrastructure
- Connects resources w/ loads
- Line capacity & routing



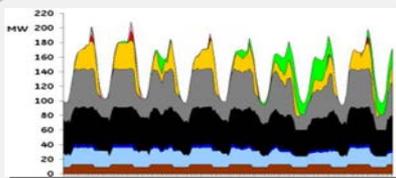
Area Load Definition:

- Specifies the location-based need for power
- Resources utilized to serve this load economically / reliably

Calcs

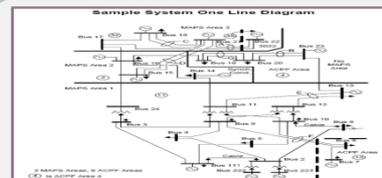
Production Cost Modeling Core Algorithms (i.e. "the engine")

Outputs



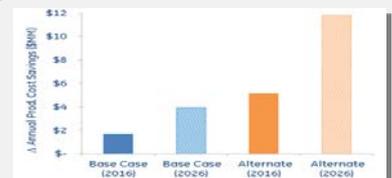
Resource Utilization:

- Operating profiles for all resources (online status, load level, operating hours, startups, etc.),



Transmission Flows:

- Load flow profiles
- Identification of limiting lines and constraints
- Congestion costs



Financial Results:

- Insight on both "system-level" and "plant-level" economics.
- For investment decisions, cost of reliability analysis, etc.

Variable Operating Costs

Incremental vs. Average Variable Cost

Variable Operating Costs

(Example shown for a Generating Resource)

Variable Operating Cost (\$/hr):

- Hourly cost required to sustain operation at a given load set-point.
- Driven by costs which are a function of utilization
- Typically consists of (but not limited to):
 - Fuel cost
 - Variable O&M
 - Emissions (i.e. environmental compliance)

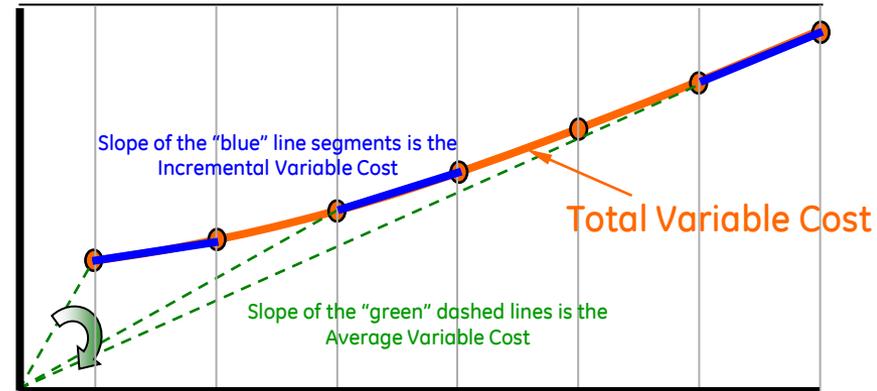
Average Variable Cost (\$/MWh):

- Calculated by dividing the Variable Operating Cost by the respective output level
- Provides a normalized representation of the "actual" operating cost incurred at a given set-point.

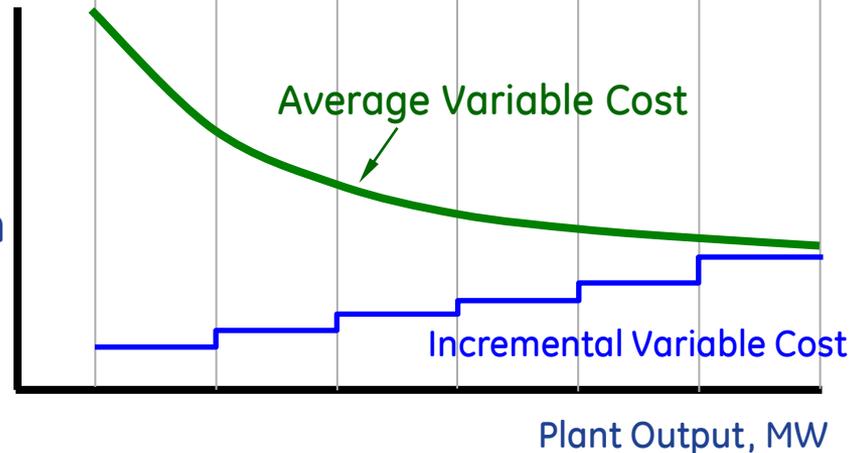
Incremental Variable Cost (\$/MWh):

- Represents the "additional cost" for the "next "MW" provided by the resource. Trend is "downward" sloping for DR resources.
- Critical to "economic dispatch"

Variable
Operating
Cost
\$/ hr



Variable
Operating
Cost
\$/ MWh



Economic Dispatch

Provides an “economically optimized” operating point for each resource

Economic Dispatch

(Example shown for a Generating Resource)

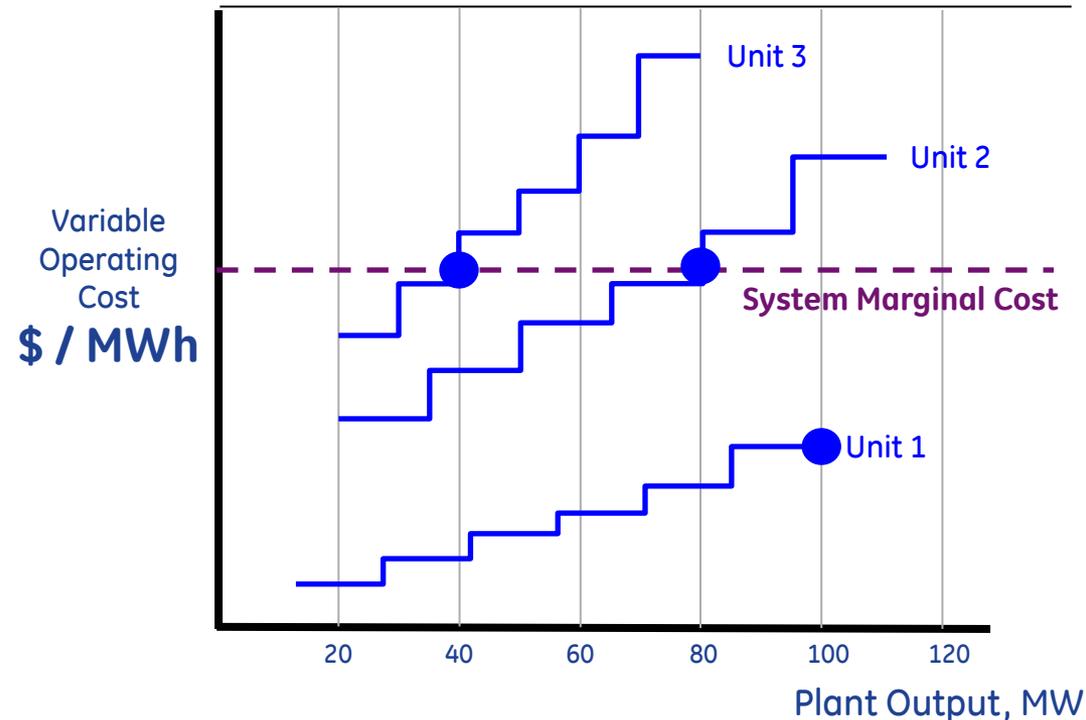
- Economic Dispatch is the process used to move the real-power set-point for resources upward and downward.
- At the power system-level, the cost to “serve the load” is minimized when committed resources are dispatched to the same “incremental variable cost”.
- The “system marginal cost” is analogous to the “clearing price” in a power market.
- Exceptions for resources that are at the extremes of their operating range.
- Deviations from the economic optimum may be necessary to meet the reliability needs of the power system.
- Trade-offs are typically driven by the “opportunity cost” of migrating a resource away from its economic optimum.

Scenario (for illustration only):

- Instantaneous system need is 220 MW
- Assume Units 1-3 are committed

Principles of economic dispatch would yield:

- Unit 1 Set-point: 100 MW (upper extreme of op range)
- Unit 2 Set-point: 80 MW (on the margin)
- Unit 3 Set-point: 40 MW (on the margin)
- Total Supply: 220 MW



Opportunity Cost

Represents the cost for deviating from economic dispatch

Opportunity Cost

(Example shown for a Generating Resource)

- Economic Dispatch would indicate "Unit 1" should be providing 100 MW (full-output).
- Consider "Unit 1" for 20 MW of upward regulation service.
- The opportunity cost of moving 20 MW from providing "energy" to serve the "ancillary" needs is characterized as:

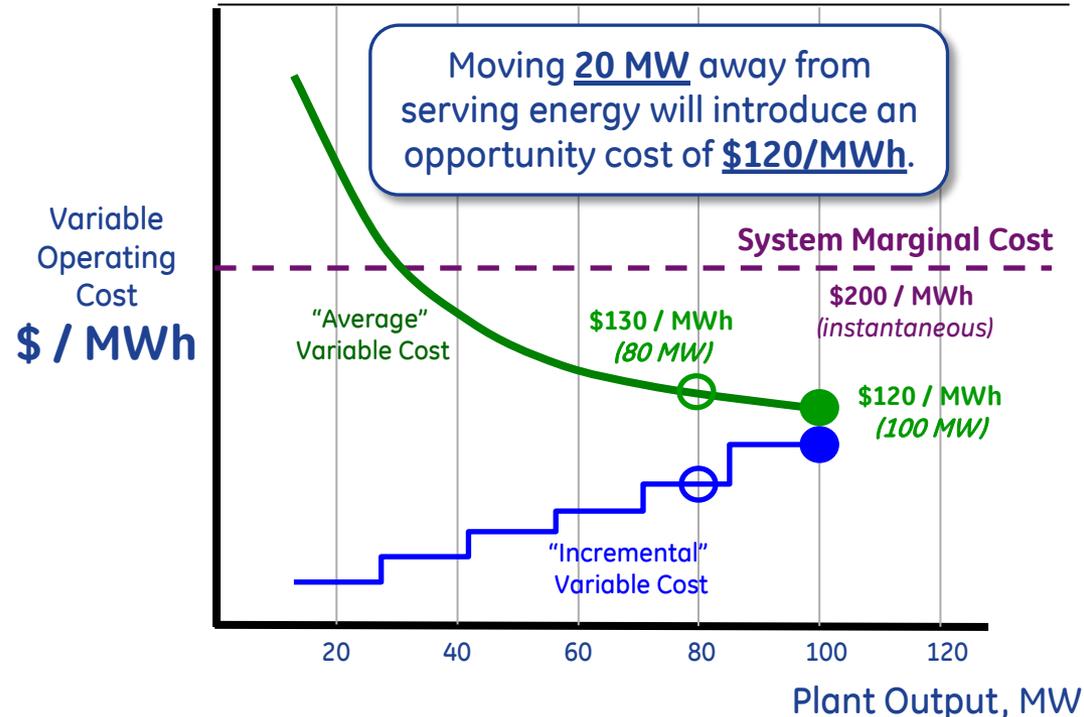
| | |
|-------------------|-----------|
| Providing 100 MW: | \$8000/hr |
| Providing 80 MW: | \$5600/hr |
| Difference: | \$2400/hr |
- Normalizing the \$2400/hr by the 20 MW, results in an opportunity cost of **\$120/MWh**.
- Resources with the "lowest opportunity cost" should be the 1st resources selected to migrate from providing energy to serve the ancillary needs of the system.
- In many locations, the opportunity cost of the "last resource" required to provide the ancillary service will set the "ancillary clearing price".

Providing 100 MW (Energy-only):

- Revenue (proxy) = $(\$200/\text{MWh}) * (100 \text{ MW}) = \$20000/\text{hr}$
- Cost = $(\$120/\text{MWh}) * (100 \text{ MW}) = \$12000/\text{hr}$
- Profit (proxy) = $\$8000/\text{hr}$

Providing 80 MW (Energy + 20 MW Regulation "stand-by"):

- Revenue (proxy) = $(\$200/\text{MWh}) * (80 \text{ MW}) = \$16000/\text{hr}$
- Cost = $(\$130/\text{MWh}) * (80 \text{ MW}) = \$10400/\text{hr}$
- Profit (proxy) = $\$5600/\text{hr}$



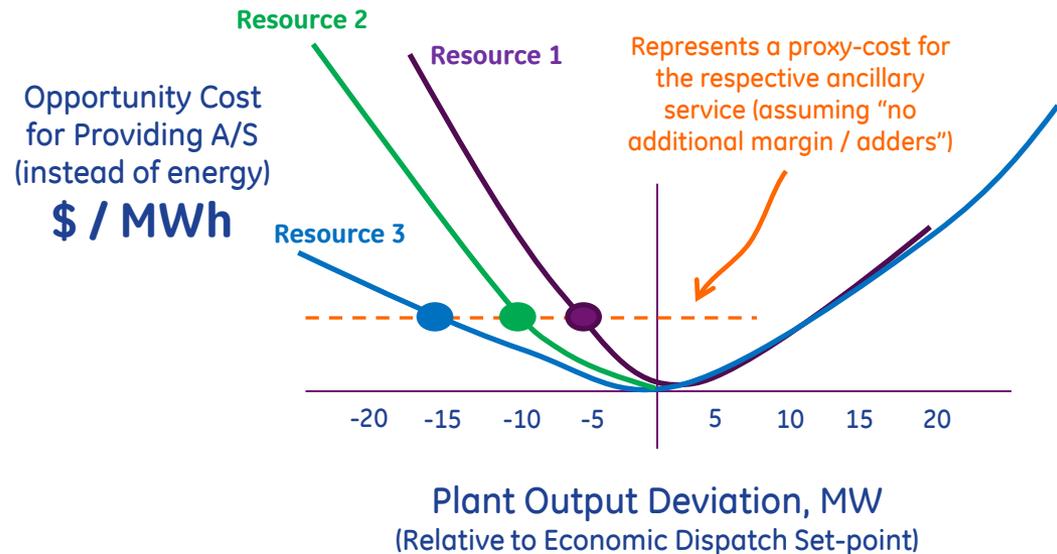
Co-optimization

A mechanism for minimizing the opportunity cost at a system-level

Co-optimization

(Applicable for any multiple resource-types)

- Co-optimization ensures that ancillary services are sourced from the most-economically viable resource capable of serving the need.
- In the scenario at the right, each was allocated a portion of the total ancillary service requirement.
- In many locations, the ancillary requirements (for each service), and the corresponding opportunity costs, are evaluated and adjusted on an hourly basis.
- Often, resources are capable of providing more than a single ancillary service. Under these circumstances, multiple “co-optimization” layers are required to ensure a proper economic balance. (i.e. not just trade-offs in energy vs. ancillary, but ancillary service vs. ancillary service as well).



Scenario:

- 30 MW of “Regulation Up” is required
- Assume: All three resource are capable of providing regulation (i.e. op range, ramping, etc.)
- Economically optimized solution is:
 - Resource 1: 5 MW
 - Resource 2: 10 MW
 - Resource 3: 15 MW
 - Total Reg-Up: **30 MW**

Opportunity Cost Illustration for HECO

HECO-specific Opportunity Cost

In an effort to place the preceding material in context, the following slides will provide some HECO-specific perspective on the opportunity cost associated with migrating a resource away from providing energy and into ancillary participation.

On an individual basis, the incremental variable cost structure for each of the HECO resources will be compared to the marginal system level cost to identify the appropriate economic dispatch if that resource had been online and available. *Note: For this illustration, each resource will be individually compared to a proxy system cost. Therefore, the summation of the load set-points for each resource does not necessarily constitute a valid system solution.*

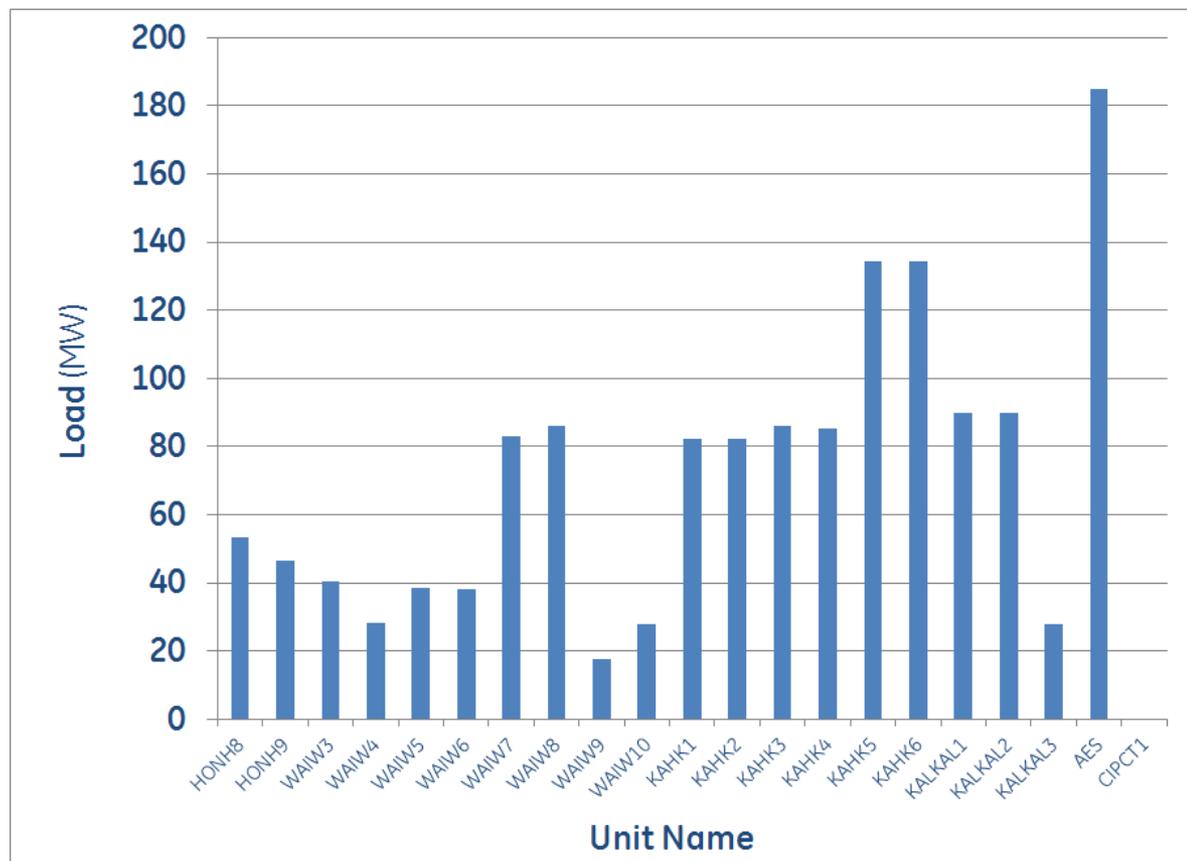
With an understanding of the economic dispatch set-point, each resource will then be perturbed away from this set-point to determine the associated opportunity cost of transferring capability away from providing energy.

Resources with the lowest opportunity cost should be the first resources transferred away from providing energy to fulfill ancillary requirements.

For this example, we'll be assuming an instantaneous marginal system level cost of \$190 / MWh.

Opportunity Cost Illustration for HECO

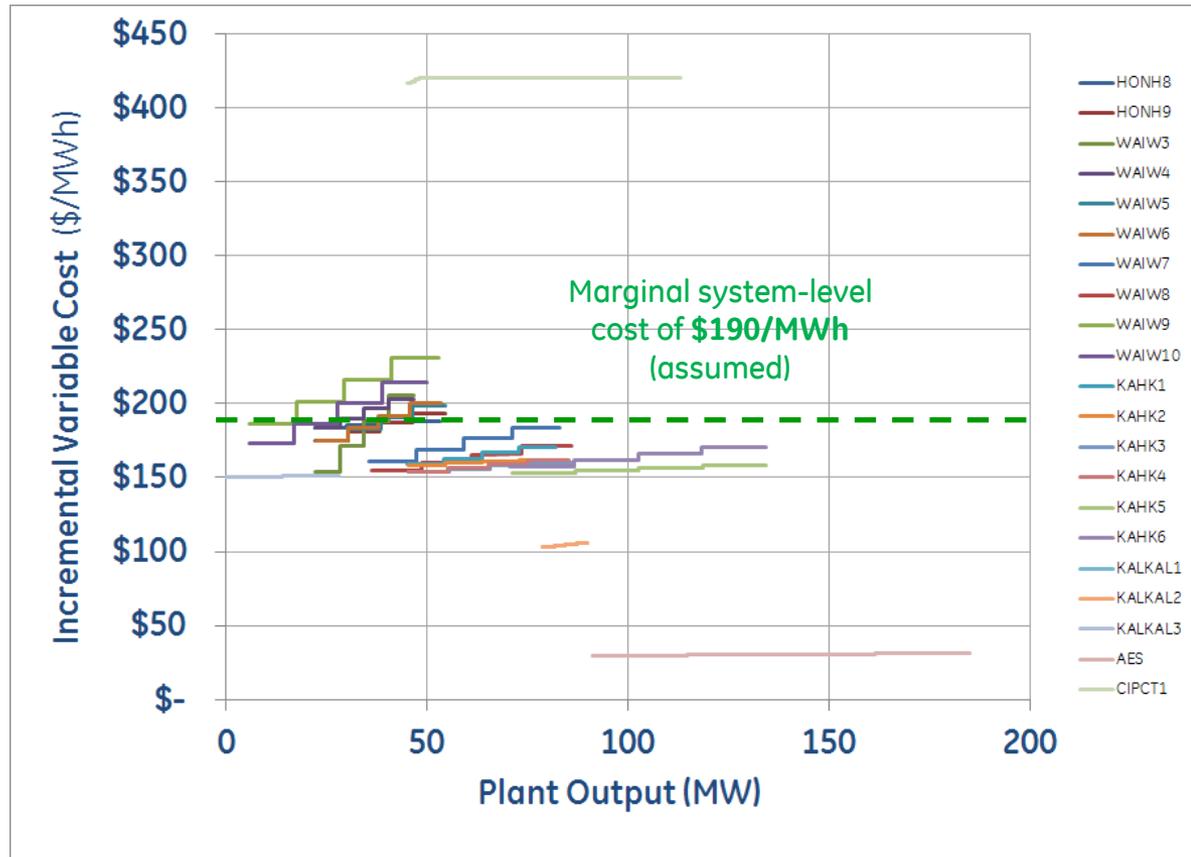
Intersection of the marginal system cost and incremental cost establishes load level



For a \$190 / MWh marginal system cost, the respective load level for each resource (if committed) would be as shown.

Opportunity Cost Illustration for HECO

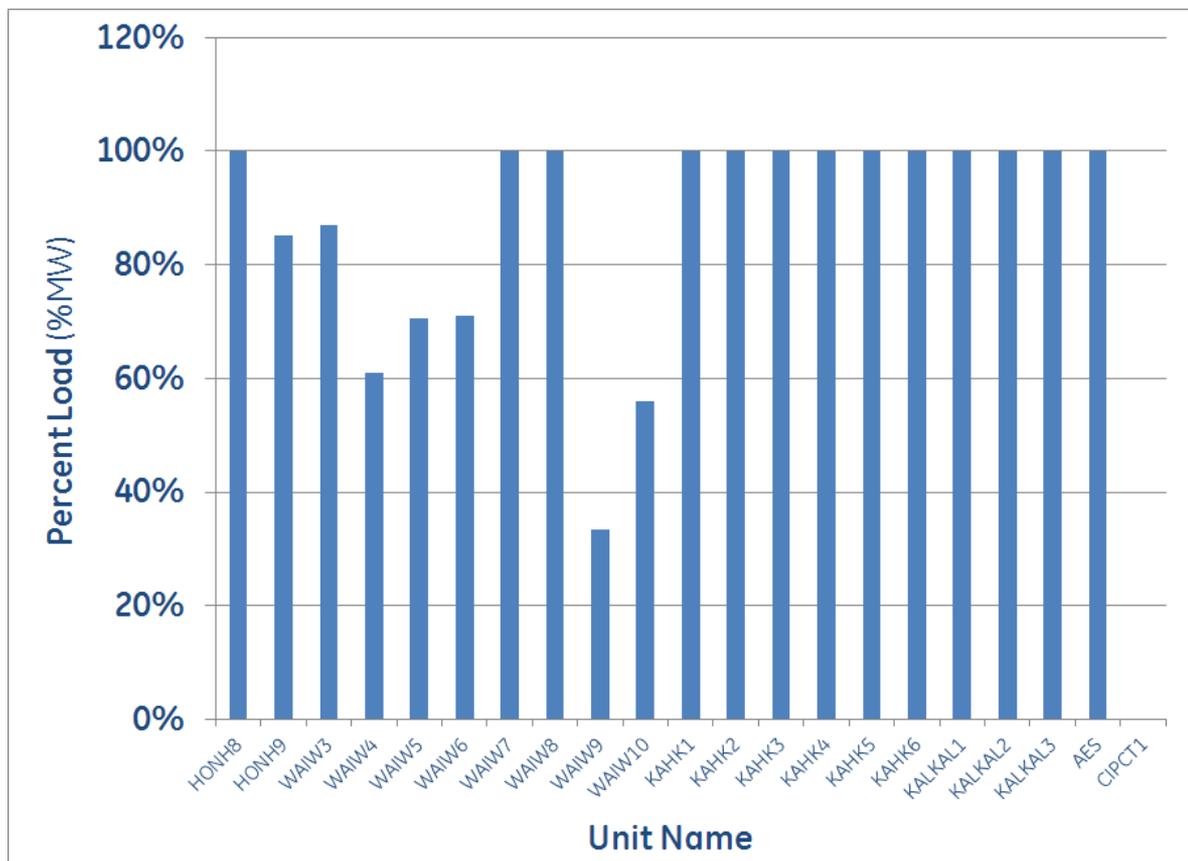
Intersection of the marginal system cost and incremental cost establishes load level



All resources shown are initially dispatched economically per their incremental variable cost structure

Opportunity Cost Illustration for HECO

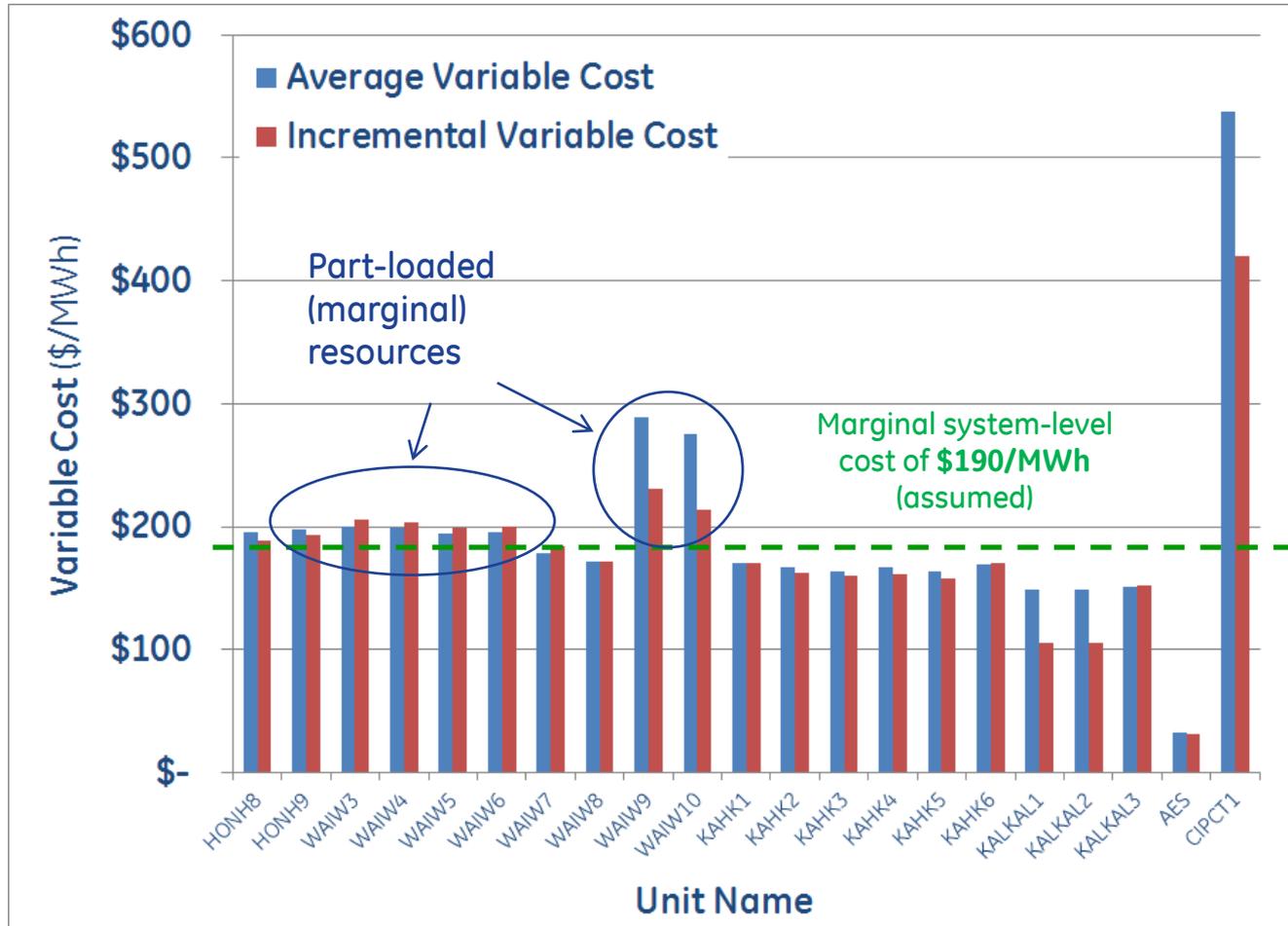
Intersection of the marginal system cost and incremental cost establishes load level



For a \$190 / MWh marginal system cost, the respective load level for each resource (if committed) would be as shown.

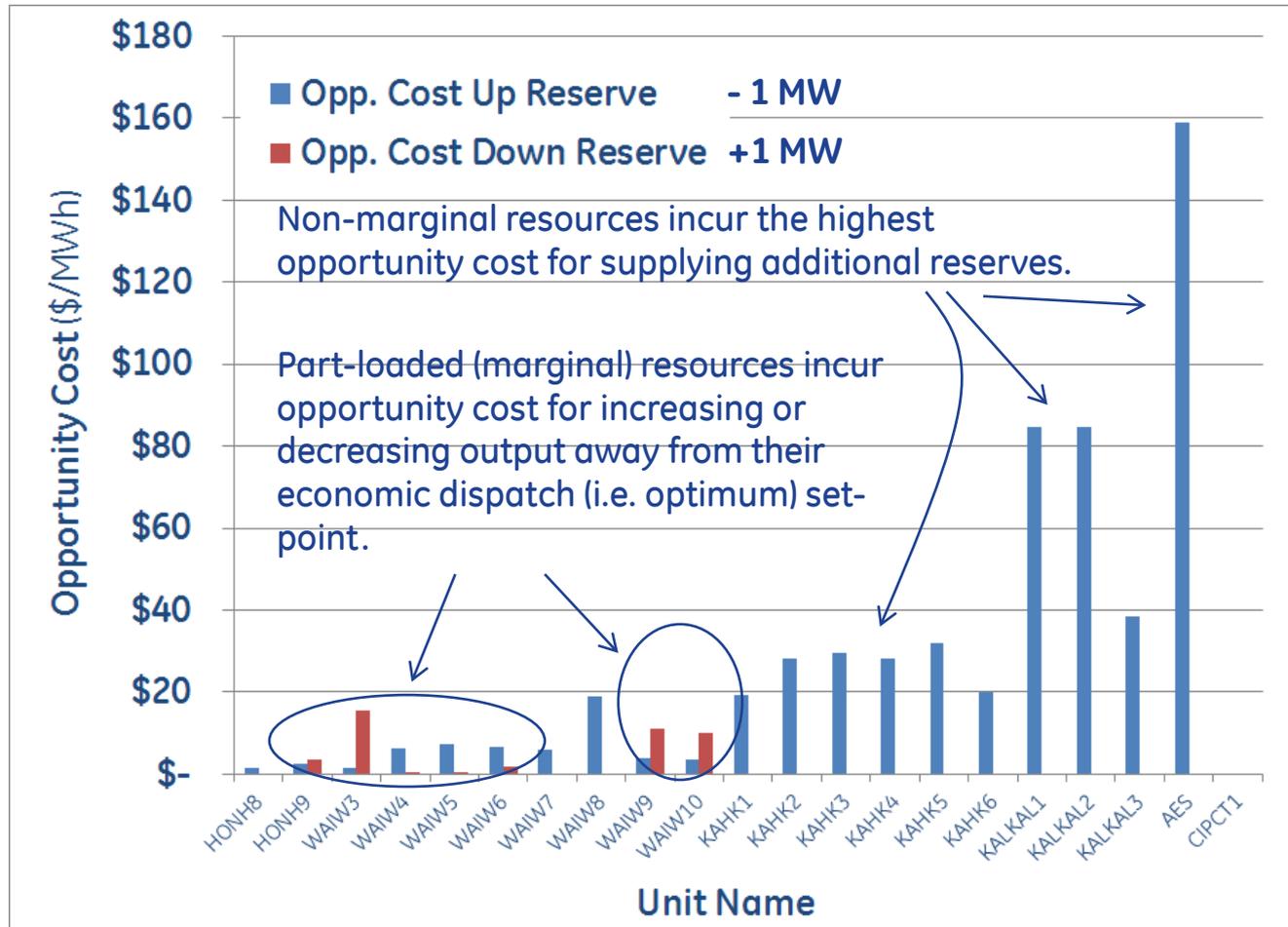
Opportunity Cost Illustration for HECO

Incremental and Average Variable Cost compared w/ the System Marginal Cost



Opportunity Cost Illustration for HECO

Instantaneous opportunity cost for shifting capability from energy to A/S



Opportunity Cost Illustration for HECO

Opportunity cost as the deviation from the economic dispatch set-point is increased

Units with:

- Lower variable cost
- Higher opportunity cost

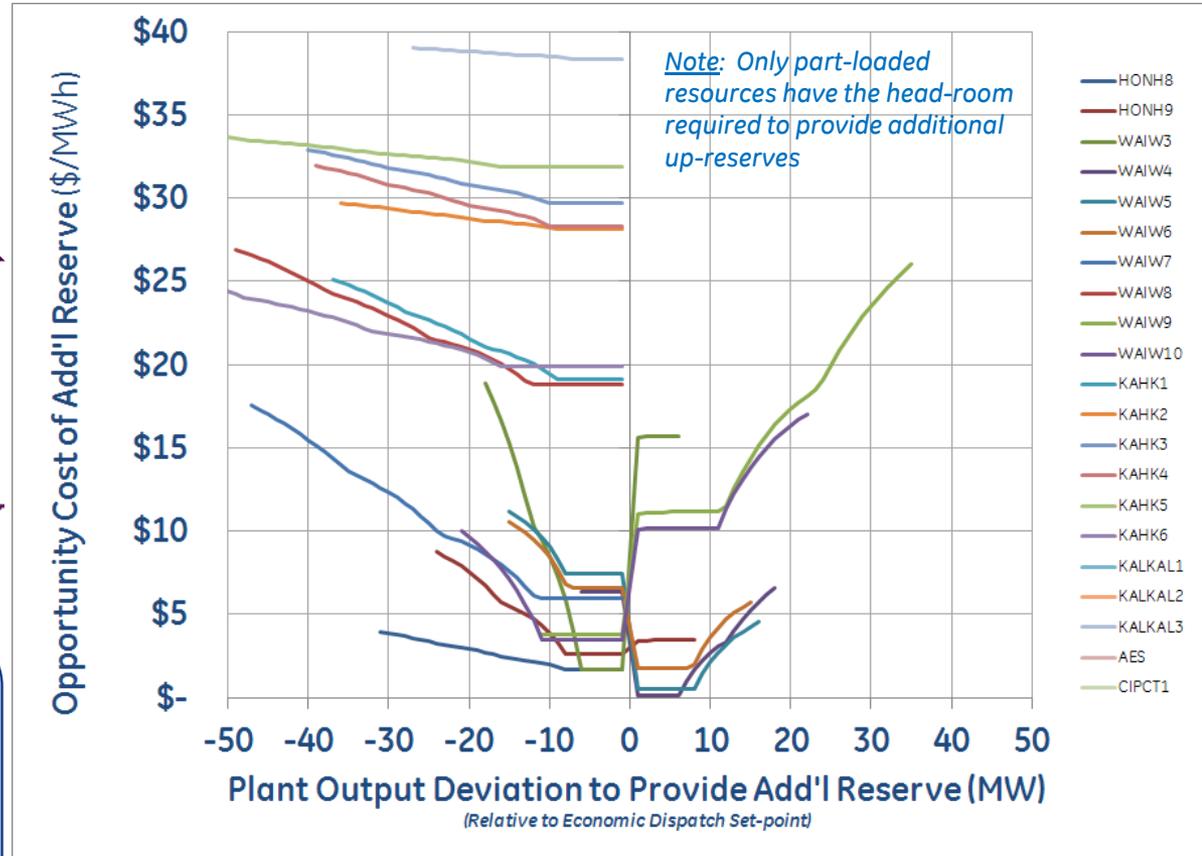
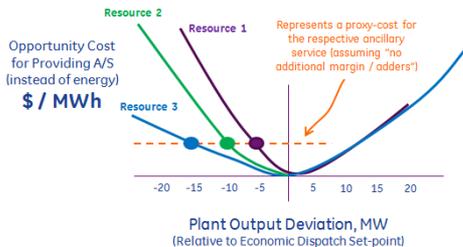


Units with:

- Higher variable cost
- Lower opportunity cost



Reference: Fundamentals of Power System Operation



Increasing Up Reserve



Increasing Down Reserve

Process for Evaluating and Selecting a Potential Future Technology Mix

Process for Evaluating a Resource Mix

Overview

This section outlines a methodology that can be exercised during a resource planning process to evaluate and assist with the selection of a future technology mix that is compatible with the system-level interconnection and ancillary service requirements.

Specifically, the methodology focuses on minimizing the overall production cost and capital expenditure required to obtain a “least-cost” portfolio while observing system reliability needs.

Additional consideration is given to parameters which are more difficult to quantify economically, such as propensity for a given portfolio to improve future renewables penetration and/or reduce risk exposure.

Process for Evaluating a Resource Mix

Description of Approach

Using HECO Scenario 4A (as an example), each of the steps outlined in the above-mentioned process will be placed in context.

It should be noted that many options are available to fulfill any observed ancillary service deficiencies, such as: *New generation, Energy storage, Demand response programs, Transmission technologies, and Existing generation modifications/retrofits*

To ensure that an optimal (*economic, risk, environmental*) solution is achieved, it is recommended that a series of options be developed and analyzed via the process described on the following slides.

Due to the complexity of the simulations required to generate the data that would be required to perform this analysis, the following process will not be able to be demonstrated in its entirety. A separate study would be required to calibrate a suitable simulation and fully execute the process.

Step 1: (Example)

Identify Current or Future Scenario

Begin with an established current or future scenario. It is assumed that the resource-specific variable cost characteristics (i.e. heat rate curves, variable O&M cost, startup costs), min-up/down times, ramp-rates, storage capacity, DR availability/activation thresholds, and system-level future economic scenario (i.e. fuel cost/availability, system load forecast, etc.) are known values.

Select HECO 4A
for this Example
(including subsequent slides)

| | HECO (Oahu) | MECO (Maui) | HELCO (Big Island) |
|--|---|---|---|
| Most Recent IRP | HECO IRP 2009-2028 (Sep 2008) | MECO IRP 2007-2026 (April 2007) | HELCO IRP 2007-2026 (May 2007) |
| Resource Planning Study to support future IRP | ? | Available from MECO | HELCO Resource Planning Study (June 2012) |
| Other renewable integration studies | OWIST & HSIS (Available from GE) | HSIS (Available from GE) | |
| Load Forecast | From OWIST and HSIS | Base Line From HSIS | Base Line From Resource Planning Study |
| Scenario 1: Moderate penetration Renewables or mix definition | HSIS Scenario 4A 360 MW Dist Solar PV 400 MW Cent Solar PV 100 MW On-shore Wind No Off-Shore Wind | HSIS Base Line (2012 system) 15 MW Dist Solar PV 0 MW Cent Solar PV 72 MW On-shore Wind | HELCO 100% renewables intermittent - heavy 22 MW Biomass 100 MW Wind (centralized) 100 MW PV (centralized or distributed) 50 MW Geothermal |
| Scenario 2: High penetration Renewables or mix definition | HSIS Scenario 4B 160 MW Dist Solar PV 200 MW Cent Solar PV 100 MW On-shore Wind 200 Off-Shore Wind (same solar & wind MWh as 4A) | HSIS Scenario 3 30 MW Dist Solar PV 15 MW Cent Solar PV 72 MW On-shore Wind Scenario 3: Heavy Intermittent Renewables 22 MW Biomass 100 MW Wind, 100 MW PV 50 MW Geothermal | HELCO 100% renewables geothermal/ dispatchable - heavy 42 MW Biomass 50 MW Wind (centralized) 50 MW PV (centralized or distributed) 100 MW Geothermal |

Step 1: (cont'd)

Identify Current or Future Scenario

To provide a comprehensive evaluation, it may be necessary to perform an uncertainty analysis of the key parameters which influence the characterization of a given future scenario. The results of the uncertainty analysis would yield the relevant bounds for each key parameter. With the uncertainty bounds understood, a matrix of the desired evaluation conditions for a parametric sensitivity analysis could be established. This process would be executed for each evaluation condition to ensure a robust analysis of the potential resource mix.

- *A contemporary example of why the up-front uncertainty analysis would be beneficial is the increased adoption of distributed solar PV on the Hawaiian islands. The increase in the use of distributed solar PV has a tendency to change the system load forecast (i.e. net-load shape) which will be served by the centralized resource technologies targeted by this report. Without an uncertainty analysis, an inaccurate representation of the load forecast could result; this would have the potential to drive a sub-optimal resource mix.*

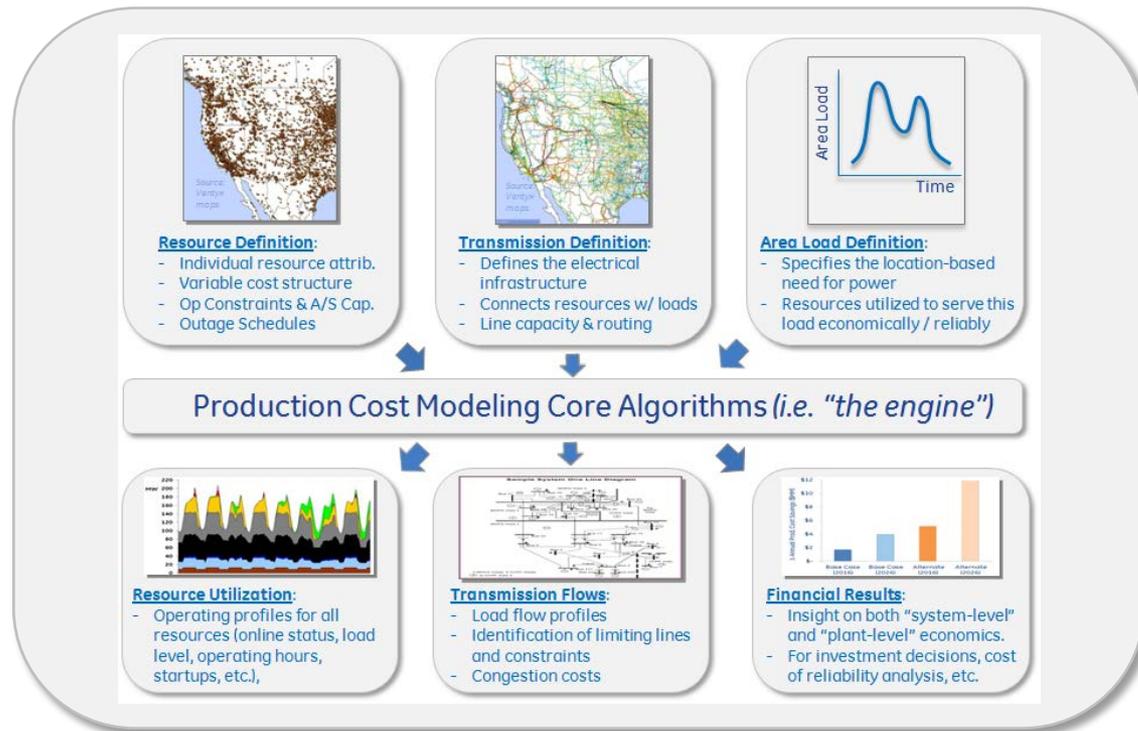
Similar uncertainty analysis of the resource-specific variable cost characteristics, operability constraints, storage/DR characteristics, fuel cost/availability, etc. may be required to develop a robust evaluation matrix to guide the sensitivity analysis.

Step 2:

Obtain Production Cost Simulation

Obtain a production cost simulation that is capable of performing security constrained unit commitment (SCUC) and security constrained economic dispatch (SCED)

- The production cost simulation (or post-processing algorithms) should be capable of analyzing intra-hour behavior to fully evaluate the ancillary service performance
- Simulation needs to be able to “co-optimize” the energy and ancillary services.



Step 3:

Estimate required "system-level" amounts for each ancillary service

Assess/Anticipate the required amount (and minimal level of acceptable responsiveness) that is required for each ancillary service. Provide these ancillary requirements to the production cost simulation and corresponding post-processing algorithms. These ancillary requirements will be interpreted as constraints by the simulation so that it can reserve the respective ancillary capability from each of the available resources. *Note: Iteration will be required to optimize.*

HECO Ancillary Service Matrix
(Actual HECO spreadsheet accompanies this report and covers Scenarios 4A & 4B)

| Ancillary Services Definitions & Capability Study | | | | | | | | | | |
|---|--|--|---|--|---|--|--|--|--|---|
| HECO Ancillary Services | | | | | | | | | | |
| Ancillary Service | How is the need determined? | Which resources can provide it? | How much (minimum amount) is required/held? | Which type of resource currently provides it? (Type 1-3) | Which type of resource currently provides it? (Ownership) | Relevant Interconnection Requirements | Observations | Current System | | Recommendations on standards and ancillary services |
| | | | | | | | | Scenario 1 - 2015 Scenario 4A | Scenario 2015 Scenario 4B | |
| Vertical Response | Planning studies involving transient stability simulations of contingencies to determine primary frequency response and minimum number of synchronous units that need to be online | All online synchronous generators, Wind farms with synthetic inertia, DER | 1000 number of units need to be online | 3 | U | Interconnecting thermal units should have an inertia constant (H) of 2000 or higher; Section 12.2 of IC Staff | The response of the current system appears to be adequate (to be verified by WECC) | Not defined in this scenario | Not defined in this scenario | One or more of the following changes may be required under Scenario 4A and 4B: (1) Require interconnecting wind plants to provide frequency response from frequency response base; (2) Require synthetic inertia; (3) Obtain primary frequency response from frequency response base; (4) Present DER PV from tripping not an ancillary service... need to do with DER DMS? (Current wind to provide under frequency response?) |
| Frequency Response | Planning studies involving transient stability simulations of contingencies to determine governor response | Online synchronous generators with droop that have headroom, Wind farms with droop | To cover for loss of largest unit (100MW) | 3 | U | The unit speed-droop characteristic shall have a nominal setting of 1.2 percent (1.2%/100) and a variable setting between 1.0 percent (1.0%/100) and 1.5 percent (1.5%/100). The Facility Energy (MWh) shall be capable of operating in autonomous or drop mode as required by Company in its site document, Section 12.2 of IC Staff. | The response of the current system appears to be adequate (to be verified by WECC) | To cover for loss of largest unit (100MW) | To cover for loss of largest unit (100MW) | |
| Under-Frequency Response | Planning studies involving transient stability simulations of contingencies to determine governor response | Online synchronous generators with droop that have headroom, Wind farms with droop | To cover for loss of largest feeder (100MW) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | To cover for loss of largest unit (100MW) and/or a transmission fault, 100MW (single line) under loss of adjacent transformer and/or adjacent 40kV feeders | To cover for loss of largest unit (100MW) and/or a transmission fault, 100MW (single line) under loss of adjacent transformer and/or adjacent 40kV feeders | Allow wind plants to provide under frequency response? |
| Over-Frequency Response | Planning studies involving transient stability simulations of contingencies to determine governor response | Online synchronous generators with droop that have headroom, Wind farms with droop | To cover for loss of largest feeder (100MW) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | To cover for loss of largest unit (100MW) and/or a transmission fault, 100MW (single line) under loss of adjacent transformer and/or adjacent 40kV feeders | To cover for loss of largest unit (100MW) and/or a transmission fault, 100MW (single line) under loss of adjacent transformer and/or adjacent 40kV feeders | Allow wind plants to provide over frequency response? |
| Regulation | | Online synchronous generators or DER that have headroom, Battery storage, DR | Covered by operating reserves (see below) | | | | | Covered by operating reserves | Covered by operating reserves | |
| Up | | Online synchronous generators or DER that have headroom, Battery storage, DR | Covered by operating reserves (see below) | | | | | Covered by operating reserves | Covered by operating reserves | |
| Down | Determined from operating reserves study (mentioned below) | Online synchronous generators or DER that have headroom, Battery storage | Covered by operating reserves (see below) | | | | | Covered by operating reserves | Covered by operating reserves | |
| Load following | | Online synchronous generators that are on DER | Covered by operating reserves (see below) | | | | | Covered by operating reserves | Covered by operating reserves | |
| Spinning Reserves | Typically, equal to the size of the largest unit in the system. Planning studies involving transient stability simulations of contingencies | Online synchronous generators with droop that have headroom, Battery storage, DR | To cover for loss of largest unit (100MW) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | To cover for loss of largest unit (100MW) | To cover for loss of largest unit (100MW) | The contingency reserves (spinning reserves) will remain at 100 MW unless the base of the DER is not expected to be the single largest contingency. |
| Contingency | Statistical analysis of variations in load and renewable generators in the minute to 1-hour timeframe. Quick start capability (discussed below) is taken into account in calculating spin requirements | Online synchronous generators or DER that have headroom, Battery storage, DR | No explicit requirement | | | | The response of the current system appears to be adequate (to be verified by WECC) | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | Further analysis is required to determine the economics of the spinning capacity meeting the additional reserve requirement. The existing spinning reserves are approximately 100 MW. Other means of obtaining spinning reserves (from battery storage and DR) should be |
| Operating Reserves (1) | | Online synchronous generators or DER that have headroom, Battery storage, DR | No explicit requirement | | | | The response of the current system appears to be adequate (to be verified by WECC) | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | Further analysis is required to determine the economics of the spinning capacity meeting the additional reserve requirement. The existing spinning reserves are approximately 100 MW. Other means of obtaining spinning reserves (from battery storage and DR) should be |
| Non-Spinning Reserves | | Online synchronous generators or DER that have headroom, Battery storage, DR | No explicit requirement | | | | The response of the current system appears to be adequate (to be verified by WECC) | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | As a function of forecast of wind and solar power, the system will have a high time (30 min) to 100MW, less than to the right | Further analysis is required to determine the economics of the spinning capacity meeting the additional reserve requirement. The existing spinning reserves are approximately 100 MW. Other means of obtaining spinning reserves (from battery storage and DR) should be |
| Contingency | Based on the amount of MW that is available from quick start units within an hour. Some of this capacity can be online towards the no-spin operating reserves. The remainder of the reserves need to be spinning | Quick Start units, DR | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | |
| Operating Reserves (2) | | Quick Start units, DR | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | |
| Operating Reserves (3) | | Quick Start units, DR | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 3 | U | | The response of the current system appears to be adequate (to be verified by WECC) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | 1000 MW of quick start units available (used for meeting peak load and to cover forecast uncertainty) | |

Step 4:

Identify “resource-level” ancillary service capability

Identify the amount of each ancillary service that can be performed by each resource. This establishes the subset of the respective resource’s capability that could be allocated to the given ancillary service. Items such as operating range, startup times, ramp-rates, min-up/down times, inertial response, black start capability, etc. are key considerations.

Example:
Representative
Ramp Rate
Capability for HECO
Resources

(other attributes would require similar definition for each resource)



| Unit | Actual 2012 | Target Upward | Target Downward | Maximum Upward |
|----------|-------------|---------------|-----------------|----------------|
| | (MW/min) | (MW/min) | (MW/min) | (MW/min) |
| HONH8 | 1.4 | 1.4 | 1.4 | 5.0 |
| HONH9 | 1.3 | 1.3 | 1.3 | 5.0 |
| WAIW3 | 1.4 | 1.4 | 1.4 | 4.0 |
| WAIW4 | 0.7 | 0.7 | 0.7 | 4.0 |
| WAIW5 | 3.0 | 3.0 | 3.0 | 5.0 |
| WAIW6 | 3.0 | 3.0 | 3.0 | 5.0 |
| WAIW7 | 3.0 | 5.0 | 3.0 | 7.0 |
| WAIW8 | 3.0 | 5.0 | 3.0 | 7.0 |
| WAIW9 | 3.0 | 5.0 | 5.0 | 10.0 |
| WAIW10 | 3.0 | 5.0 | 5.0 | 10.0 |
| KAHK1 | 3.0 | 5.0 | 3.0 | 7.0 |
| KAHK2 | 1.6 | 5.0 | 3.0 | 7.0 |
| KAHK3 | 3.0 | 5.0 | 3.0 | 7.0 |
| KAHK4 | 3.0 | 5.0 | 3.0 | 7.0 |
| KAHK5 | 3.0 | 7.0 | 3.0 | 10.0 |
| KAHK6 | 3.0 | 6.0 | 3.0 | 8.0 |
| CIP CT-1 | 3.0 | 10.0 | 10.0 | 13.0 |
| AES | 2.5 | | | |

Step 4: (cont'd)

Identify “resource-level” ancillary service capability

The following table provides an overview of the ancillary service compatibility *that would be assumed* for each HECO resource if a detailed ancillary service assessment of Scenario 4A were performed. *Note: Previous simulations and analysis of Scenario 4A have not explicitly considered the ancillary service obligations with the granularity depicted in the table below.*

| HECO Resources - Scenario 4A | Duty | Fuel | Prime Mover | Cap. (MW) | Ancillary Services Compatibility | | | | | | | | |
|------------------------------|----------|--------------|-------------|-----------|----------------------------------|------------------------------|------------|----------------|------------------|----------------------|---------------------|-----------------|-------------|
| | | | | | Inertial Response | Frequency Responsive Reserve | Regulation | Load Following | Spinning Reserve | Non-Spinning Reserve | Replacement Reserve | Voltage Support | Black Start |
| AES | Baseload | Coal | ST | 185 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| H POWER | Baseload | Biomass/Wast | ST | 73 | ✓ | --- | --- | --- | --- | --- | --- | ✓ | --- |
| HONUA WASTE UNIT | Baseload | Biomass/Wast | ST | 6 | ✓ | --- | --- | --- | --- | --- | --- | ✓ | --- |
| KAHE 1 | Baseload | LSFO | ST | 82 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | ✓ |
| KAHE 2 | Baseload | LSFO | ST | 82 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | ✓ |
| KAHE 3 | Baseload | LSFO | ST | 86 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | ✓ |
| KAHE 4 | Baseload | LSFO | ST | 85 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | ✓ |
| KAHE 5 | Baseload | LSFO | ST | 134 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| KAHE 6 | Baseload | LSFO | ST | 134 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| KALAELOA CC | Baseload | LSFO | CC | 90 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| KALAELOA CC | Baseload | LSFO | CC | 90 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| WAIU 7 | Baseload | LSFO | ST | 83 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| WAIU 8 | Baseload | LSFO | ST | 86 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | --- | ✓ | --- |
| HONOLULU 8 | Cycling | LSFO | CT | 53 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| HONOLULU 9 | Cycling | LSFO | CT | 54 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 3 | Cycling | LSFO | CT | 47 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 4 | Cycling | LSFO | CT | 47 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 5 | Cycling | LSFO | CT | 55 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 6 | Cycling | LSFO | CT | 54 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| AIRPORT DSG 8 MW | Peaking | Biomass/Wast | CT | 8 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| CIP CT BIODIESEL | Peaking | Biomass/Wast | CT | 113 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 10 | Peaking | Diesel | CT | 50 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| WAIU 9 | Peaking | Diesel | CT | 53 | ✓ | ✓ | ✓ | ✓ | ✓ | --- | ✓ | ✓ | --- |
| OAHU CENTRALIZED SOLAR | Solar | Solar | Solar PV | 400 | --- | --- | --- | --- | --- | --- | --- | ✓ | --- |
| OAHU DISTRIBUTED SOLAR | Solar | Solar | Solar PV | 360 | --- | --- | --- | --- | --- | --- | --- | ✓ | --- |
| OAHU WIND 30MW | Wind | Wind | Wind | 30 | --- | --- | --- | --- | --- | --- | --- | ✓ | --- |
| OAHU WIND 70MW | Wind | Wind | Wind | 70 | --- | --- | --- | --- | --- | --- | --- | ✓ | --- |

Step 5:

Execute the Production Cost Simulation

Execute the production cost simulation for the respective scenario. Review the hourly (and sub-hourly data as applicable) to ensure that all ancillary services requirements (plus other relevant system constraints) were observed. *i.e. sufficient system-level regulation, spinning reserve, etc. was reserved.*

Step 6:

Identify Trends in the Results

If the ancillary service requirements were not successfully achieved, or it appears that excess ancillary capability is available, consider the trends in the deficiencies (or excess):

- Are the deficiencies (or excess) driven by inadequate responsiveness from the available resources?
- Are the deficiencies (or excess) driven by inadequate operating range?
- Are the deficiencies (or excess) present in all hours or only some hours?

Step 7:

Consider potential solutions to alleviate deficiencies and improve system efficiency

Adjustments to operating procedures:

- Adjusted minimum run-times
- Relaxed qualifications/requirements for respective A/S participation
- Activation thresholds for DR,
- storage device charging procedures
- Relaxed “must-run” rules

Retrofits of existing resources:

- Increased plant output
- Improved turndown on thermal units
- Elevated ramp-rates
- Reduced start times
- Synthetic inertia & governor response from renewables

New resources:

- Fossil
- Storage
- Demand response
- Renewable assets
- Inter-island connectivity

Coupled Benefits

Are there resource adjustments (or new resources) that would alleviate multiple deficiencies (or excess)?

i.e. Re-tuning the synthetic inertia of a wind-turbine in conjunction with pitch-control enhancement might facilitate improvements to both inertia and regulation capabilities.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions: Inertial Response – Scenario 4A

Observations

- The inertial response of the system appears to be adequate in Scenario 4A.

Recommendations

- Consider requiring interconnecting wind and solar plants to provide synthetic inertia to further strengthen the inertial response capability.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Frequency Responsive Reserve – Scenario 4A

Amount Required

- Under-frequency response: Needs to be able to cover loss of largest unit (185 MW)
- Over-frequency response: To cover loss of load events: 140MW (daytime) under a transmission fault; 90MW (night-time) under the loss of 80MVA transformer and loss of adjacent 46kV feeders.

Observations

- For under-frequency*, the results of HSIS study show that:
 - Enforcing "no trip" of distributed PV on under-frequency excursion helped to reduce the frequency drop by 2.2-3.4 Hz (if UFLS is not active).
 - Use of frequency responsive load (50MW @ 59.5 Hz trip), and synthetic inertia from wind plants can support the system during loss of generation contingency by reducing the frequency nadir by up to 0.3 Hz, in cases where synchronous generators are displaced by renewables.
- For over-frequency*:
 - Over-frequency control (5% droop, 36mHz dead-band) from renewables seems to improve the system performance under 140MW of load rejection in a challenging hour. The burden on the thermal units gets reduced by 43% and the frequency excursion decreases by 0.7 Hz.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Frequency Responsive Reserve – Scenario 4A

Recommendations

- For under-frequency, *one or more of the following changes may be required under Scenario 4A and 4B (additional simulation / analysis would be required to confirm):*
 - *Obtain primary frequency response from frequency responsive load*
 - *Prevent distributed PV from tripping (not an ancillary service... more to do with IEEE 1547)*
 - *Permit curtailed wind and solar resources to provide under-frequency response*
- *For over-frequency:*
 - *Consider allowing wind and solar resources plants to provide over-frequency response.*

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Regulation & Load Following – Scenario 4A

Observations

- The regulation and load following needs of the system are currently covered by operating reserves and deemed to be adequate.

Recommendations

- No firm recommendations at this time. Further analysis may yield a more economically optimal means of obtaining the regulation & load following services.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Spinning Reserve – Scenario 4A

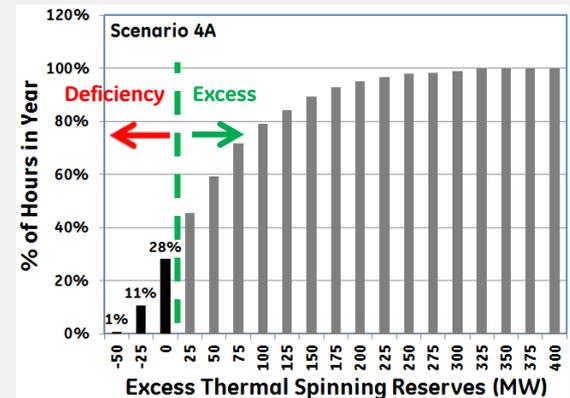
Amount Required

- Contingency Reserves: Needs to be able to cover loss of largest unit (185 MW)
- Operating Reserves: No explicit requirement, but required to cover statistical variation in load and renewable generation in the 1 minute to 1 hour timeframe. Quick start capability is taken into account when calculating spinning reserve requirements.
 - Max variation: Day-time (6am-8pm) = 239MW; Night-time (8pm-6am) = 32MW.

Observations

- In Scenario 4A, a deficiency of Spinning Reserves is anticipated 28% of the time (up to 50 MW maximum)
- Due to sufficient reserve participation from baseload units, the full 50 MW would only be required 1% of the time.
- However, in some hours, cycling units are committed to meet the higher operating reserves requirement & net load.

Analysis of Spinning Reserve: HECO Scenario 4A



Steps 6/7: (cont'd)

Note: Comprehensive validation of the recommendations in this step require additional simulation runs and analysis which are presently determined to be outside the scope of this study.

Identify Trends / Consider Solutions : Spinning Reserve – Scenario 4A

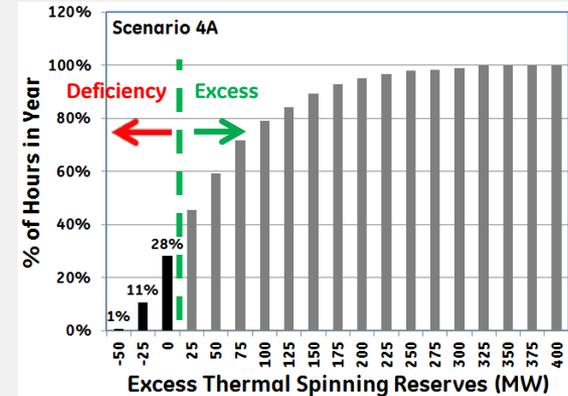
Recommendations

Multiple options exist to relieve the anticipated Spinning Reserve issues. Two options will be presented below:

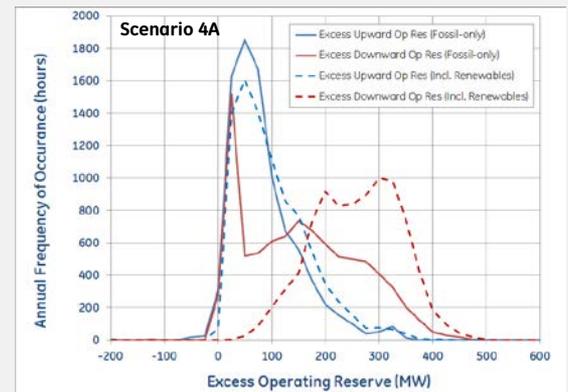
Option #1: To alleviate the deficiency, consider the addition of 50-MW BESS or DR resource. Beyond relieving the shortage, this option could potentially lower the reserves requirement on thermal units and help to de-commit cycling generation which would allow the system to absorb more solar & wind energy.

Option #2: To relieve the excess spinning reserve, consider allowing curtailed renewables to provide reserves. Modern Wind / Solar facilities are capable of responding quickly to load set-point adjustments. This action may reduce commitment on thermal units (reducing excess reserves), and potentially provide for increased penetration of renewable resources.

Spinning Reserve Adequacy



Inherent Spinning Reserve From Renewables



Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Non-Spinning Reserve – Scenario 4A

Amount Required

- Contingency Reserves: All contingency reserves are required to be spinning on an island system.
- Operating Reserves: No explicit requirement for non-spinning operating reserves.

Observations

- The response of the current system appears to be adequate.

Recommendations

- None.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Black Start – Scenario 4A

Amount Required

- The MWs and location of black start units are determined based on a planning study
- Currently provided by the Kahe, Waiau, and Campbell units.

Observations

- Black start capability of the system is probably sufficient since there is no significant load growth in Scenario 4A. Further analysis may be required to confirm.

Recommendations

- None.

Steps 6/7: (cont'd)

Note: Additional information can be found in the spreadsheet which accompanies this report titled: "HECO Ancillary Services for Scenarios".

Identify Trends / Consider Solutions : Voltage Support – Scenario 4A

Observations

- Currently provided by all online generators with voltage and reactive power controls (including Wind, Solar, and Sync. Condensers)
- The response of the current system appears to be adequate.

Recommendations

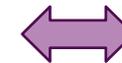
- There may a need for additional voltage support if the “must-run” rules on existing thermal units is relaxed.

Steps 6/7: (cont'd)

Identify Trends / Consider Solutions : Many Permutations of Solutions are Available

| | |
|---|--|
| C | Currently deployed: Assumed to be available for HECO Scenario 4A |
| A | Future Option: Available commercially |
| E | Future Option: Emerging capability in demonstration phase |
| T | Future Option: Technically feasible, but not currently being pursued |

| Technologies | Ancillary Services Compatibility | | | | | | | | |
|--|----------------------------------|------------------------------|------------|----------------|------------------|----------------------|---------------------|-----------------|-------------|
| | Inertial Response | Frequency Responsive Reserve | Regulation | Load Following | Spinning Reserve | Non-Spinning Reserve | Replacement Reserve | Voltage Support | Black Start |
| Generation | | | | | | | | | |
| Solar Thermal | A | T | T | T | T | --- | --- | A | T |
| Solar Photovoltaic (Transmission Connected) | T | T | T | T | T | T | T | T | --- |
| Wind (non-synchronized / power conversion) | A | A | A | A | A | T | T | A | --- |
| Wind (synchronized) | A | A | A | A | A | T | T | A | T |
| Hydropower | A | A | A | A | A | A | A | A | A |
| Geothermal | A | A | A | A | A | --- | --- | A | T |
| Biomass ST | C | A | A | A | A | --- | --- | C | --- |
| Oil-fired ST | C | C | C | C | C | --- | --- | C | C |
| Coal ST | C | C | C | C | C | --- | --- | C | --- |
| Combined Cycle (Gas/Oil/Biomass/Waste) | C | C | C | C | C | A | A | C | A |
| Simple Cycle (Gas/Oil/Biomass/Waste) | C | C | C | C | C | C | C | C | C |
| Reciprocating Engines (Gas/Diesel/Bio) | A | A | A | A | A | A | A | A | A |
| Energy Storage | | | | | | | | | |
| Pumped Hydropower | A | A | A | A | A | A | A | A | A |
| CAES - Comp. Air Energy Storage | E | E | E | E | E | E | E | E | T |
| Solid Batteries | E | E | A | E | A | E | E | E | E |
| Flow Batteries (Redox) | T | T | T | T | T | T | T | T | T |
| Flywheels | E | E | E | E | --- | --- | --- | T | --- |
| PEV | T | T | E | T | T | T | T | T | T |
| Fuel Cells (PEM) | T | T | T | T | T | T | T | T | T |
| Demand Response | | | | | | | | | |
| Fast Auto DR | T | A | A | T | A | A | A | --- | --- |
| Direct Load Control | T | A | E | T | A | A | A | --- | --- |
| Interruptible Load | T | A | T | T | A | A | A | --- | --- |
| Price Responsive Demand | T | T | T | T | A | A | A | --- | --- |
| Transmission | | | | | | | | | |
| Synch. Cond.: Large motor frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: Air-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Synch. Cond.: H2-cooled generator frame | A | --- | --- | --- | --- | --- | --- | A | --- |
| Shunt FACTS devices (STATCOM, SVCs)* | --- | --- | --- | --- | --- | --- | --- | A | --- |
| HVDC Transmission Technologies* | --- | --- | --- | --- | --- | --- | --- | A | A |
| Desirable Attributes / Retrofit Options | | | | | | | | | |
| Improved Turndown (MinGen) Capability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Elevated Ramp-rate Capability | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| Faster Startup Capability | | | | | | | | | |



Resource mix that was considered in the simulation of Scenario 4A

- Many alternative options are available to fulfill the desired renewables penetration levels associated with Scenario 4A.
- The associated A/S permutations of resource types (and modifications) along with technology readiness is captured in the table at the left.

Steps 6/7: (cont'd)

Identify Trends / Consider Solutions : Synergies between technology types

When selecting new resources and/or resource modifications to alleviate ancillary constraints, there may be synergies available. For example:

- When allowing VG (solar/wind) to participate in A/S, the addition of a moderate amount of storage may have the potential enable more periods where VG can provide the A/S needs. Further, the availability of the storage may help to cover a portion of the A/S requirements that would have otherwise been provided by dispatchable thermal generation ... further increasing renewables penetration objectives. DR may offer benefits which are analogous to those of storage.
- As additional “non-synchronous” generation is added to the power system for the purposes of providing both energy and ancillary services, there may be a need for the addition of transmission technologies such as synchronous condensing units to be added to ensure sufficient reactive power.

It should be noted that the degree to which synergies will be available and their corresponding benefit is highly dependent upon the respective scenario being considered. The current process being described provides a method for evaluating a technology mix in a given scenario. As each scenario/mix combination is evaluated, other potential synergies between technologies may emerge.

Steps 8/9:

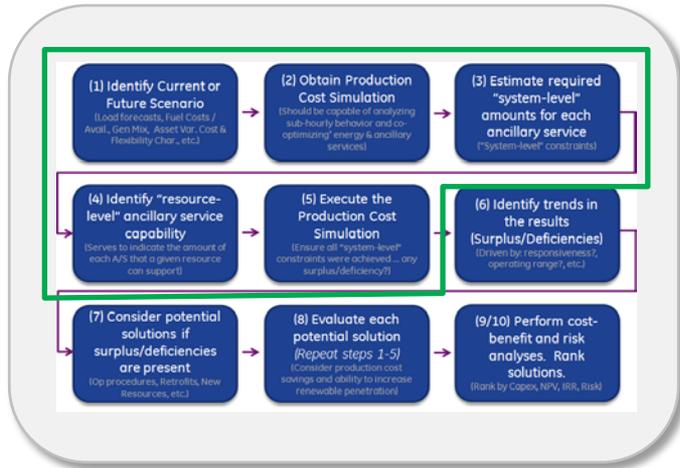
Evaluate the economic viability of each potential solution

Note: Completion of this step requires additional simulation runs and analysis which are presently determined to be outside the scope of this study. Conceptual illustration only.

Step 8: For each potential solution identified, repeat steps 1-5:

- Consider/evaluate the change in total cost required to serve the anticipated system load profile.
- Potential for the respective solution to facilitate the desired trajectory of renewables penetration over-time.

Step 9: Perform a cost-benefit analysis which evaluates the year-over-year (YOY) system-level benefit (typically in the form of reduced production cost) of the proposed solution relative to the capital cost required to achieve the respective solution. Rank the solutions according to their economic viability (i.e. NPV, IRR, etc.)



Step 10:

Evaluate the risks associated of each potential solution

Note: Completion of this step requires additional simulation runs and analysis which are presently determined to be outside the scope of this study. Conceptual illustration only.

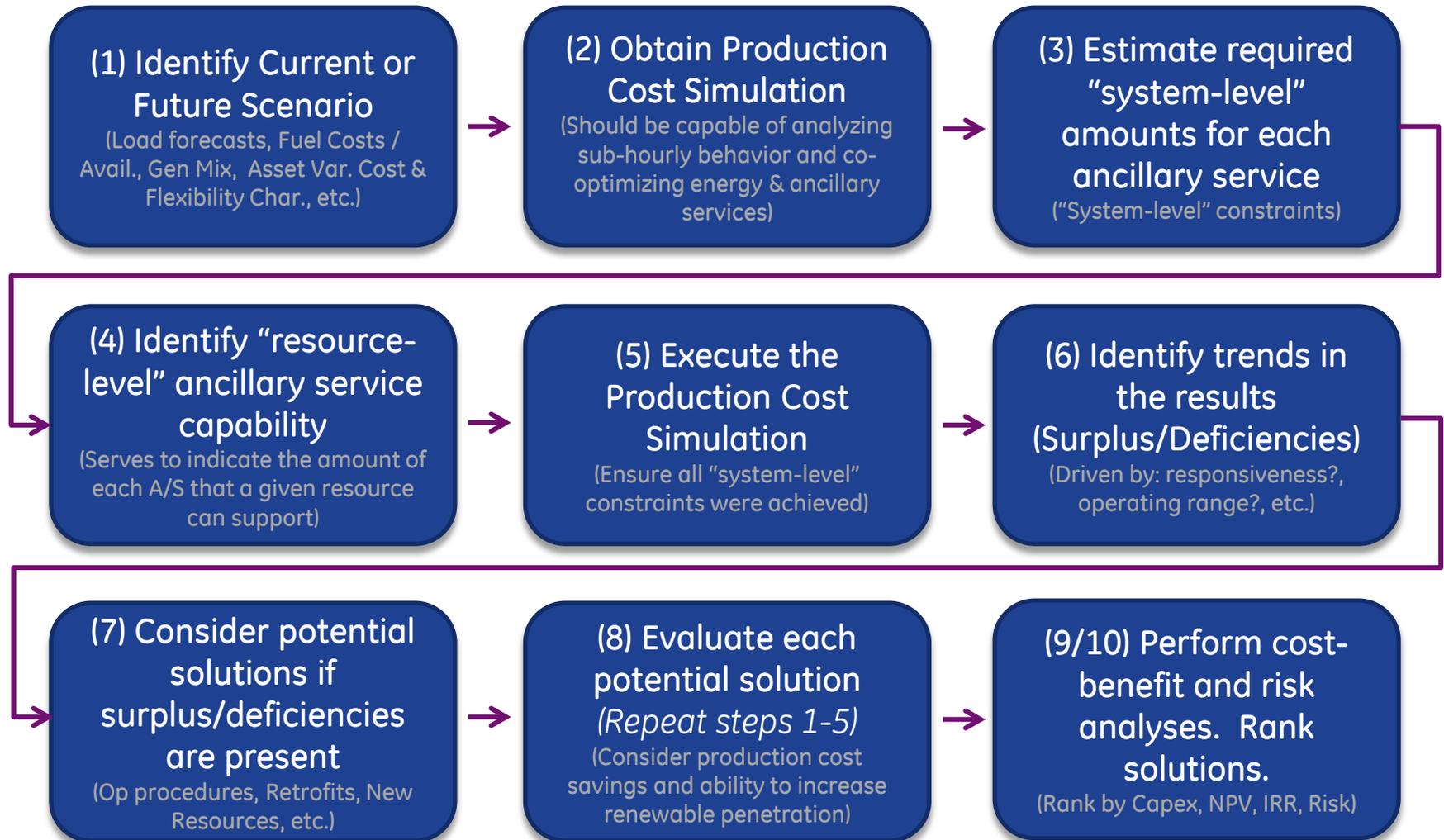
A comprehensive risk assessment of the potential options should also be conducted and weighted against to the economic viability to ensure that the selected solution is robust and reliable.

Potential Risks to consider (not limited to the following):

- Inadequate response from renewables due to instantaneous availability
- Available down-reserves and stable operating region of thermal units during loss of load events
- Voltage/VAR support sufficiency
- Reductions in inertial response capability
- Unfavorable impacts to “system-level” variable cost of operation
- Impact to existing utility / IPP contracts may require modifications to accommodate schedule changes
- Challenges associated with monitoring / controlling DR participation on a centralized basis

Process to Estimate Technology Mix

Summary



Considerations for Specifying and Acquiring Ancillary Services

Task 4: Scope & Deliverables

Outline considerations for specifying and acquiring ancillary services

Objectives:

- Promote a least-cost portfolio of resources that can supply ancillary services and interconnection requirements that attempt to protect reliability, maximize renewable output and minimize energy costs
- Highlight costs, technology availability, fuel availability or other risks associated with the recommended ancillary services and potential technology mix, with contributions from HPUC and HECO
- Outline factors and provisions to consider for future resources:
 - Type of ancillary services and performance requirements (Task 1)
 - Technology/manufacturer neutral response capabilities for interconnection requirements for new generators (Task 2)
 - Risk, cost and cost-effectiveness methods explored in other power systems
 - Process to compare alternative ancillary service offerings
- Describe any additional study work, including estimated timeline and cost, that may be required to identify the type and amount of ancillary services required

Task 4: Scope & Deliverables

Outline considerations for specifying and acquiring ancillary services

Approach:

- Summarize findings in Tasks 1-3
- Identify potential risks such as Hawaii specific resource costs, technology availability, fuel availability, and other that may impact the ability of the Hawaiian utilities and HPUC to build an effective portfolio of resources to provide ancillary services, fulfill interconnection requirements or address other system considerations

Methods for Procuring Ancillary Services

Procuring Ancillary Services

Overview of Approaches for Obtaining, Compensating, and Incentivizing

This section puts forth some potential approaches and mechanisms which can be used to obtain, compensate, and incentivize resources for providing ancillary services.

The following **four** approaches will be highlighted in this section:

1. Market Clearing Price
2. Reimbursement of Offer Price
3. “Make-whole” Compensation
4. Condition of Interconnection

The above listing is not intended to be exhaustive; however, the GE team believes that it contains a representative subset of the most viable techniques which could be considered. Further, it should be noted that each option is not mutually exclusive and may incorporate aspects of the surrounding approaches.

Procuring Ancillary Services

Method 1: Market Clearing Price

The Marketing Clearing Price approach is leveraged primarily by wholesale power markets:

- For this method, each resource submits (or is assigned) an offer price for the respective ancillary service.
 - Most often, resources submit offer prices that are based on their opportunity cost to reserve the headroom or legroom required to provide the service.
 - Some resources, such as storage devices, do not have an opportunity cost because they do not directly provide energy. Instead, their offer price may be based on startup, variable O&M, charging costs, or other expenses associated with providing the respective A/S.
 - In addition to the cost to provide the service, many markets allow resources to include “additional margin” in their offer price. In some cases, the resource may use the additional margin to hedge against increased variable O&M costs (i.e. cycling wear & tear). In other cases, the resources may simply leverage the additional margin to cover “cost uncertainty” and/or attempt to enhance their ancillary profitability.
 - In some markets, the offer price is capped. The cap is often derived by calculating the cost for a unit to provide the service and adding [up to] a maximum allowable margin. The lesser of the submitted price and the capped price is then used as the offer price in the market clearing algorithms.

Procuring Ancillary Services

Method 1: Market Clearing Price (cont'd)

- The “market clearing price” for the ancillary service is driven by the offer price of the last rank-ordered* resource required to satisfy the system-level ancillary requirement (for the respective ancillary service). For this approach, all participating resources will receive the “same price” for the given period (typically 1-hour increments).
 - *In many wholesale markets, there exists both a day-ahead clearing price and a real-time (or supplemental) clearing price (as-required) to ensure sufficient ancillary availability.*
- To incentivize “no risk” participation, some markets will compensate for “actual incurred” costs which are larger than the revenues derived from the ancillary market clearing price via “make-whole” payments. This ensures that resources are “no worse off” for having provided ancillary services.
- Due to the fact that all participating resources receive the same price for a given ancillary service, it is important to note that most resources, with the exception of the marginal ancillary resource, will earn a financial benefit (i.e. profit) for providing the respective A/S.

* A “low to high” ranking of the offer prices for each participating resource.

Procuring Ancillary Services

Method 2: Reimbursement of Offer Price

The Reimbursement of Offer Price is an alternative that could potentially be leveraged between two contracting parties seeking to enter into a bilateral agreement for A/S. It is a logical compromise between the “market clearing price” and “make-whole compensation” approach.

- Instead of a “clearing price” for the ancillary service, each resource is compensated on an individual basis for providing the service.
- The offer price for each resource would likely be derived in a similar fashion to the Market Clearing Price methodology. Specifically, the resource’s “cost to provide + margin” (including opportunity costs) would serve as a rational basis for the offer price. If the agreement is between a utility and IPP, the offer price could be based on the anticipated production cost savings for the utility. The final ancillary service price would be based on a negotiated value between the respective parties.
- The period for which this contractually agreed to price is valid could be varied (i.e. hourly, daily, monthly, annually, or simply set at a constant rate for contract period, etc.)
- Similar to the Market Clearing Price approach, it is recommended that the Reimbursement of Offer Price incentivize participation by providing a “no-risk” contract architecture through the reimbursement of “actual incurred” costs (i.e. if incurred costs are higher than the compensation that would be derived via the offer-price).
- Due to the fact that resources are compensated on an individual basis, profitability (for the resource providing the service) is limited to the margin included in the offer price.

Procuring Ancillary Services

Method 3: Make-whole Compensation

The Make-whole Compensation approach is another alternative that could potentially be leveraged between two contracting parties seeking to enter into a bilateral agreement for A/S. Most wholesale markets include “make-whole compensation” provisions in their architecture. This method extracts the “spirit & intent” of those provisions.

- At its core, the rationale for “Make-whole Compensation” is to explicitly compensate participating resources for their costs (including opportunity costs) associated with providing A/S. This method is designed to make the participating resource indifferent toward providing ancillary services.
- Instead of negotiating an offer-price, the resource-specific cost structure would be shared between the contracting parties so that an accurate assessment of incurred costs could be obtained.
- Due to the fact that resources are compensated on an individual basis, and only for their cost to provide the service, there is no additional profitability potential for participating in A/S. For the three approaches discussed thus far, this method will typically result in the lowest overall production cost to reliably serve the load.
- It is important to note that while this approach adequately and explicitly compensates resources for their A/S participation, it does not incentivize that participation.

Procuring Ancillary Services

Method 4: Condition of Interconnection

It is important to note that all power systems (historical, existing, and future) require the use of certain interconnection requirements and ancillary services to ensure the system reliability is maintained. In many cases, such as with regulated utilities, the explicit compensation of resources for ancillary participation has not been required to maintain a reliable system. For this reason, the [Condition of Interconnection](#) approach was included in this list of options.

- The “Condition of Interconnection” approach would simply require ancillary service capability and participation from interconnecting resources.
- Resources would not be explicitly remunerated for providing ancillary service capability or for the associated costs incurred.
- The incentive for resources to provide ancillary service capability would be driven by the accompanying right to participate in selling energy.
- For this type of agreement, it is implied that the participating resources would derive financial benefit from the sale of energy alone that was sufficiently large enough to cover both the cost to provide energy and the cost to provide A/S.
- Due to the lack of explicit compensation, the “Condition of Interconnection” approach has the potential to offer the lowest production cost of the four methods described.

Procuring Ancillary Services

Forward Planning Approach to Derive Rational Ancillary Service Contract Prices

Much attention has been focused on obtaining ancillary services from resources with the lowest offer price and/or lowest “cost to provide” (including opportunity costs).

One potential method for assessing the basis of a “rational” ancillary service offer price would be to leverage a production cost simulation with the capability to co-optimize energy and ancillary services. For a given future scenario, with a known resource mix, the simulation could be exercised and evaluated at both a resource-level and a system-level to draw conclusions about a rational offer price for the respective resource:

- At a resource-level, the results of the simulation could be interrogated to identify the perceived cost (including opportunity cost) for each resource to provide a given ancillary service. **To develop an offer price, the hourly observations for each resource could then be aggregated and averaged over a period that aligned w/ the desired contractual period.**
- At a system-level, the simulation could be exercised by individually enabling / disabling the respective ancillary service capability for each resource under consideration. **The resulting benefit (i.e. “reduction”) in the overall annual production cost could be used as a basis for assessing the ancillary service offer price for each particular resource.**

To adequately bound the offer price, it is recommended that both the resource-level and system-level assessments be conducted.

Hawaii-Specific Ancillary Service Procurement

Procuring Ancillary Services

Methods for Obtaining Ancillary Services in Hawaii

On Hawaii, ancillary services are presently obtained from dispatchable resources through a method which is similar to the previously mentioned “Condition of Interconnection” approach. Specifically, the utilities have the ability to dispatch resources to provide ancillary services without explicit compensation to the respective resources.

Going-forward, there will be a continued desire to increase the penetration of renewable resources on the Hawaiian system which has the potential to increase the system-level ancillary service requirements.

As the system-need for ancillary services increases, it may be necessary to incentivize new resources to provide (or existing resources to expand upon) their ancillary service capability. This incentive would likely come in the form of explicit financial compensation and include aspects of either the “make-whole compensation” or “reimbursement of offer price” methods. **However, it should be noted the use of these methods has the potential to increase the overall production cost as a result of the explicit compensation for [some of/all of] the ancillary services. Careful consideration is required before integrating such remuneration methods.**

Procuring Ancillary Services

Methods for Obtaining Ancillary Services in Hawaii

As outlined in the technology table (Part I, Task 2), renewable resources (i.e. wind/solar) are capable of providing many ancillary services. The use of these resources for providing A/S may help to facilitate their increased penetration and potentially reduce production costs as it introduces another degree of freedom for commitment & dispatch. Current RFP's and draft PPA's are seeking to leverage this capability from VG resources.

Relative to the current environment, in which resources are not explicitly compensated for fulfilling the system-level ancillary obligations, requiring the wind/solar to provide ancillary services via the "Condition of Interconnection" approach would certainly be an equitable option.

Due to the fact that wind/solar resources are presently compensated based on their energy contract price, which likely includes some fixed and capital cost recovery, there are periods when wind/solar are *more expensive* to operate than some non-renewable resources on the system (*i.e. periods where the energy contract price is higher than the marginal system cost*). During these periods, it may result in a system level production cost savings to curtail wind/solar to provide ancillary services. However, the existing wind/solar contracts have provisions which preclude the curtailment of these resources for economic reasons. **Therefore, during periods where wind/solar are curtailed exclusively for the purposes of providing ancillary services (i.e. up-reserves), the use of "Make-whole Compensation" would be recommended.**

Procuring Ancillary Services

Methods for Obtaining Ancillary Services in Hawaii

It should be noted that the existing wind/solar contracts purposefully prevented curtailment for economic reasons in an effort to maximize renewable penetration. Therefore, to adopt the previous recommendation, an adjustment to the existing contracts would likely be required.

Energy storage devices have the potential to enhance penetration of renewable resources and/or lower the overall production cost. The process for “Evaluating and Selecting a Potential Resource Mix” could be leveraged to help quantify these potential benefits.

Due to the fact that energy storage resources are energy-neutral and operate exclusively for the purposes of providing ancillary services, the use of “make-whole compensation” is not applicable (i.e. storage resources have no opportunity costs). **Therefore, an explicit remuneration method, such as “Reimbursement of Offer Price” may be required to incentivize the development & participation of energy storage resources to supply ancillary services.**

To obtain a value for the ancillary services offered by the energy storage resources, it is likely that the previously mentioned “system-level” use of a production cost simulation would be required. Specifically, the simulation could be exercised by individually enabling / disabling the respective ancillary service capability for each resource under consideration. The resulting benefit (i.e. “reduction”) in the overall annual production cost could be used as a basis for assessing the ancillary service offer price.

Procuring Ancillary Services

Methods for Obtaining Ancillary Services in Hawaii

Ancillary service participation from DR, transmission, and retrofit options have the potential to reduce production costs, improve renewables penetration, and avoid/defer/attenuate major capital expenditure.

Similar to energy storage resources, an **explicit compensation method would likely be required to incentivize participation from DR and/or transmission-related technologies.**

To incentivize the modification (i.e. retrofit) of existing resources to provide, or expand upon, their ancillary service capability, further use of **explicit compensation may be required to cover upgrade costs.**

Procuring Ancillary Services

Methods for Obtaining Ancillary Services in Hawaii

It should be noted that some resources have the potential to increase (or decrease) the required amount of ancillary services on the system. Further, some resources have the potential to provide more ancillary capability than other resource types.

In some cases, such as wind/solar, an individual resource has the potential to increase the required amount of ancillary services on the system. However, these resources also have [typically] low variable operating cost and have the potential to reduce the overall production cost for the system.

As a result, it is **not recommended** that **individual resources**, which induce additional ancillary obligations on the system, **be additionally penalized**.

Instead, it is recommended that the impact on **overall production cost** (including total ancillary services costs), coupled with other policy-related directives such as **renewable penetration targets**, be **used as the metric** to **assess the viability** of a particular resource.

Risk Assessment and Other Considerations

Risk Considerations

Outline considerations for specifying and acquiring ancillary services

- Hawaii specific resource costs
- New/emerging technology availability
- Ability to uprate/upgrade existing resources
- Fuel availability and fuel infrastructure
- Wind and solar forecasting process
- Interconnection costs
- Inter-Island transmission connections
- Challenges associated with monitoring / controlling Demand Response participation on a centralized basis
- Load shaping programs
- Inadequate response from renewables due to instantaneous availability
- Available down-reserves and stable operating region of thermal units during loss of load events
- Voltage/VAR support sufficiency
- Reductions in inertial response capability
- Unfavorable impacts to “system-level” variable cost of operation
- Impact to existing utility / IPP contracts may require modifications to accommodate schedule changes

Risks are highlighted in the “Observations” column of the scenario workbooks for each system

Technology Risks

Generation Technology Risks

- **Wind Turbines:**
 - Variable generation
 - Unstable incentive structures (i.e. government tax credits)
- **Gas Turbines / Combined Cycles:**
 - Volatile fuel prices
 - Fuel transport costs
- **Simple Cycles:**
 - Volatile fuel prices
 - Fuel transport costs
- **Reciprocating Engines:**
 - To be added

Generation Technology Risks

- **Solar Thermal:**
 - Unstable incentive structures (i.e. government tax credits)
 - Potential negative environmental impact - large installations can disrupt ecosystems/Permitting can be a major issue in Hawaii
- **Solar PV:**
 - Variable generation
 - Unstable incentive structures (i.e. government tax credits)
- **Hydropower:**
 - Potential negative environmental impact - large installations can disrupt ecosystems/Permitting can be a major issue in Hawaii
- **Geothermal:**
 - Potential negative environmental impact - large installations can disrupt ecosystems/Permitting can be a major issue in Hawaii

Generation Technology Risks

- **Biomass:**

- Unstable incentive structures (i.e. government tax credits)
- Cost of collecting biomass

- **Coal:**

- Negative environmental impact
- Fuel transport costs

Storage Technology Risks

- **PHS:**

- Energy naturally wants to spread out, so compressing water behind a dam creates the risk of an uncontrolled energy release
- High costs/market liquidity/market price uncertainty (revenues from ancillary services hugely volatile)
- Arbitrage revenue - after efficiency is taken into account this is not a huge money spinner at some market prices
- Market risk (i.e. change in ISO rules)
- Potential negative environmental impact - large installations can disrupt ecosystems/Permitting can be a major issue in Hawaii
- There is a real option value that may not be captured unless risk is explicitly identified and quantified - plant operations decisions must incorporate these risks
- A serious disadvantage is dependence on specific geological formations or man-made reservoirs
- Difficult construction – depends on topography

Storage Technology Risks (Comments)

Comments from HREA:

- Risk of Structural Failure: We understand with proper design and installation, the risks of dam or reservoir failures are very low. In addition, a Pumped Storage facility using advanced Roller-Compacted Concrete (“RCC”) technology would mitigate structural risk with a design that incorporates a deep reservoir with most of its capacity below ground level. See also the Division of Safety of Dams (“DSOD”), Department of Water Resources in California for additional information (<http://www.water.ca.gov/damsafety/>).
- High costs/market liquidity/market price uncertainty: All renewable projects in Hawaii face similar costs/market risks. Re Pumped Storage, we understand construction costs would be similar to those for a wind farm of similar MW capacity. We agree that there could be risks associated with Pumped Storage that operates in the “classic” duty cycle for pumping during off-peak hours and generating during peak hours. However, we believe additional revenues for a number of ancillary services, such as load following, frequency response, spinning reserve, inertial stability (Wr2), voltage support, VAR generation/control, and black start capability, can reduce that risk significantly. The key will be ability to negotiate a PPA that helps meet system needs and provides an adequate revenue stream such that investors can make an acceptable return on their investment.
- Arbitrage revenue: As discussed previously, Pumped Storage may not be able to accomplish the primary goal of energy arbitrage, i.e., buy low, sell high or higher, in Hawaii. However, we believe a Pumped Storage facility with PPA that includes appropriate payment for generation and ancillary services can be financially viable.

Storage Technology Risks (Comments)

Comments from HREA:

- Environmental Impacts: All projects have this risk, especially in Hawaii. We understand that FERC has revised its licensing requirements for “low impact hydro,” which includes Pumped Storage. This revision is believed to reduce the time required to obtain a FERC license. In parallel, the developer of a Pumped Storage facility will need to prepare an EIS as part of the overall permitting process, just like any major renewable project. In addition, the reservoirs could be designed to be a source of fresh water.
- Risk of geological formations or man-made reservoirs: We do not believe Pumped Storage facilities will need to use existing geological formations in Hawaii, and in many instances the use of existing geological formation is not ideal due to soil stability and porosity concerns. The risk associated with man-made reservoirs can be mitigated through design and implementation approaches as discussed above. Furthermore, the FERC licensing review and approval process is rigorous.
- Difficult Construction: We agree. Construction costs will be higher in remote areas and sites that present topographic challenges, e.g., remote, steep terrain, just as it would be with any construction project. For pumped-storage the “sweet spot” tends to be an elevation difference of 300 to 600 feet; otherwise equipment costs become prohibitive for pumping more than 600 feet and generation efficiencies and outputs do not provide the return on investment below 300 feet. We believe that there are numerous potential sites in Hawaii that meet this criteria as well as being in relatively accessible locations.

Storage Technology Risks

- **CAES:**

- Energy naturally wants to spread out, so compressing air underground creates the risk of an uncontrolled energy release
- High costs/market liquidity/market price uncertainty (revenues from ancillary services hugely volatile)
- Arbitrage revenue - after efficiency is taken into account this is not a huge money spinner at some market prices
- Potential negative environmental impact - large installations can disrupt ecosystems/Permitting can be a major issue in Hawaii
- Determining the appropriateness of an underground aquifer geological structure is always challenging - it is difficult to determine, with precision, the exact characteristics of what actually exists underground without core sampling (i.e., test wells)
- Underground storage requires a special site with the appropriate geological characteristics (normally these are salt caverns but on the mainland depleted natural gas fields, or other types of porous rock formations could be used)
- Above ground storage requires large pressure vessels or pipelines
- Need a fuel for the gas turbine - the fuel could be biodiesel, ethanol, or hydrogen (fuel cost impacts exist)

Storage Technology Risks

- **Batteries:**

- Energy naturally wants to spread out, so packing it into a small space like a battery creates the risk of an uncontrolled energy release like a fire or explosion (lithium-ion batteries, sodium-sulfur batteries) -newer lithium-ion batteries store more electricity than other electrochemical storage systems
- Cascading failure/thermal runaway happens when a cell fails and releases its energy as heat which can cause adjacent cells to fail and generate heat, as well, leading to melting materials and fires (water can't always be used to extinguish an electrical fire, since water can conduct electricity)
- Limited lifetime - need to be replaced periodically
- Maintenance requirements higher than competing technologies
- Storage capacity is limited – cannot attain same capacity as pumped storage
- Sensitive to heat: service life can be reduced considerably if operated above rated temperature
- Battery life depends on cycle-depth
- Flow batteries complicated compared to standard batteries as they require pipes (susceptible to leakage), valves, pumps, storage tanks sensors, control units, and secondary containment vessels
- Energy densities in flow batteries are generally lower when compared to portable batteries such as Li-ion

Storage Technology Risks

- **PEVs:**

- The technology is still in its infancy
- In a car, a battery is exposed to a wide range of humidities, temperatures and electrical loads, and all of these factors influence the battery's reliability, and if they get too extreme, they can cause a thermal runaway condition
- Unstable incentive structures (i.e. government tax credits) limits PEV adoption
- Leverages the existing electrical delivery system but additions to the existing system are necessary:
 - The “smart-grid” infrastructure must be installed to accept PEVs
 - Convenient outlets for households that lack them (e.g. high rise apartments, building without garages etc.) as well as outlets in parking lots and on parking meters
 - Fast chargers that refill a battery in minutes rather than hours (fast chargers can refill batteries in 10-15 minutes) - they require heavier wires than most households have and thus will at least be located at gas stations and other key places
 - Tariffs and monitoring equipment that discourages recharging during peak hours - need large disincentives to discourage filling up during peak hours
- Uncertain ability of the electrical distribution system to manage bi-directional flow of power (what % of a feeder's load can be back fed through transformers?)
- New demand may stress low voltage distribution lines
- Storage degradation (= operating cost) if deep discharge of battery
- Need to prioritize driving needs

Storage Technology Risks

- **Flywheels:**

- Energy naturally wants to spread out, so packing it into a small space like a flywheel creates the risk of an uncontrolled energy release like a fire or explosion (i.e. Beacon Power 20 MW flywheel systems in Stephentown, N.Y)
- Material strength and safety concerns limit energy output
- While very efficient in short duration response functions, flywheels are not currently designed for providing long-duration energy response
- Flywheels are not well suited to provide spinning/non-spinning reserve - the limiting factor for flywheels is the duration of the response required

- **Fuel Cells:**

- The technology is still in its infancy
- Energy naturally wants to spread out, so packing it into a small space like a fuel cell creates the risk of an uncontrolled energy release like a fire or explosion

Demand Response Program Risks

- **Fast Auto DR:**

- Regulatory approval (if any)
- Finding the appropriate DR resource – and sizing/speed for different A/S offerings (frequency control, load following, regulation up/down, spinning and non-spinning reserves)
- DR resource qualification (meeting the strict requirements)
- Technical complexity and readiness, system integration, and technical inter-operability
- Determination of the right level of incentives and pricing scheme

- **Direct Load Control:**

- Regulatory approval (if any)
- Finding the right types of resources, resource mix, and resource size
- Customer selection, agreement, and engagement
- Determination of the right level of incentives
- Lack of verification of system breakdowns and customer over-rides in DLC with one-way communication

- **Interruptible Load:**

- Regulatory approval (if any)
- Finding the right types of resources, resource mix, and resource size
- Customer selection, agreement, and engagement
- Determination of the right level of incentives and rate design
- Potential for lack of response by customer in the event of instruction by the utility for customer action to interrupt the load

Demand Response Program Risks (Continued)

- **Price Responsive Demand:**
 - Regulatory approval (if any)
 - Finding the right types of resources, resource mix, and resource size
 - Customer selection, agreement, and engagement
 - Technical system design and implementation (AMI, Communications, etc.)
 - Resource aggregation and system integration
 - Appropriate Dynamic Pricing Rate Design and determination of the right level of incentives (different approaches for different dynamic pricing type such as TOU, CPP, CPR/PTR and RTP require)
 - Degree and level customer response (which usually depends on the end-use resource type, impact on comfort and convenience, pricing rates and perceived level of savings, availability of enabling technologies such as in-home-displays, home energy management systems, smart thermostats, smart appliances, or automated, programmable, and communicable response systems, etc.)

Methodology for Determining Operating Reserves

Method for Determining Op Reserves

Overview

This section outlines the methodology to determine the operating reserves requirement to counteract the intra-hour variability of renewable energy.

The methodology specifies a reliability level of 99.99%; implying that if the operating reserves are made available as per the specified requirement, the renewable variability can be effectively counteracted for 99.99% of the time.

Operating reserves, as defined, is a function of spinning and non-spinning resources that can be made available within an hour.

At a certain defined level of non-spinning resources, the process outlines the required commitment of spinning reserves to sustain the variability for the forecasted level of renewables.

Definitions

Contingency Reserves

- MWs to cover for the loss of the largest unit

Operating Reserves

- MWs to cover for the variability of wind and solar
- Spinning Reserves + Non-spinning Reserves
 - Spinning Reserves
 - Available headroom (MWs) from committed thermal units
 - Non-Spinning Reserves
 - Available MW capacity from quick-start units
 - These units can be started in less than an hour

Total Reserves = Contingency Reserves + Operating Reserves

Oahu

Contingency Reserves = 185 MW

Spinning Reserves = Committed thermal units

Non-Spinning Reserves = W9,W10,DG,CT1 (if not already committed)

Factors Impacting the MW Availability from Non-Spinning Resources

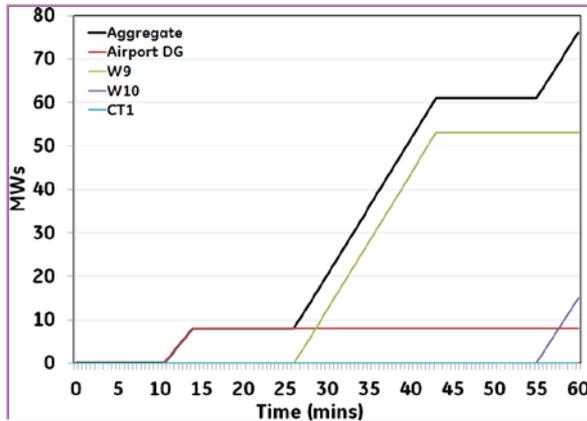
- Response time from the operator
 - Assumed to be 10-min
- Availability of the units
 - Assumed all units to be available
- Ramp rates of the units
 - We will show the extreme cases on the next slide
- Starting sequence of the units
 - We will show the extreme cases on the next slide
- Time delay between start of successive units
 - We will show the extreme cases on the next slide

Non-Spinning Resource Contribution

We will use the following non-spin start-up sequences for Oahu and Maui

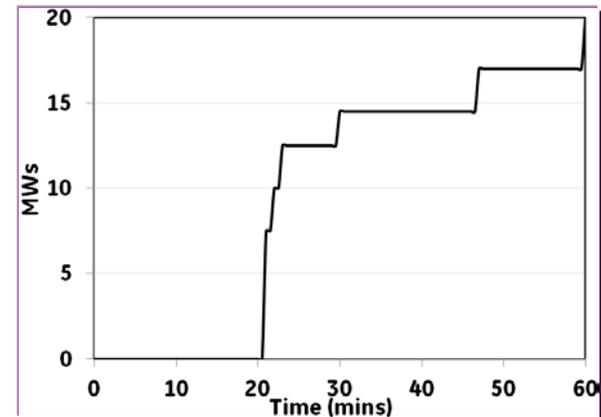
- This assumes normal ramp rates of quick-start units
- Operator reaction time of 10-min is assumed

Oahu Quick-starts



| Time Period | MWs |
|-------------|-------|
| 0-10 min | 0 MW |
| 10-20 min | 6 MW |
| 20-30 min | 10 MW |
| 30-40 min | 35 MW |
| 40-50 min | 59 MW |
| 50-60 min | 64 MW |

Maui Quick-starts



| Time Period | MWs |
|-------------|---------|
| 0-10 min | 0 MW |
| 10-20 min | 0 MW |
| 20-30 min | 10.5 MW |
| 30-40 min | 14.5 MW |
| 40-50 min | 15 MW |
| 50-60 min | 17 MW |



Operating Reserves on Oahu

Operating reserves are needed to sustain inter-hour (up to 60-min) variability

Spinning + Non-spinning reserves $\geq 10, 20\text{min}, 30\text{min}, \dots, 60\text{min}$ $\Delta_{\text{wind+solar}}$

Operating reserves must satisfy the following (with operator action time = 10min):

1. Between 0-10min:

- Spinning reserves + Non-spinning reserves $\geq 10\text{min}$ $\Delta_{\text{wind+solar}}$
- Non-spinning cannot contribute

2. Between 0-20min:

- Spinning reserve + Non-spinning $\geq 20\text{min}$ $\Delta_{\text{wind+solar}}$
- Only airport DG may participate

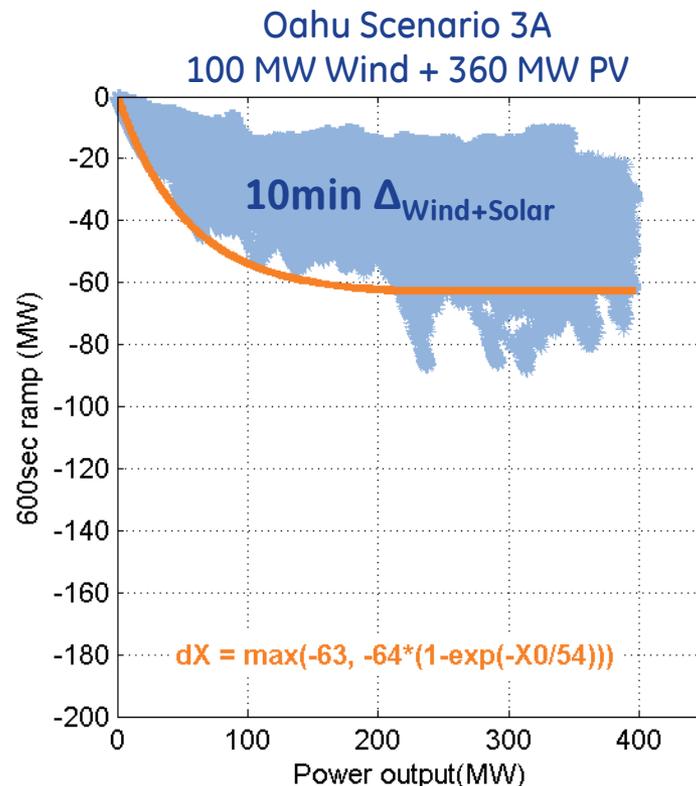
3. This process is repeated for the remainder of the hour in 10-min increments, until we satisfy the following equations:

- Spin Res + Non-spin Res $\geq 30\text{min}$ $\Delta_{\text{wind+solar}}$, 40min $\Delta_{\text{wind+solar}}$, 50min $\Delta_{\text{wind+solar}}$, 60min $\Delta_{\text{wind+solar}}$
- While taking into account the quick-start (non-spin) availability in different time intervals

How do we measure Variability?

Analysis Using Scatter Plots

- Each dot corresponds to a drop in wind + solar power in a 10min period
- The orange curve encapsulates 99.99% events in two years
- If the operating reserves follow the orange curve, the system will be able to counteract 99.99% of such 10-minute events

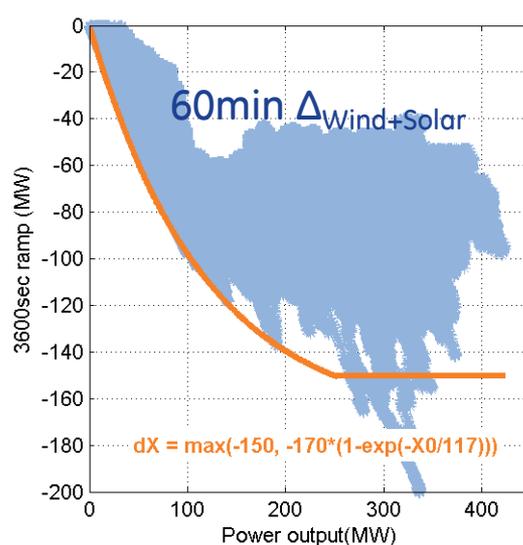
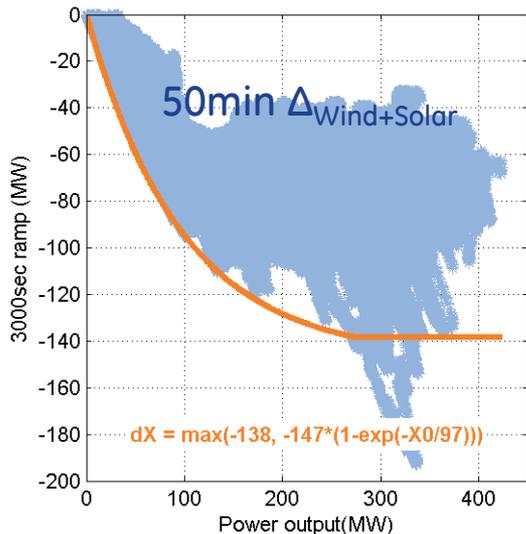
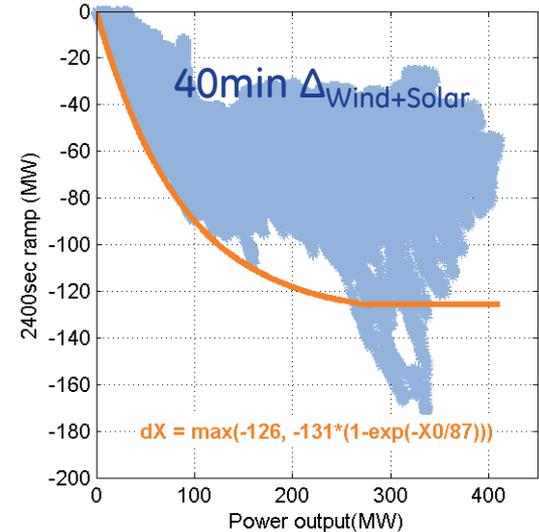
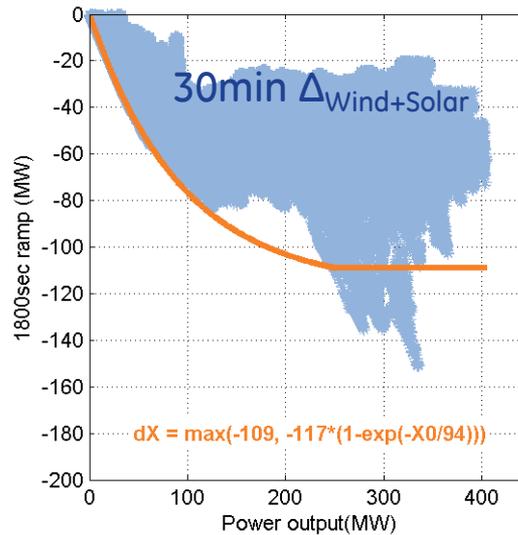
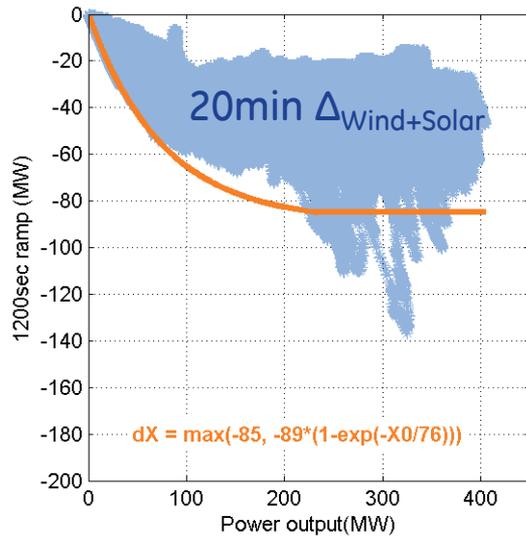


Scatter Plots – Rolling window with 2sec steps

- There are 31.5M data points in 2 years (for full days)
- Only 0.01% of the points are outside the orange curve

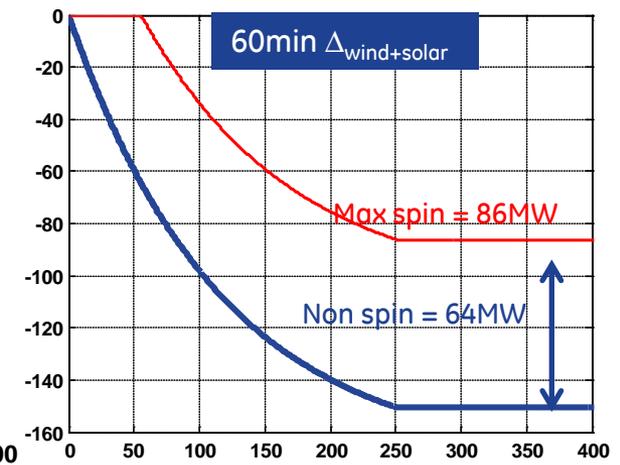
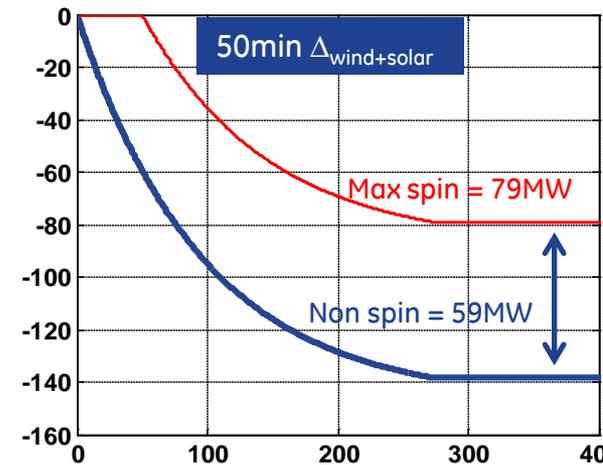
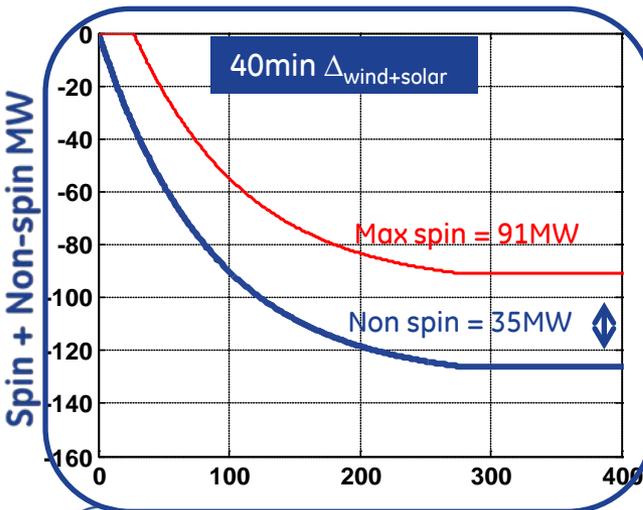
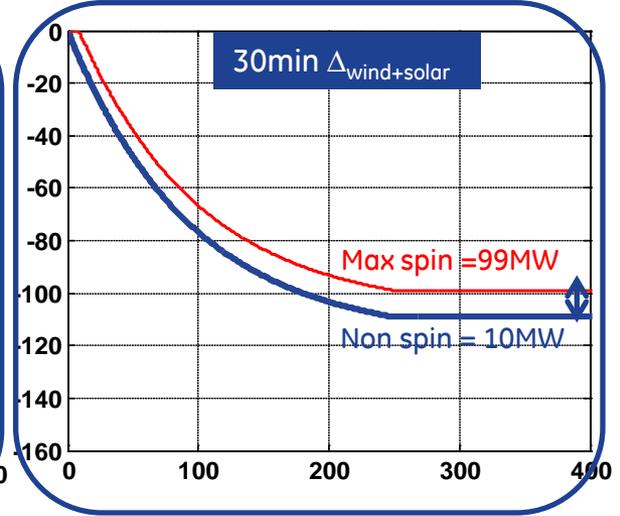
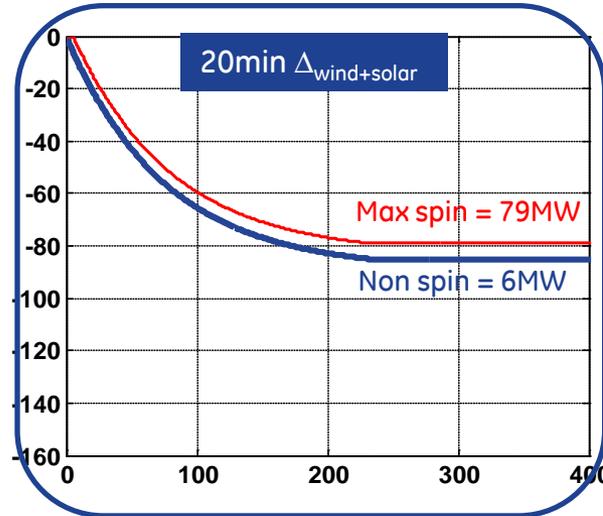
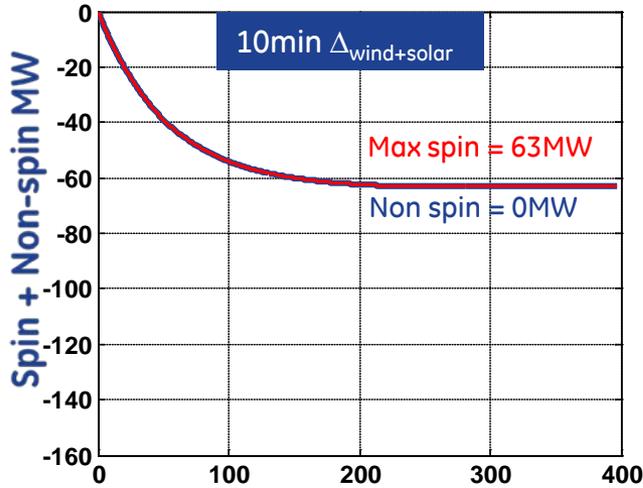
Variability in Other Time Windows

Within an hour



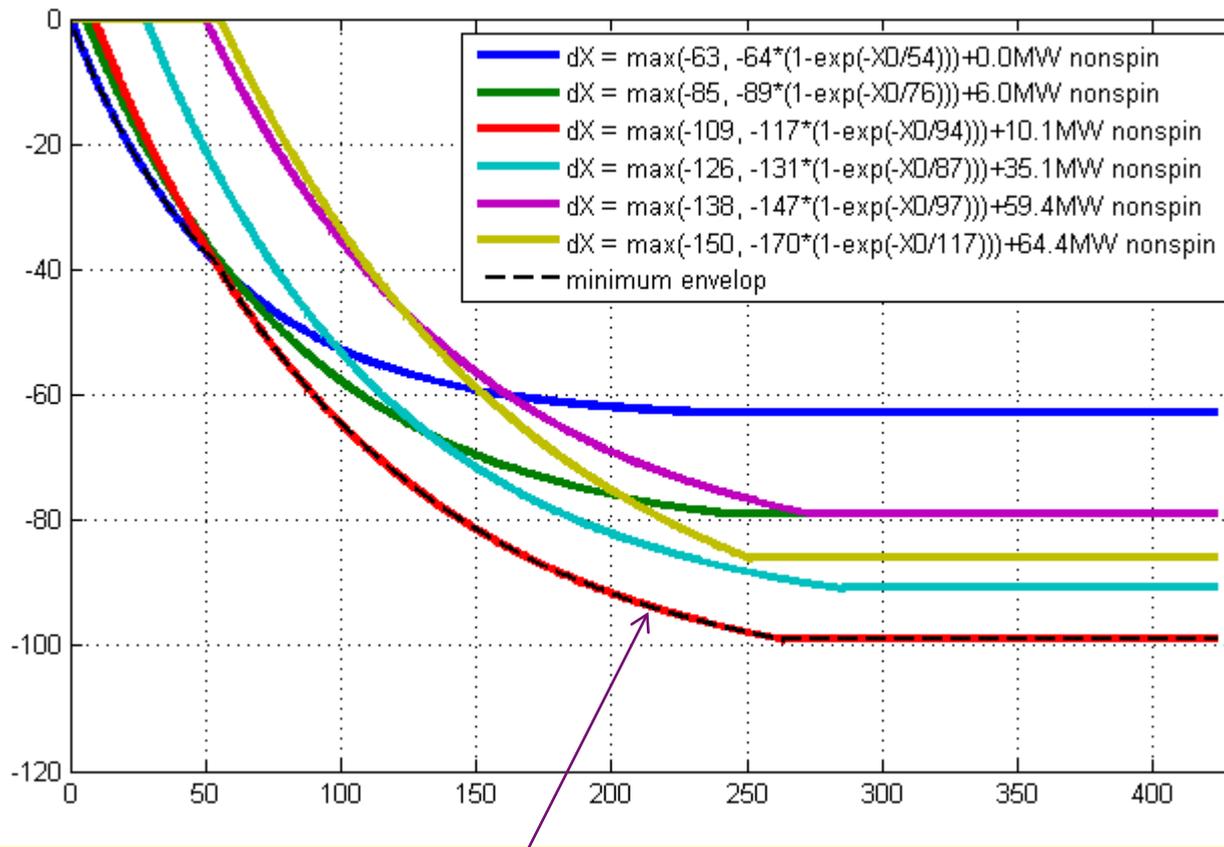
Operating Reserves

Assuming MW availability from quick-starts to be the average within a 10-min time interval



Operating Reserves Requirement

Envelope of the 6 previous curves



- The final spinning reserve is the envelop of all the 6 curves
- However, this assumes MW availability from quick-starts as the average in a given 10-min time period

Final Operating Reserves Requirement

Accounting for MW availability from quick-start units in finer time resolution

In the previous analysis, we used average MW availability in 10-min period from the quick-start units

Now we will be accounting the contribution of the quick-starts in more finer detail
→ every minute

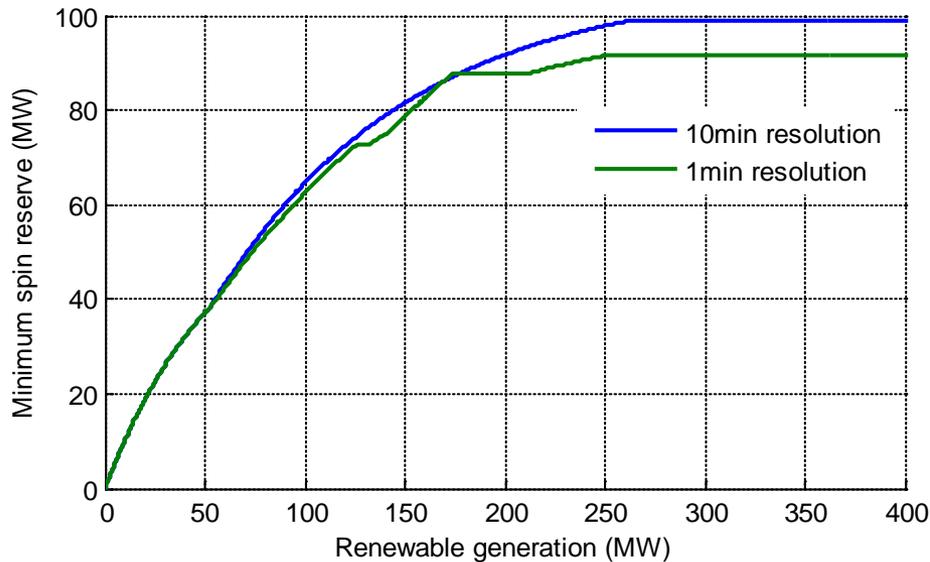
The operating reserves criteria remains the same:

- Spin + Non-spin reserves $\geq \Delta_{\text{Wind+Solar}}$ in different time intervals (now moving in steps of 1-min) within an hour

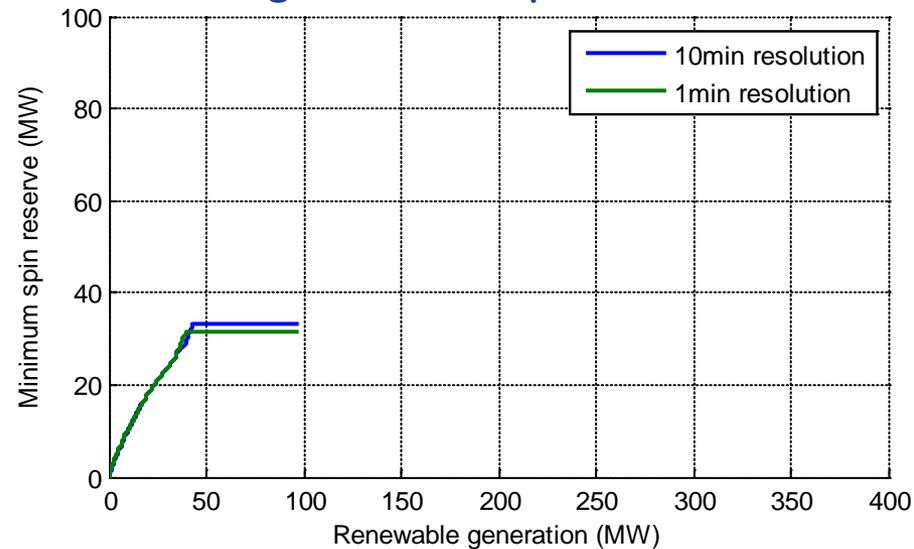
Oahu Spinning Reserves

Scenario 3A

Day-Time (6am-8pm)



Night-Time (8pm - 6am)



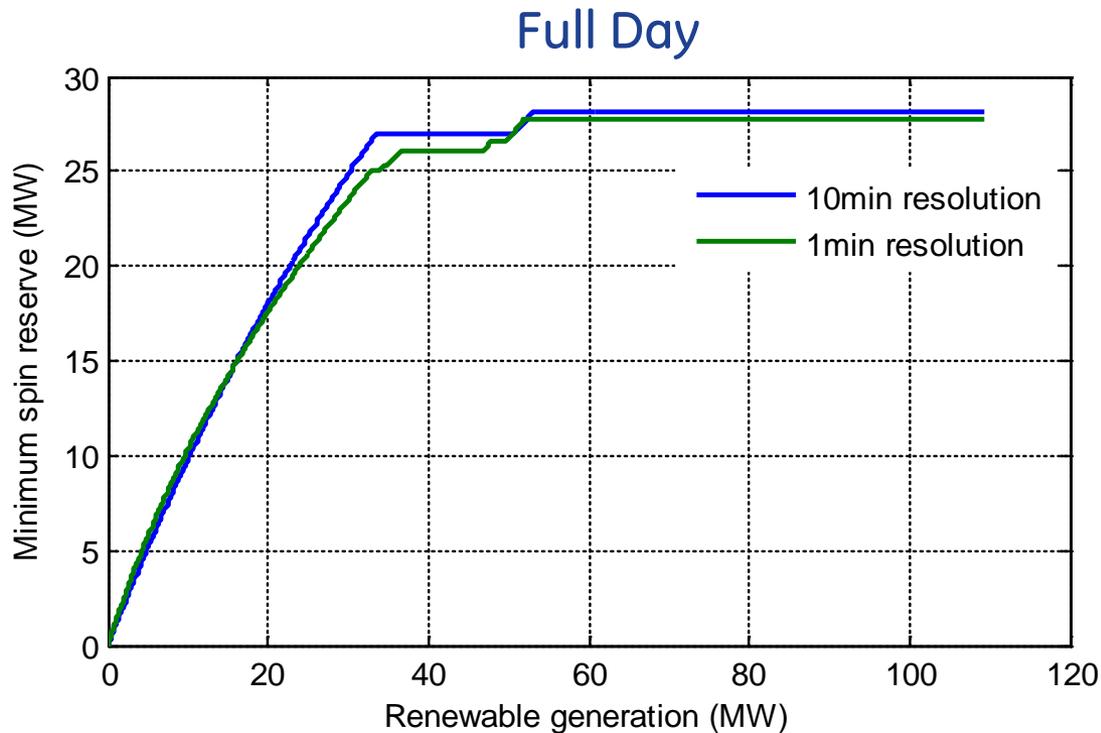
Spinning Reserves are very similar between the two strategies:

Blue → accounting MW availability from quick starts as average within 10-min

Green → accounting MW availability from quick starts every minute

Maui Spinning Reserves

Scenario 3



Spinning Reserves are very similar between the two strategies:
Blue → accounting MW availability from quick starts as average within 10-min
Green → accounting MW availability from quick starts every minute

References

References

- (1) NREL: National Renewable Energy Laboratory, Renewable Electricity Futures Study (Vol. 4 of 4), Bulk Electric Power Systems: Operations and Transmission Planning, 2012
- (2) NERC: North American Electric Reliability Corporation, Special Report: Potential Reliability Impacts of Emerging Flexible Resources, November 2010
- (3) NREL: National Renewable Energy Laboratory, Operating Reserves and Variable Generation, August 2010
- (4) Kirby, B., Proposed Ancillary Services, October 31, 2011
- (5) Kirby, B., Ancillary Services: Technical and Commercial Insights, July 2007
- (6) NERC: North American Electric Reliability Corporation, Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation, March 2011
- (7) Hawaii Reliability Standards Working Group, Glossary of Terms, Version 1 – 2012, Docket No. 2011-0206
- (8) NERC: North American Electric Reliability Corporation, NERC IVGTF Task 2.4 Report: Operating Practices, Procedures, and Tools, March 2011
- (9) Black & Veatch, Cost and Performance Data for Power Generation Technologies, February 2012
- (10) US Energy Information Administration (EIA), Annual Energy Outlook (AEO), Energy Market Module (EMM), 2011
- (11) Gas Turbine World (GTW), Performance Specifications, 2012 Edition, Volume 42
- (12) Bechtel Corporation, Concentrated Solar Thermal Plants Downstream of the Solar Field – Design/Optimization of the Associated Power Generation Cycle

References

- (13) Power Engineering, Hydroelectricity: The Versatile Renewable, June 1, 2009
- (14) GE Energy, Western Wind and Solar Integration Study, Prepared for National Renewable Energy Laboratory, May 2010
- (15) Oak Ridge National Laboratory, National Hydropower Association, Hydropower Research Foundation, Summary Report on a Summit Meeting: Pumped Storage Hydropower, September 2010
- (16) Renewable Northwest Project, Summary Report on Coal Plant Dynamic Performance Capability, August 2010
- (17) GE Energy (Miller, N., Leonardi, Bruno), New York Independent System Operator, Feasibility Evaluation of Energy Storage for Black Start Services on the NYISO System, December 16 2011
- (18) Milligan, M., Kirby, B., Utilizing Load Response for Wind and Solar Integration and Power System Reliability, Presented at WindPower 2010, Dallas, Texas, May 23–26 2010
- (19) Hawaii Renewable Energy Development Venture Technology Assessment - Grid Energy Storage Systems (<http://www.hawaiirenewable.com/wp-content/uploads/2009/12/16.-Energy-Storage.pdf>)
- (20) Pratt, Rob (Pacific Northwest National Laboratory), Najewicz, Dave (GE Appliances), Opportunities for Mass Market Demand Response to Provide Ancillary Services, October 2011
- (21) Raslter, Dan (EPRI), Akhil, Abbas (ERPI), Gauntlett, Dave (AECOM), Cutter, Eric (E3), Energy Storage System Costs 2011 Update Executive Summary - Presented to Storage System Suppliers, February 22 2012
- (22) Freund, Sebastian (GE GRC), Shu, Mark (GE Energy), Stoffer, Bart (GE Energy), 2010 insights: Grid-base energy storage, January 19 2011

References

- (23) Young, Russell (GE Energy), Manz, Devon (GE Energy): Utility Energy Storage, 2010
- (24) Federal Energy Regulatory Commission, Assessment of Demand Response & Advance Metering, Staff Report, February 2011
- (25) http://www.ercot.com/content/gridinfo/etts/flywheel/presentations/PSWG_meeting_082410.pdf
- (26) http://www.beaconpower.com/files/Beacon_Power_presentation_ESA%206_7_11_FINAL.pdf
- (27) DOE, Office of Energy Efficiency and Renewable Energy: 2010 FUEL CELL TECHNOLOGIES MARKET REPORT, June 2011