BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

Petition of PPL Electric Utilities Corporation	:	
for Approval of Tariff Modifications and	:	
Waivers of Regulations Necessary to	:	Docket No. P-2019-3010128
Implement its Distributed Energy Resources	:	
Management Plan	:	

DIRECT TESTIMONY OF STEPHEN WHITLEY

PPL Electric Statement No. 4

December 11, 2019

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Stephen Whitley, and my business address is 33 Emerald Glen, Laguna Niguel, California 92677.

Q. WHAT IS YOUR CURRENT OCCUPATION?

A. I am an electric industry consultant doing business as Stephen Whitley LLC. I provide consultation, testimony, and advice to various clients in the electric industry on matters including planning, operations, engineering, environmental, distributed energy resources, electricity markets, Regional Transmission Organization ("RTO") and Independent System Operator ("ISO") policies and procedures, and regulatory affairs.

Q. WHAT IS YOUR EDUCATIONAL BACKGROUND?

A. I received a Bachelor of Science in Electrical Engineering from Tennessee Technological University in 1970.

Q. PLEASE DESCRIBE YOUR PROFESSIONAL EXPERIENCE.

A. I have over 49 years' experience in the electric energy industry. From 2018 to present, I have served as a consultant for various clients in the electric industry to include provision of technical reports and expert testimony in various state and RTO/ISO regulatory proceedings. From 2016 to 2018, I served as a Trustee to the Southwest Power Pool ("SPP") Regional Entity -- a North American Electric Reliability Corporation ("NRDC") Regional Reliability Council. I also served as an advisor to the Board of Directors of the New York Independent System Operator, Inc. ("NYISO") during this period. From 2008 to 2015, I served as the President/CEO of the NYISO. Key initiatives during this period were the NYISO led Broader Regional Markets initiative saving consumers in New York, New England, PJM Interconnection, LLC ("PJM"), and Midcontinent Independent System Operator ("MISO") over $300 million per year in the energy markets; expansion of the NYISO markets to better accommodate renewables, storage/batteries/flywheels, and increase the utilization of demand-side resources; the NYISO-led Eastern Interconnection Planning Collaborative, where I served as Chair of the Executive Committee; development of a new state-of-the-art power control center for the NYISO; and the development of a comprehensive transmission planning process in New York that led to major bulk power transmission expansion in New York. From 2000 to 2008, I served as the COO for ISO New England, Inc. ("ISO-NE"). Key initiatives during this period included: the introduction of demand response to the New England markets (essential to bringing the concept and experience of the Tennessee Valley Authority ("TVA") Economy Surplus Power ("ESP") program to New England); development of a transmission planning process and transmission cost allocation process to New England; and development of comprehensive energy and capacity markets in New England designed to maintain reliability and least cost to consumers. From 1970 to 2000, I served in various capacities at the TVA ranging from system protection engineer to General Manager System Operations to VP Transmission over the 30 year period. Key accomplishments during this period relating to the PPL project were the development of the TVA ESP program, which was the forerunner of today's Demand Response programs across the country.

Q. DO YOU HAVE EXPERIENCE WITH DISTRIBUTED ENERGY RESOURCES ("DERS")?

A. I have significant experience with the operation and benefits of DER assets on the electric system and to electric consumers based on my roles in the operation of electric systems in three different footprints — TVA, New England, and New York. In addition, I live in southern California with Time-of-Day rates, have residential solar generation on my home, and drive an electric vehicle, which also makes me familiar with the subject discussed here from a consumer perspective.

Q. HAVE YOU PREVIOUSLY TESTIFIED AS A WITNESS BEFORE THE PENNSYLVANIA PUBLIC UTILITY COMMISSION ("COMMISSION")?

A. No.

Q. HAVE YOU BEEN RETAINED BY PPL ELECTRIC UTILITIES CORPORATION ("PPL ELECTRIC" OR THE "COMPANY") TO TESTIFY ON BEHALF OF THE COMPANY IN SUPPORT OF THE ABOVE-CAPTIONED PETITION?

A. Yes.

Q. WOULD YOU PLEASE DESCRIBE THE SUBJECT MATTER OF YOUR TESTIMONY?

A. My testimony will describe the impact of DERs and other "behind the meter resources," including issues that have been experienced in other states due to electric utilities' failures to take steps to monitor and manage these technologies. I also will provide additional support for why the Company's proposal is best addressed in a utility-specific proceeding, rather than a statewide proceeding.

Q. ARE YOU SPONSORING ANY EXHIBITS WITH YOUR TESTIMONY?

A. Yes, I am sponsoring the following exhibits:

1. PPL Electric Exhibit SW-1 – "California ISO FAST FACTS: What the duck curve tells us about managing a green grid" (https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf); and
2. PPL Electric Exhibit SW-2 – "Renewables in Hawaii" Presentation from the NERC Board of Trustees Meeting on February 6, 2014 (https://www.nerc.com/gov/bot/Agenda%20highlights%20and%20Mintues%202013/Board_of_Trustees_Presentations-February_6_2014.pdf).

A. IMPACT OF DERS AND BEHIND METER RESOURCES

Q. CAN YOU PROVIDE SOME BACKGROUND ON THE INCREASE IN "BEHIND THE METER" RESOURCES AND THEIR IMPACT?

A. In my experience, the nature of the grid is changing, in large part because generation that has traditionally come from centralized plants is increasingly coming from DERs connected on the distribution system. These are often called "behind the meter" resources. In grid operations, they have often been included in programs called "Demand Response (DR)" or "Demand-side Management (DSM)." With these programs, grid operators can call on these resources to reduce regional or local demand during times of emergencies as a tool to maintain system reliability. To comply with the operator's request, DSM providers could either actually reduce consumption, turn on behind the meter generation (often backup generators), or both.

Today many more options are available with the rapidly growing number of behind the meter resources available. Examples include solar panels, storage batteries, electric vehicles, and many Wi-Fi controlled devices at individual homes such as swimming pool pumps, backup generators, etc. The potential impact of this growing category of resources is very significant. Now is the time to get out ahead of this impact and prepare the system for the most effective method of DER management. Very significant savings to consumers and the environment can be achieved if this is done properly with better transparency, visibility, and operational management by both the distribution system operator (in this case PPL Electric), and the grid operator (in this case PJM).

Q. COULD YOU PLEASE EXPAND ON WHY PPL ELECTRIC NEEDS TO TAKE ACTION NOW TO GET AHEAD OF THE IMPACT OF DERS?

A. It is critically important for electric utilities, such as PPL Electric, to plan and prepare for the deployment of DERs well in advance of their widespread deployment. On the transmission side, the RTO/ISOs, such as NYISO, ISO-NE, and PJM, must be able to monitor and balance electric generation and load. This is vitally important for maintaining the safety, reliability, and stability of the transmission systems. The RTO/ISOs must be able to accurately forecast the system and locational demand for the next 15 minutes, next hour, next day, next season, and next several years to ensure sufficient transmission and generating resources are available under their control to: (a) balance supply and demand in real time; (b) position the system to be prepared to meet severe weather conditions and sudden contingency events (loss of network components such as lines, towers, of generating units); (c) meet all applicable national and regional reliable standards, and (d) dispatch all available resources in the most efficient manner for the benefit all consumers.

My significant experience with the operation of DR resources in New York provides an apt comparison to the challenges presented by DERs. Our staff at NYISO always knew the amount of DR that had previously signed up with a commitment to reduce demand upon request, but we never knew how much we would actually get in real time. Sometimes the response was good, but much of the time the program under performed. As a result, our operators had to constantly overcommit other generation (normally gas-fired generation) to maintain system reliability. This is very costly to consumers and the environment. If the operators had better transparency, visibility, and operational management of behind the meter resources through the distribution system operators (*e.g.*, Consolidated Edison, Inc., New York State Electric and Gas Corporation, Central Hudson Gas & Electric Corp., Long Island Power Authority, New York Power Authority, Niagara Mohawk Power Corp. d/b/a National Grid, municipalities, etc.), this could have been avoided. This is actually one of the major goals of New York's Reforming the Energy Vision ("REV") procedure aimed at expanding the effective use of DERs in New York.

Transmission system operators must have the real-time visibility and accurate information to plan and operate the systems with many market participants. In the case of DERs, aggregators have entered the market by bundling small distributed generators to participate in the transmission markets. In this case, their participation is accepted based upon claims without transparency or ability to measure DER contributions. When there is a mismatch of actual DER generation compared to what has been committed, the imbalance of generation and load can cause serious problems for the transmission system. When the RTO/ISOs do not have accurate and verifiable information, they have to guess and over commit other generation that is under their control as mentioned above. Aggregators actually benefit by this lack of visibility and transparency because it is very difficult to verify if they did or did not perform properly. This could be easily corrected by adoption and implementation of PPL Electric's DER Management proposal. This would be a major step forward in the evolution of grid management and would be implemented the right way.

Today, however, DERs are being deployed on the electric distribution system with no adequate measures to ensure that those systems are kept in balance, and their availability, operation, and performance are not visible or transparent to the distribution operator or the grid operator. As this expands, the cost to consumers and the threat to reliability will become overwhelming and unsustainable.

I strongly believe that now is the time to get out ahead of this issue. The Company's proposal is sound and puts the correct infrastructure in place to allow proper implementation to occur. As the entity that owns the electric distribution system has a responsibility to provide safe, reliable, and affordable service, PPL Electric is best positioned to be the party in charge of monitoring and managing the DERs interconnected with its distribution system. Thus, PPL Electric's DER Management Petition is ripe, and these issues should be addressed now in this proceeding.

In states such a California or Hawaii, where the penetration of renewables and electric vehicles are at a higher pace, problems have already surfaced at the distribution and ISO and distribution levels due to the lack of real time information and management.

In California, the state has a goal of 50% of retail electricity from renewable power by 2030. Today, California is at about 25% renewable electricity at retail and is experiencing significant operational reliability issues. PPL Electric Exhibit SW-1 describes the issues at the ISO level. With heavy penetrations of wind and solar, other conventional types of resources have retired reducing the ramping capability of the existing generation fleet. Figure 2 (called the Duck Curve) of this Exhibit indicates that the California ISO ("CAISO") already needs a ramping capability of 13,000 MW over 3 hours to maintain system reliability balancing supply and demand in real time. This is driven primarily by the amount of solar that comes off quickly when the sun goes down each day. To mitigate this problem today, CAISO's operators have to keep a significant amount of surplus capacity (fast responding thermal generation) on line to respond to the sudden loss of solar. The operators have similar problems during the morning hours as the sun rises. At the ISO level, California desperately needs additional flexible resources to react quickly and meet expected operating levels. Similar to the problems experienced in Hawaii, the local distribution companies in California also have reliability issues due to the lack of visibility and management of this behind the meter generation. These problems are becoming more critical as the levels of behind the meter solar and electric vehicle charging increase.

In Hawaii, renewable energy goals have been set at 100% by 2045, but actual penetration levels have peaked at 27.6% for the past two years due to operational problems that are being experienced. PPL Electric Exhibit SW-2 provides a summary of the issues experienced in 2014 at a presentation by the Hawaiian Electric Company at a NERC Board of Trustees meeting. At that time, reliability issues had surfaced with an 18% penetration level of renewables on the system. Many of the state-sponsored renewable initiatives were subsequently modified, reduced, or capped due to a number of reliability issues. In Hawaii, many of the individual distribution circuits have rooftop solar capacity exceeding 100% of the daytime minimum load implying 2-way power flow on the distribution circuit. Severe voltage fluctuations have also been experienced. This two-way flow of energy requires a flexible, visible, and controllable distribution network to accommodate the high number of behind-the-meter resources. The utilities and state regulators in Hawaii are moving forward to address these issues with a wide array of distribution automation projects on a crash basis (see T&D World article "Modern Grids of Hawaii" dated Nov 1, 2018[1]). These projects include storage, advanced inverter grid support functions for all solar photovoltaic installations, dynamic volt-amps reactive ("DVAR") controllers, protective system upgrades, and comprehensive distribution system automation to improve situation awareness.

Hawaii and California should have been much more proactive to get ahead of these issues before they caused reliability and customer problems. In my opinion, they

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[1] Rodney Chong, *Modern Grids of Hawaii*, T&D WORLD (Nov. 1, 2018), https://www.tdworld.com/distribution/modern-grids-hawaii.

should have focused on getting the right information, infrastructure, and protocols in the hands of the distribution system operators up front. In that manner, costs could have been reduced, reliability could have been maintained, and customer frustration could have been minimized. Now is the time for Pennsylvania to get ahead of these issues and approve the PPL DER Management proposal.

B. UTILITY-SPECIFIC VERSUS STATEWIDE PROCEEDINGS

Q. DO YOU BELIEVE THAT THE ISSUES RAISED BY THE COMPANY'S PROPOSAL SHOULD BE ADDRESSED IN A STATEWIDE PROCEEDING?

A. Absolutely not. A statewide proceeding is not the correct approach for these issues to be addressed by PPL Electric. As I mentioned previously, PPL Electric needs to get ahead of these issues before DERs that have inverters that lack communications become more widespread. A statewide proceeding, however, would unnecessarily delay resolving these issues. Time is the enemy on an issue such as this. These resources are growing rapidly. New York has been working on this since 2013 with several statewide proceedings and hearings with delays constantly being sought by the aggregators. Pennsylvania should show leadership and get ahead of the issue with a fundamentally sound approach. Consumer interest and reliability should have priority over any market sector's financial interest.

Furthermore, the issues regarding how DERs should be monitored and managed on an electric distribution company's ("EDCs") system are fact-specific. I believe it will be much more efficient for the Commission to follow a utility-specific proceeding as opposed to a slow statewide proceeding. Every utility may have different information

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technology ("IT") systems, automated metering infrastructure ("AMI") meters, and other electric distribution facilities and infrastructure. For example, the Company has deployed a distributed energy resources management system ("DERMS"), but other EDCs in Pennsylvania have not. Given these differences in each EDC's characteristics and systems, the best approach is a utility-specific proceeding, such as the one initiated by PPL Electric's DER Management Petition.

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY AT THIS TIME?

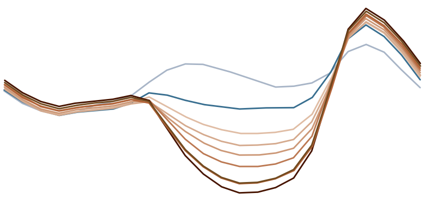
A. Yes, although I reserve the right to supplement my direct testimony.

PPL Electric Exhibit SW-1

PPL Electric Exhibit SW-1

California ISO

FAST FACTS



What the duck curve tells us about managing a green grid

The electric grid and the requirements to manage it are changing. Renewable resources increasingly satisfy the state's electricity demand. Existing and emerging technology enables consumer control of electricity consumption. These factors lead to different operating conditions that require flexible resource capabilities to ensure green grid reliability. The ISO created future scenarios of net load curves to illustrate these changing conditions. Net load is the difference between forecasted load and expected electricity production from variable generation resources. In certain times of the year, these curves produce a "belly" appearance in the mid-afternoon that quickly ramps up to produce an "arch" similar to the neck of a duck—hence the industry moniker of "The Duck Chart".

Energy and environmental goals drive change

In California, energy and environmental policy initiatives are driving electric grid changes. Key initiatives include the following:

- 50 percent of retail electricity from renewable power by 2030;
- greenhouse gas emissions reduction goal to 1990 levels;
- regulations in the next 4-9 years requiring power plants that use coastal water for cooling to either repower, retrofit or retire;
- policies to increase distributed generation; and
- an executive order for 1.5 million zero emission vehicles by 2025.

New operating conditions emerge

The ISO performed detailed analysis for every day of the year from 2012 to 2020 to understand changing grid conditions. The analysis shows how real-time electricity net demand changes as policy initiatives are realized. In particular, several conditions emerge that will require specific resource operational capabilities. The conditions include the following:

- short, steep ramps – when the ISO must bring on or shut down generation resources to meet an increasing or decreasing electricity demand quickly, over a short period of time;
- oversupply risk – when more electricity is supplied than is needed to satisfy real-time electricity requirements; and
- decreased frequency response – when less resources are operating and available to automatically adjust electricity production to maintain grid reliability.

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Green grid reliability requires flexible resource capabilities

To reliably operate in these conditions, the ISO requires flexible resources defined by their operating capabilities. These characteristics include the ability to perform the following functions:

- sustain upward or downward ramp;
- respond for a defined period of time;
- change ramp directions quickly;
- store energy or modify use;
- react quickly and meet expected operating levels;
- start with short notice from a zero or low-electricity operating level;
- start and stop multiple times per day; and
- accurately forecast operating capability.

Reliability requires balancing supply and demand

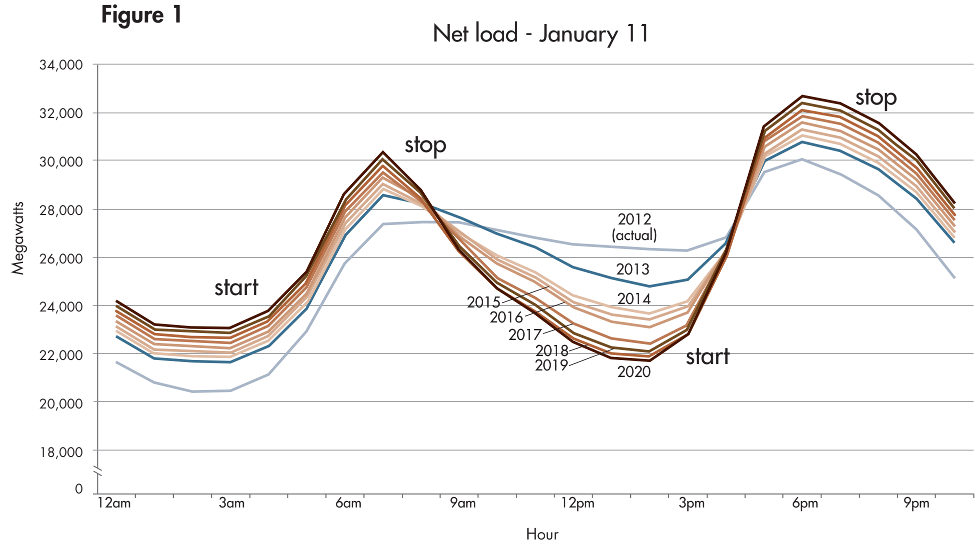
The net load curves represent the variable portion that ISO must meet in real time. To maintain reliability the ISO must continuously match the demand for electricity with supply on a second-by-second basis.

Historically, the ISO directed conventional, controllable power plant units to move up or down with the instantaneous or variable demand. With the growing penetration of renewables on the grid, there are higher levels of non-controllable, variable generation resources. Because of that, the ISO must direct controllable resources to match both variable demand and variable supply. The net load curves best illustrate this variability. The net load is calculated by taking the forecasted load and subtracting the forecasted electricity production from variable generation resources, wind and solar. These curves capture the forecast variability. The daily net load curves capture one aspect of forecasted variability. There will also be variability intra-hour and day-to-day that must be managed. The ISO created curves for every day of the year from 2012 to 2020 to illustrate how the net load following need varies with changing grid conditions.

Ramping flexibility

The ISO needs a resource mix that can react quickly to adjust electricity production to meet the sharp changes in electricity net demand. Figure 1 shows a net load curve for the January 11 study day for years 2012 through 2020. This curve shows the megawatt (MW) amounts the ISO must follow on the y axis over the different hours of the day shown on the x axis. Four distinct ramp periods emerge.

Figure 1



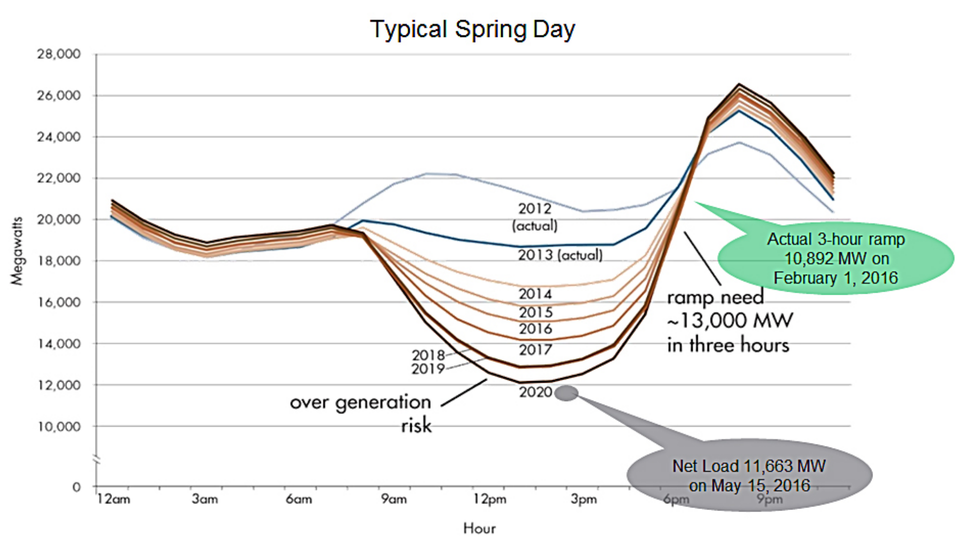
The first ramp of 8,000 MW in the upward direction (duck's tail) occurs in the morning starting around 4:00 a.m. as people get up and go about their daily routine. The second, in the downward direction, occurs after the sun comes up around 7:00 a.m. when on-line conventional generation is replaced by supply from solar generation resources (producing the belly of the duck). As the sun sets starting around 4:00 p.m., and solar generation ends, the ISO must dispatch resources that can meet the third and most significant daily ramp (the arch of the duck's neck). Immediately following this steep 11,000 MW ramp up, as demand on the system deceases into the evening hours, the ISO must reduce or shut down that generation to meet the final downward ramp.

Flexible resources needed

To ensure reliability under changing grid conditions, the ISO needs resources with ramping flexibility and the ability to start and stop multiple times per day. To ensure supply and demand match at all times, controllable resources will need the flexibility to change output levels and start and stop as dictated by real-time grid conditions. Grid ramping conditions will vary through the year. The net load curve or duck chart in Figure 2 illustrates the steepening ramps expected during the spring. The duck chart shows the system requirement to supply an additional 13,000 MW, all within approximately three hours, to replace the electricity lost by solar power as the sun sets.

Oversupply mitigation

Figure 2: The duck curve shows steep ramping needs and overgeneration risk



Oversupply is when all anticipated generation, including renewables, exceeds the real-time demand. The potential for this increases as more renewable energy is added to the grid but demand for electricity does not increase. This is a concern because if the market cannot automatically manage oversupply it can lead to overgeneration, which requires manual intervention of the market to maintain reliability. During oversupply times, wholesale prices can be very low and even go negative in which generators have to pay utilities to take the energy. But the market often remedies the oversupply situation and automatically works to restore the balance between supply and demand. In almost all cases, oversupply is a manageable condition but it is not a sustainable condition over time — and this drives the need for proactive policies and actions to avoid the situation. The duck curve in Figure 2 shows that oversupply is expected to occur during the middle of the day as well.

Because the ISO must continuously balance supply and demand, steps must be taken to mitigate oversupply risk. These actions can help avoid oversupply conditions from occurring: 1) increasing demand by expanding the ISO control area beyond California to other states so that low cost surplus energy can serve consumers over a large geographical area; 2) increase participation in the western Energy Imbalance Market in which real-time energy is made available in western states; 3) transition our cars and trucks to electricity; 4) offer consumers time-of-use rates that promote using electricity during the day when there is plentiful solar energy and the potential for oversupply is higher; 5) increase energy storage; and 6) increase the flexibility of power plants to more quickly follow ISO instructions to change its generation output levels.

Reliable grids have automated frequency response

System frequency measures the extent to which supply and demand are in balance. To ensure reliability, system frequency must be managed in a very tight band around 60 hertz. When an unexpected event occurs that disrupts the supply-demand balance, such as a loss of a generator or transmission line, frequency is impacted. These events do not allow time for manual response and balance is maintained through automated equipment. Conventional generation resources include frequency-sensing equipment, or governors, that automatically adjust electricity output within seconds in response to frequency to correct out-of-balance conditions.

Part of the renewable integration analysis conducted by the ISO uncovered concerns about frequency response capabilities due to the displacement of conventional generators on the system. The 2020 33% studies show that in times of low load and high renewable generation, as much as 60% of the energy production would come from renewable generators that displace conventional generation and frequency response capability. Under these operating conditions, the grid may not be able to prevent frequency decline following the loss of a large conventional generator or transmission asset. This situation arises because renewable generators are not currently required to include automated frequency response capability and are operated at full output (they can not increase power). Without this automated capability, the system becomes increasingly exposed to blackouts when generation or transmission outages occur.

Policy needed for flexible resources

To reliably manage the green grid, the ISO needs flexible resources with the right operational characteristics in the right location. The ISO is actively engaged in policy efforts to build awareness of the new grid needs. Working with the industry and policymakers, the ISO is collaborating on rules and new market mechanisms that support and encourage the development of flexible resources to ensure a reliable future grid.

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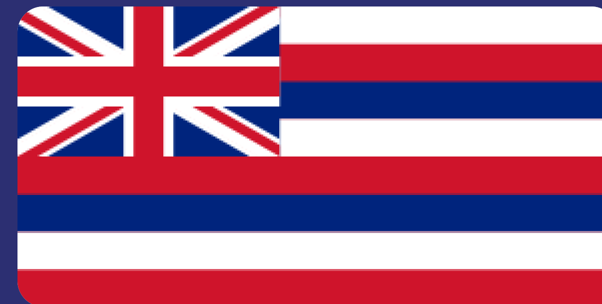
PPL Electric Exhibit SW-2

Renewables in Hawaii

Mr. Dick Rosenblum – President and CEO
Hawaiian Electric Company
NERC Board of Trustees Meeting
Phoenix, Arizona
February 6, 2014

Hawaiian Electric
Maui Electric
Hawai'i Electric Light

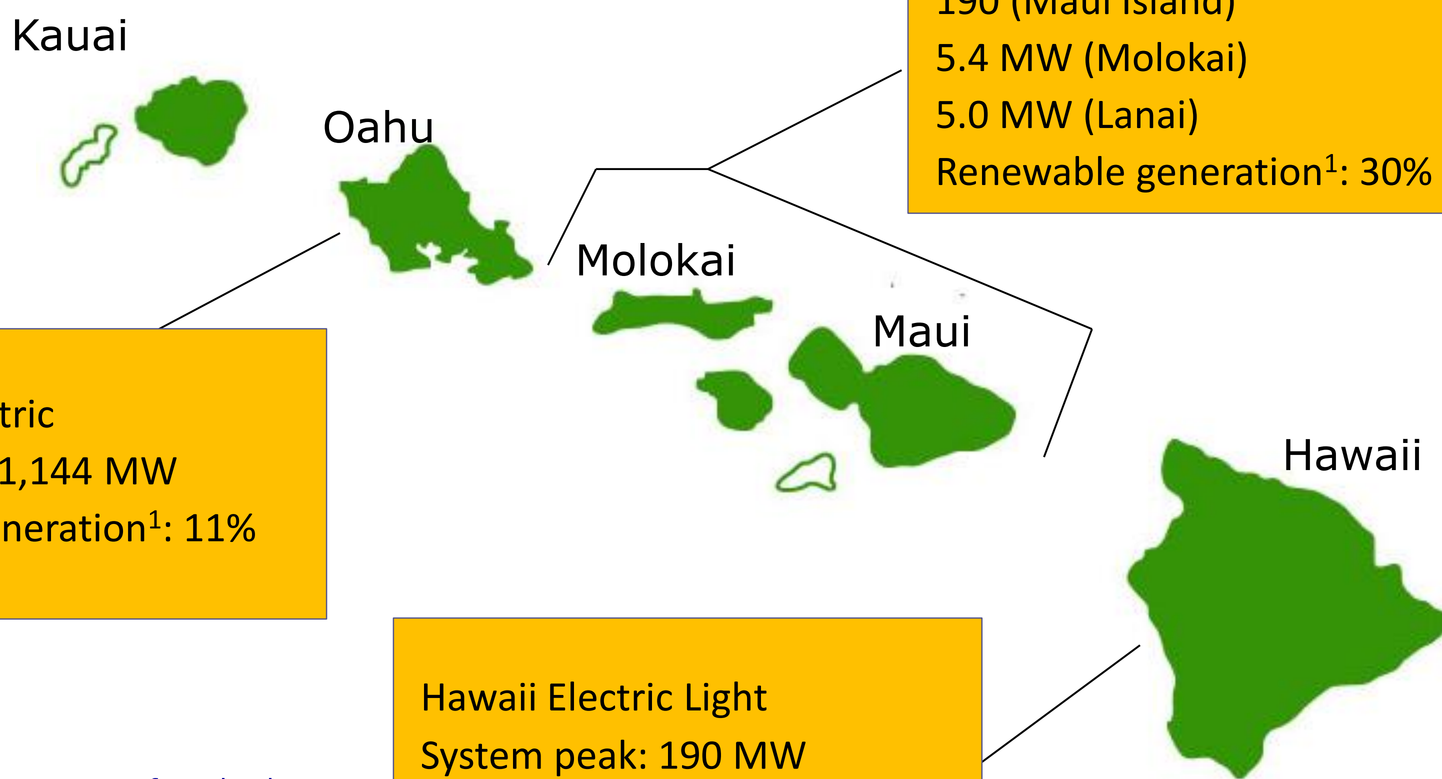
Hawaii is Different



- Each Island is an independent grid
  - We have no one to fall back on
  - Frequency excursions are common
- We have no traditional generation fuel sources
  - Our traditional generation has been petroleum-based
  - We do have generous renewable resources
- Goal to reach 40% renewables by 2030
  - We are already at 18%
- Renewables are cost effective
  - If we procure them successfully
- 10% of customers have DG (PV)
  - NEM rates provide 2-3 year payback
  - 30% Fed., 35% State and NEM
- We use load shed schemes for extreme events
  - Used to have island-wide blackouts

Hawaiian Electric Service Area and 2013 Data

100% Market Share for 95% of state: 3 utilities, 5 separate grids



Maui Electric
System peaks:
190 (Maui Island)
5.4 MW (Molokai)
5.0 MW (Lanai)
Renewable generation[1]: 30%

Hawaiian Electric
System peak: 1,144 MW
Renewable generation[1]: 11%

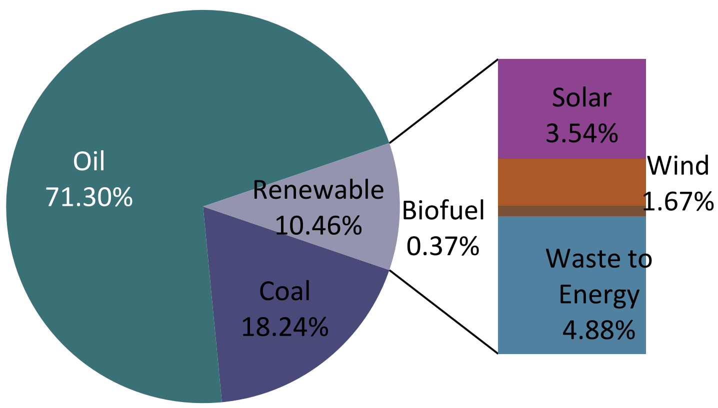
Hawaii Electric Light
System peak: 190 MW
Renewable generation[1]: 49%

[1] As a percentage of total sales

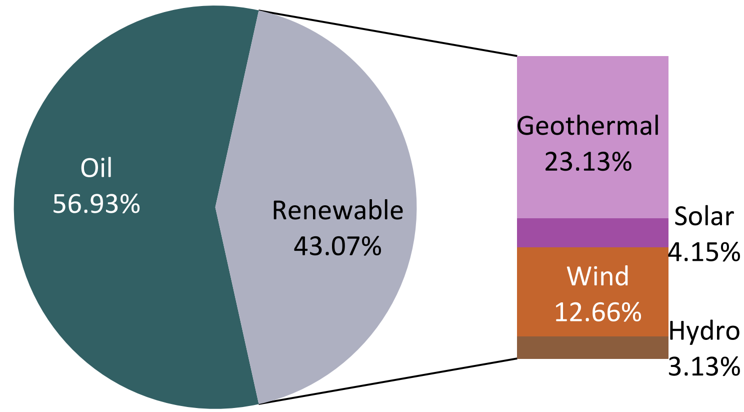
Hawaiian Electric
Maui Electric
Hawai‘i Electric Light

The Situation on Each Island is Different

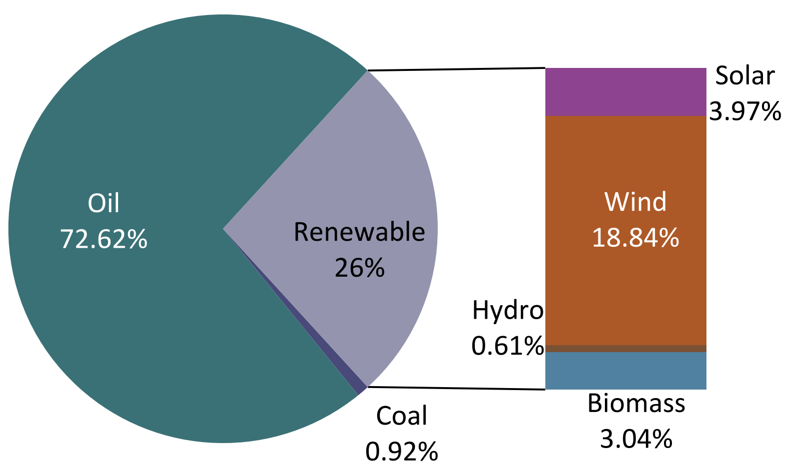
% Renewable Generation – Through November 2013



Oahu: 5.21% Variable Renewable

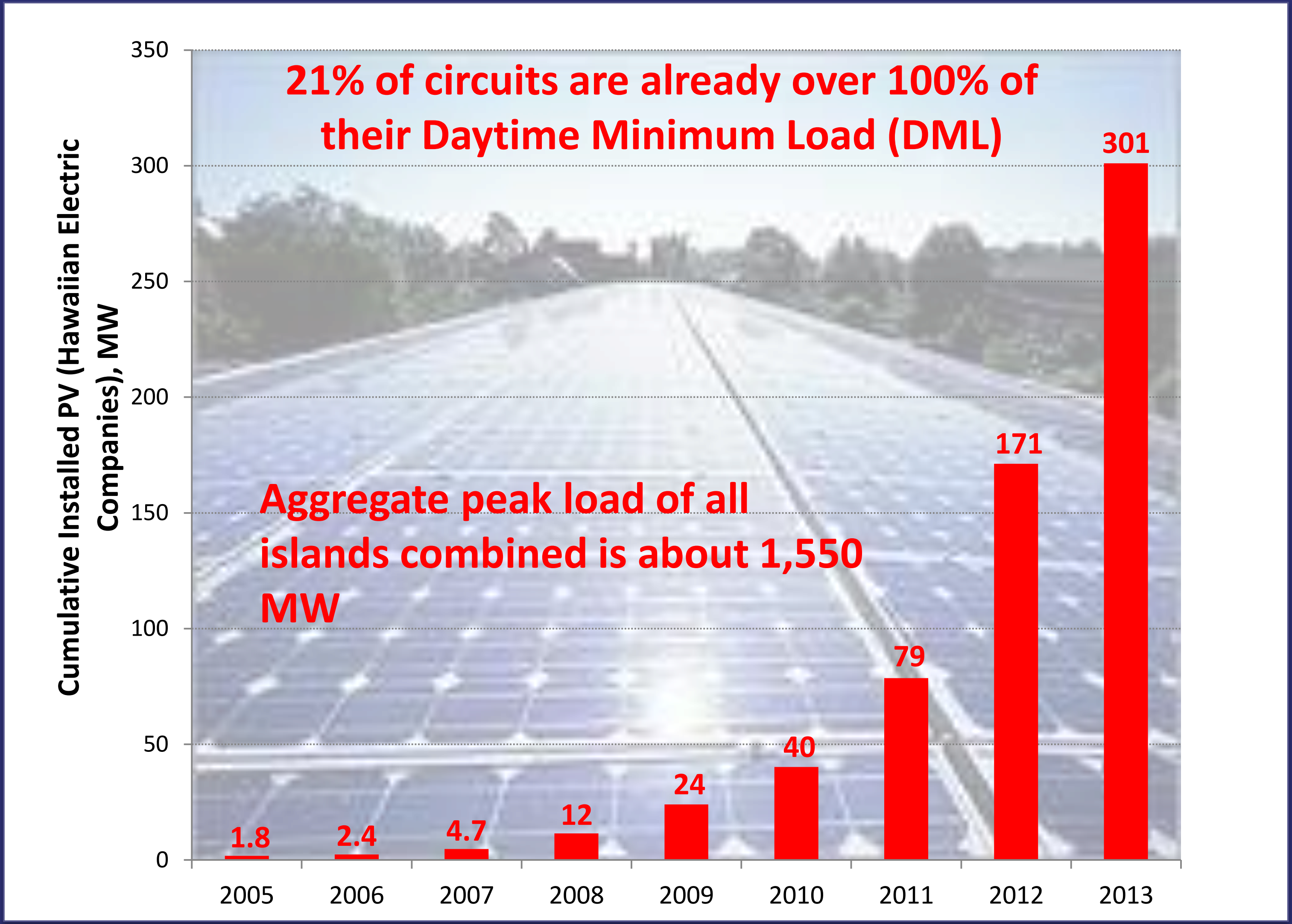


Hawaii 19.9% Variable Renewable

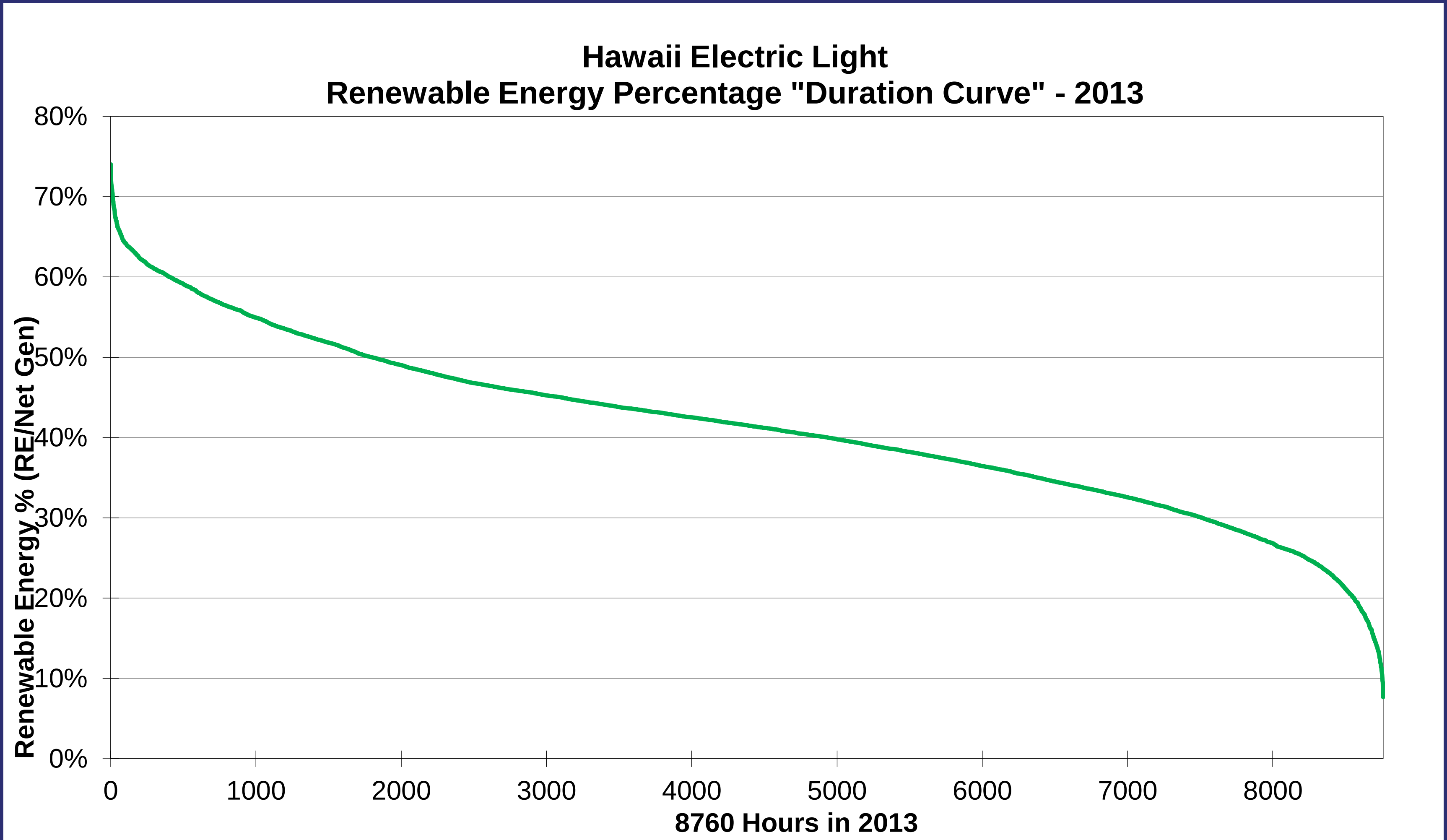


Maui 23.42% Variable Renewable

Continued High Growth of PV in Hawaii

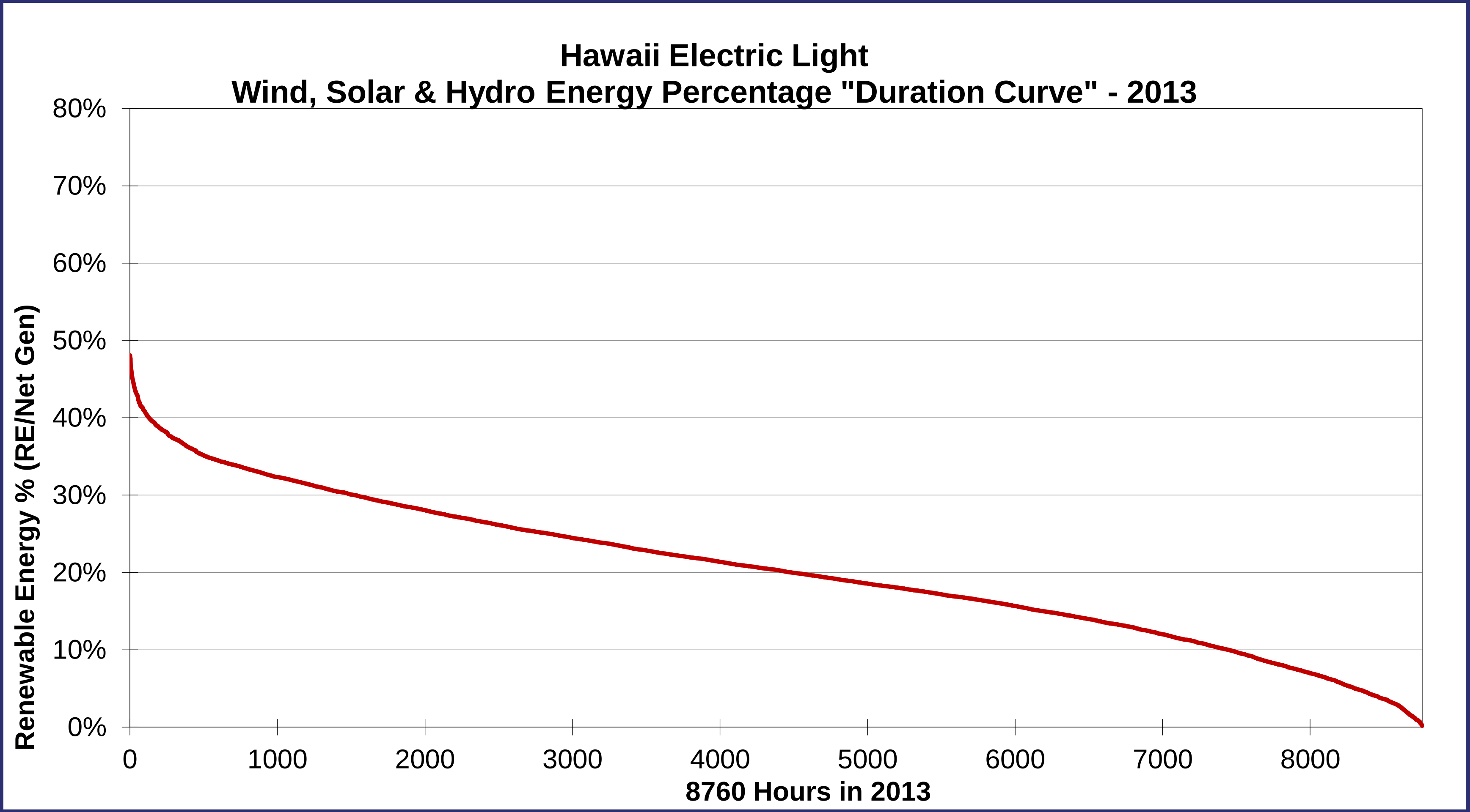


Renewable Generation Is a Significant Portion of Energy



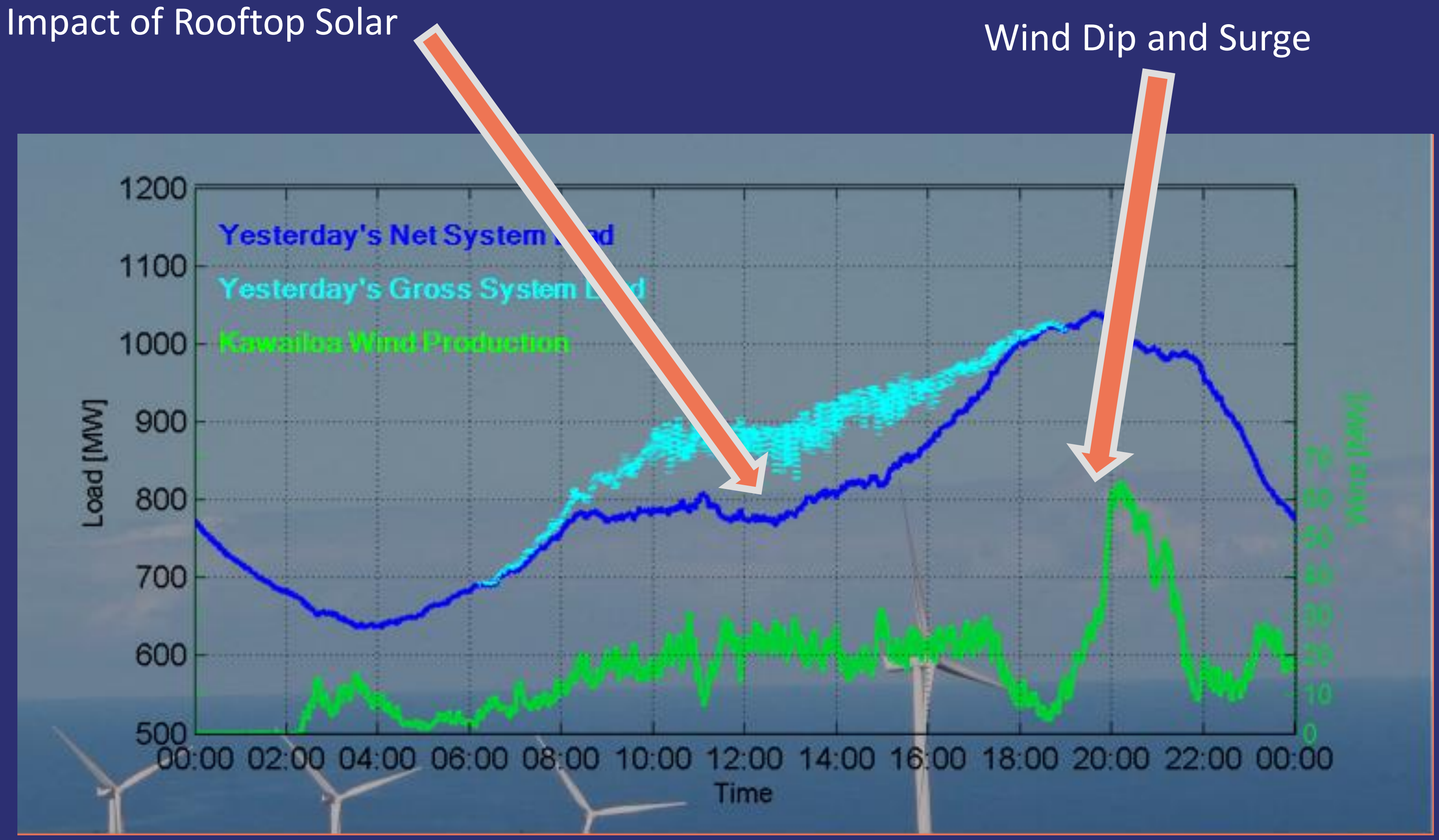
Hawaiian Electric
Maui Electric
Hawaiʻi Electric Light

Variable Generation Is a Significant Portion of Energy



Hawaiian Electric
Maui Electric
Hawaiʻi Electric Light

Typical Renewable Contribution
(Oahu: July 28, 2013)

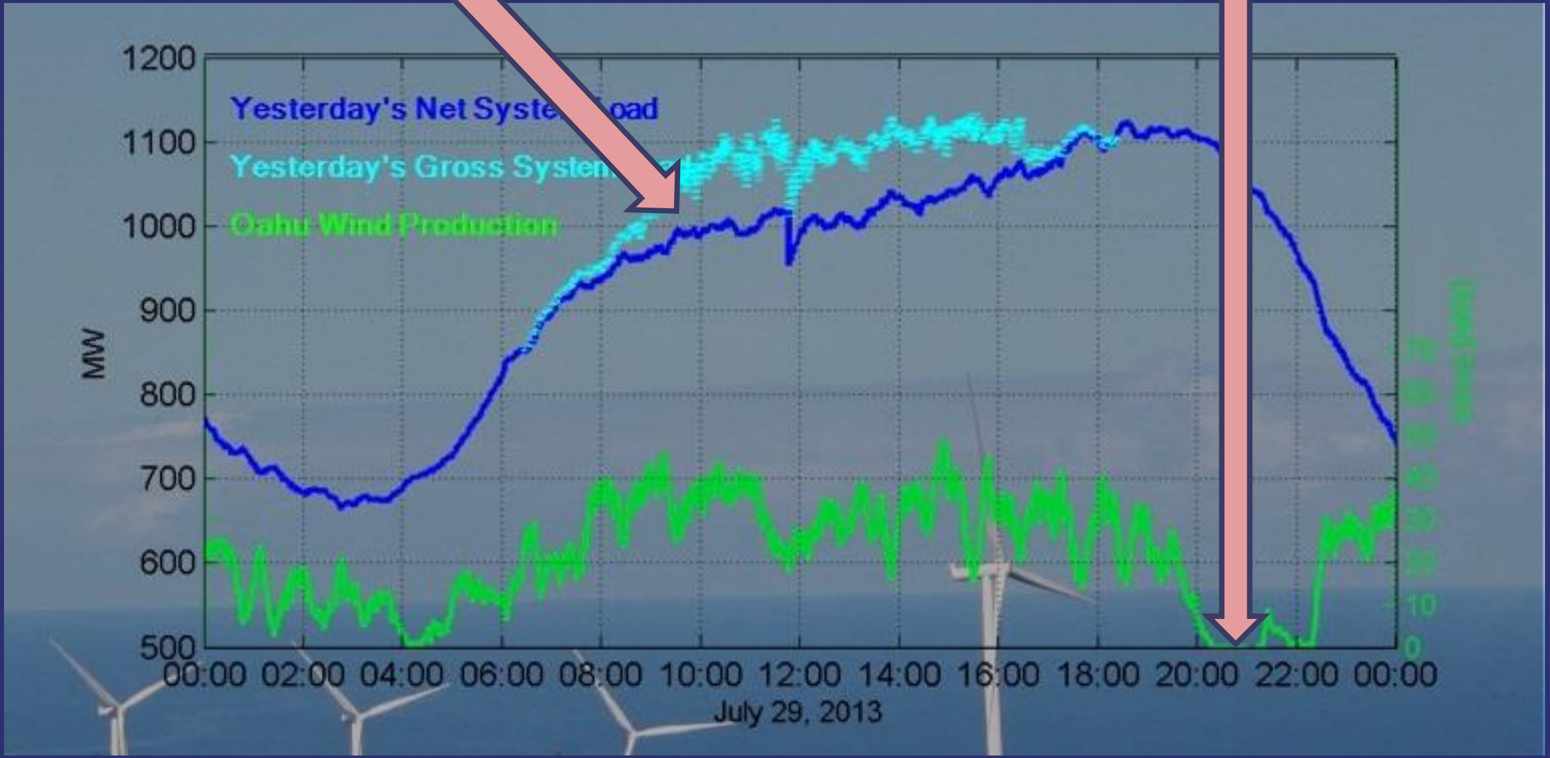


Hawaiian Electric
Maui Electric
Hawai'i Electric Light

Renewables During Tropical Storm Flossie
(Oahu: July 29, 2013)

Wind shuts down in high wind regime

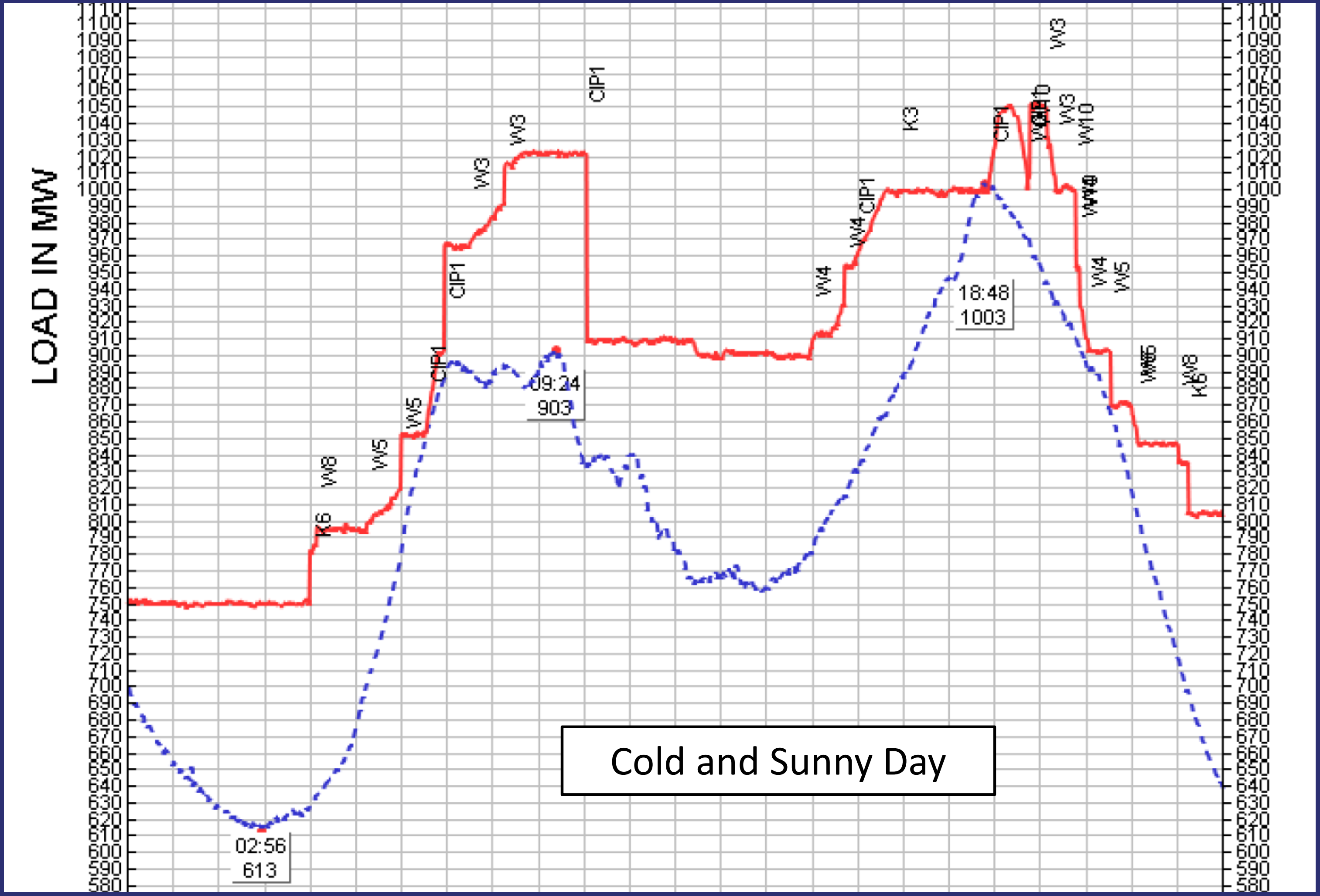
Impact of Rooftop Solar



Hawaiian Electric
Maui Electric
Hawai'i Electric Light

The “Duck” is Almost Here

(Oahu January 22, 2014)

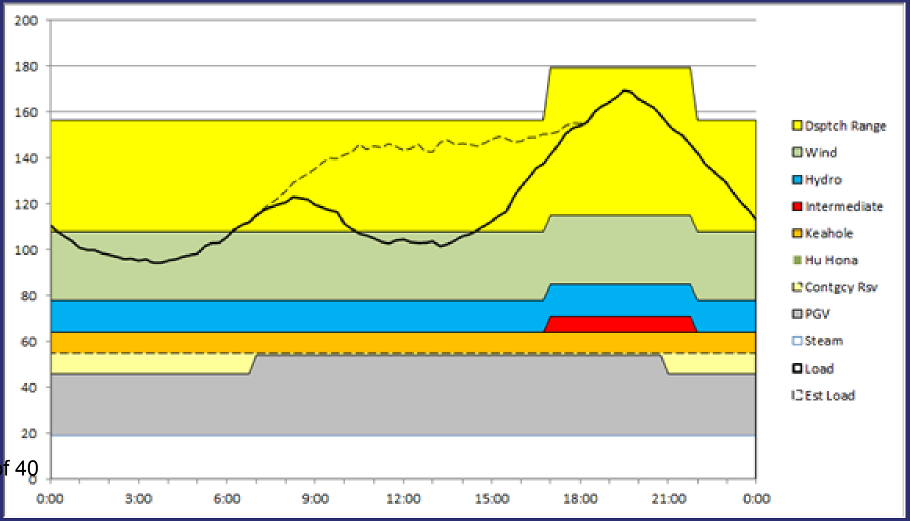


What's Changing

"Theory on the Mainland is Reality in Hawaii"

- **Generation**
  - Baseload and mid-merit driven off system
  - Replaced with fast-start, fast-maneuver generation
  - Significant generation is not visible or controllable (PV)
- **Transmission**
  - Transients are magnified
    - Sympathetic tripping of PV at high or low frequency
  - Transients are accelerated
    - Loss of inertia
    - Less generating units to "control" transients
  - Control measures are degraded
    - UFLS reduced and variable due to DG
  - Frequency instability
- **Distribution**
  - Voltage variations
  - Load rejection overvoltage
  - Islanding
  - Protection effectiveness

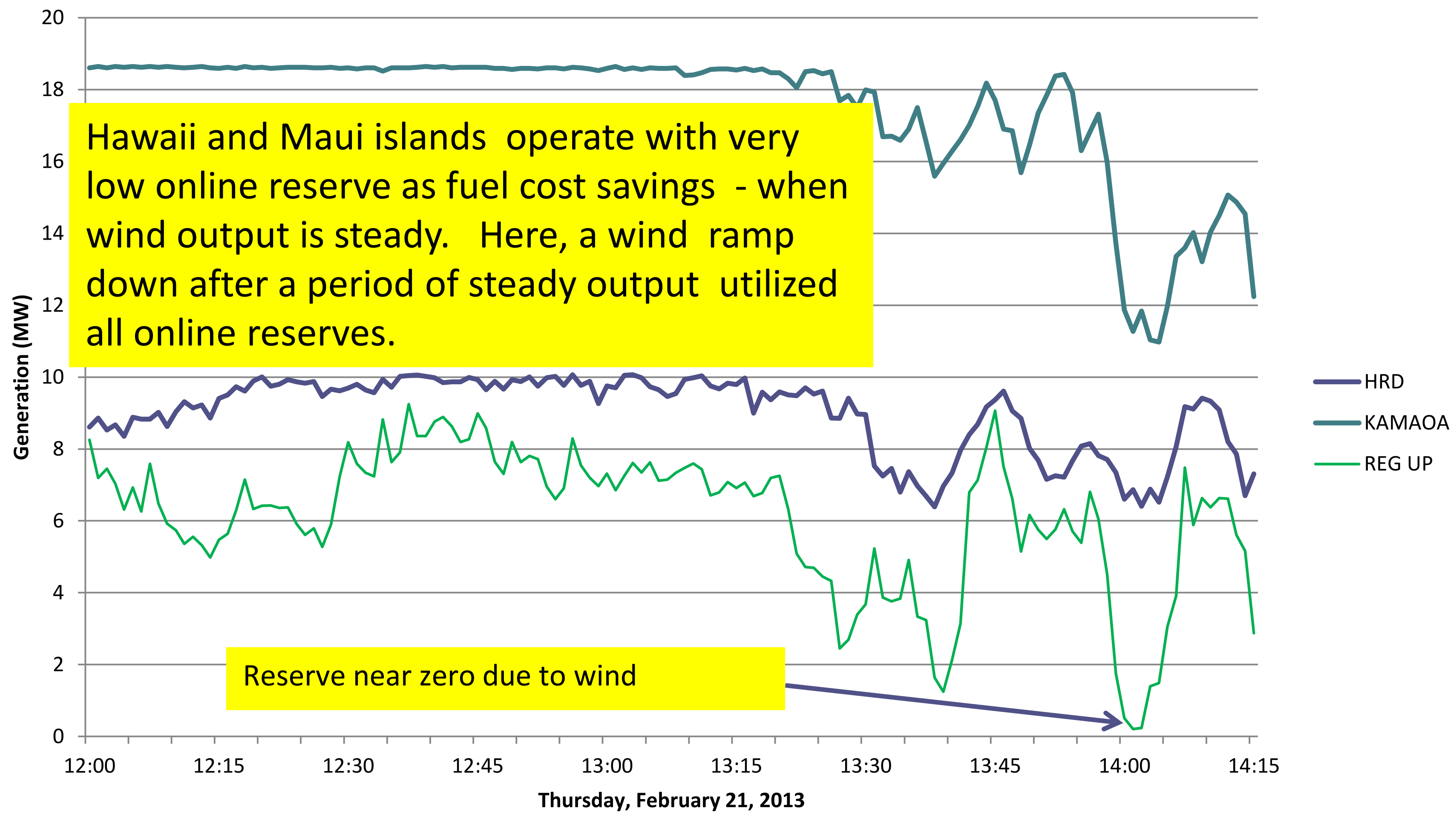
Distributed solar could displace lower-cost wind energy in 2014 (Hawaii Island)



Hawaiian Electric
Maui Electric
Hawai'i Electric Light

Mahalo!

Wind Impacts on Reserves (Hawaii Island)



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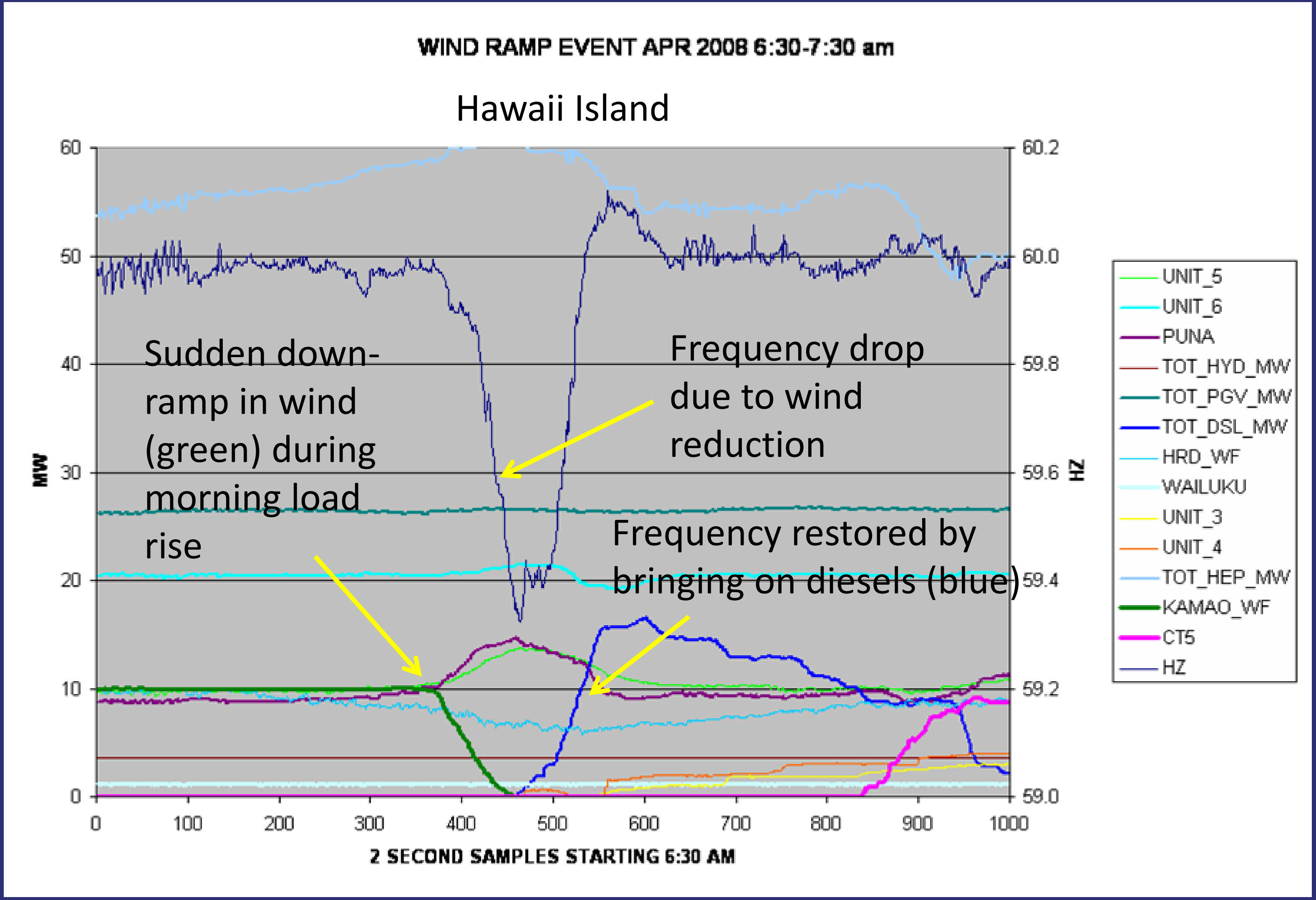
Use of Fast-Start Diesels - Wind Ramp



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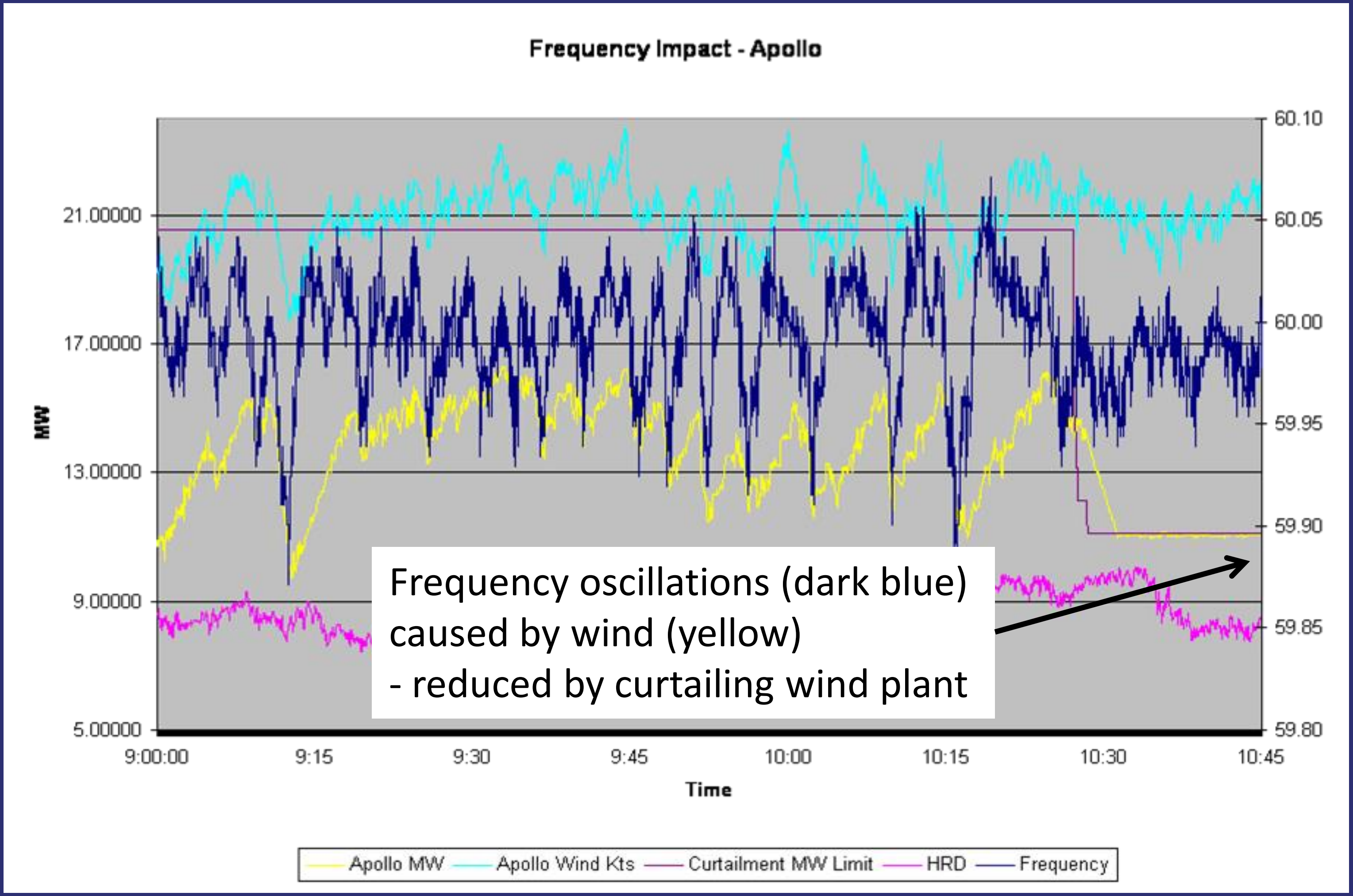
Fast Variability – Frequency Impact

Mitigated by Curtailment



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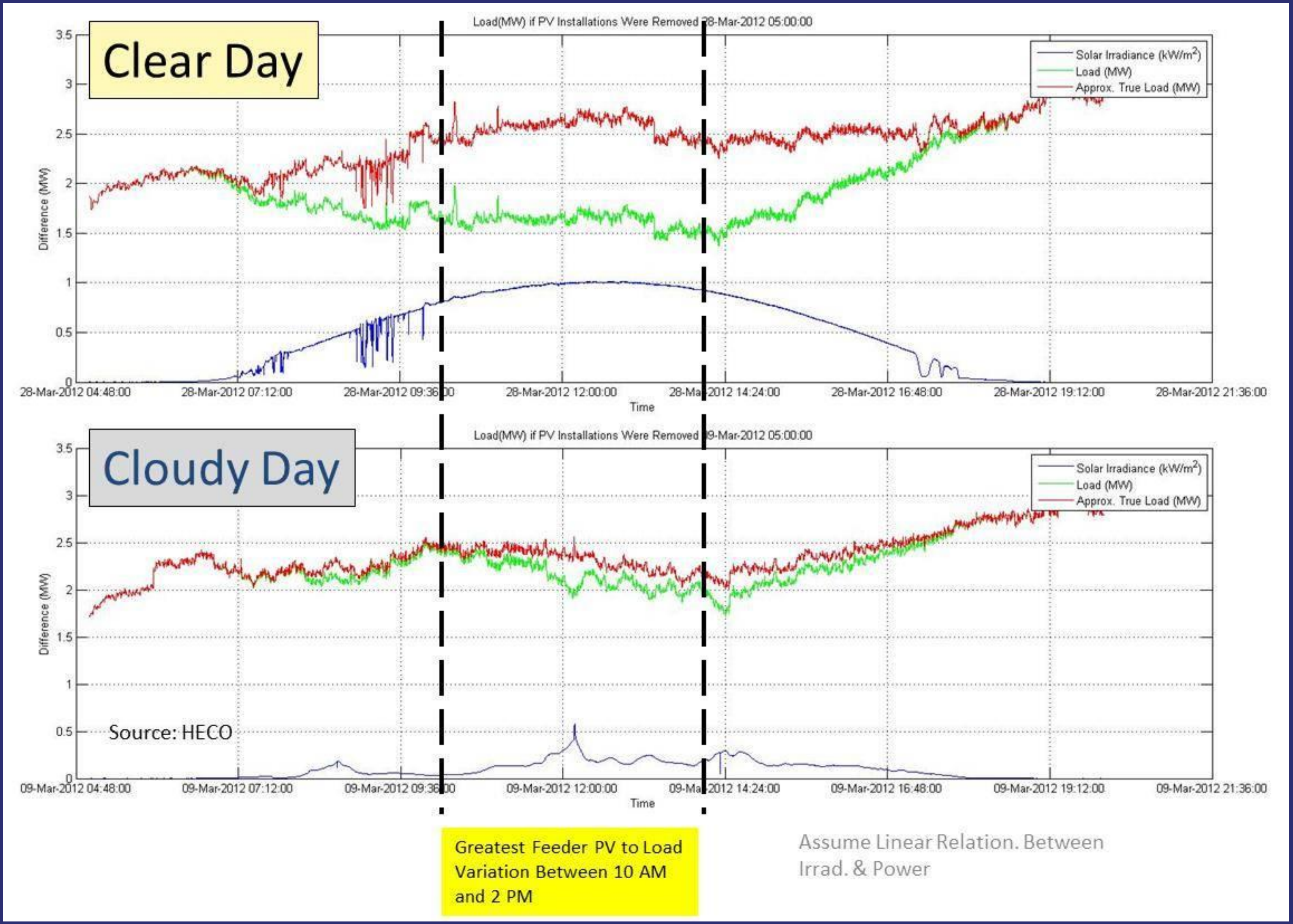
Sunny, clear day = less demand on circuit for UFLS



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Backup Slides

Mr. Dick Rosenblum – President and CEO
Hawaiian Electric Company
NERC Board of Trustees Meeting
Phoenix, Arizona
February 6, 2014

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Change in Generation Mix Impacting System Reliability and Security

- Dispatchable, frequency responsive generation displaced to accommodate variable generation.
    - – Cycled offline or operated near minimum dispatch
  - – Increased rate of change of frequency
  - – Lower Nadir (frequency low point) and/or Additional Load-shed
  - – Increased average frequency error
  - – Potential voltage limit violations/ voltage instability
- Planning must identify generation operators need to maintain <u>acceptable</u> system security
  - – Requires modeling of variable gen impacts, including DG
  - – Individual gen models become very important in simulations
  - – Reduced security margins from historical operation
    - – Individual unit performance becomes critical to system response
  - – Customers could see more outages
  - – Post-disturbance review important to verify system performance
    - – Continue improved dynamics modeling through tests, real-time monitoring, PMU's

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Impacts on Frequency Control / System Balancing for Island Grids

- Disadvantages of island systems
  - All imbalance between generation and demand results in frequency error (no interchange)
  - Single facility can have large influence on frequency, due to small system size
    - Small frequency bias (can be 2-3 MW/ .1 Hz on Maui and Hawaii)
  - Limited ability to leverage geographic diversity to mitigate variability
  - Operated closer to security constraints than most power systems
  - Faults cause frequency/voltage deviations beyond typically experienced on mainland – risk of large aggregate loss of gen from distributed generators
  - Wind/solar PV difficult to forecast due to variable weather patterns
- Advantages of island systems
  - No market – operators have direct control of generating assets which maximizes operational flexibility: not constrained by market rules or design
  - Generating resources used for peaking/emergency conditions on the islands provide flexible resources useful for variable generation (fast-start generating units)

Mitigation of Impacts on Frequency Control / Balancing

- Increased dispatchable gen operating range, ramp rates
- Measure/correct governor droop response for critical dispatchable generators to design (4-5%)
- Modifications to AGC to improve frequency control with wind generation
- Online Reserve modifications
  - maintain online reserves for increased ramping and regulation requirements –
  - dynamic requirement based on observed variability and amount of variable gen
- Fast-starting generation used to mitigate unexpected ramp events

Measures Taken to Improve System Security/Frequency Control

- Interconnection requirements for all trans. connected gen – including wind, large solar, and geothermal
  - Droop, inertial response, ramp rate, voltage regulation voltage regulation, expanded disturbance ride-through requirements (reflecting island grid conditions)
  - Active power control (curtailment)
    - used routinely to avoid excess energy during lower-demand periods
    - Used to smooth excessive variability
  - Ramping control both up and down for wind plant (Maui Electric)
- Modified underfrequency Load shed schemes required for system dynamic behavior with new generation mix
  - Tripping time reduced from 19 to 8 cycles on Hawaii island
  - A time-delay block added for ramp-type contingencies (loss of combine cycle gas turbine or wind ramps)
  - Fewer blocks, larger amount shed to restore closer to normal frequency
- Future: Measures to manage High Penetration of Distributed Gen
  - Interconnection requirements for DG – expanded ride-through, frequency response, voltage control (discussed more later)
  - Dynamic Load-shed scheme (discussed more later)

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Active Power Control needed for DG

- Island systems have significant amounts of must-take renewable generation (wind, hydro, geothermal)
- Excess energy conditions routinely occur during off-peak hours
- DG at forecast levels will force daytime curtailment and may force dispatchable units below minimums
- Island systems more vulnerable to system failure
  - Once a portion of system is reenergized, DER will reconnect
  - If a restoration is needed during high solar production, it will be difficult to balance the system (already a difficult task)
- Where feasible, communication and control by interfacing to DG relays from nearby sub RTU is being deployed

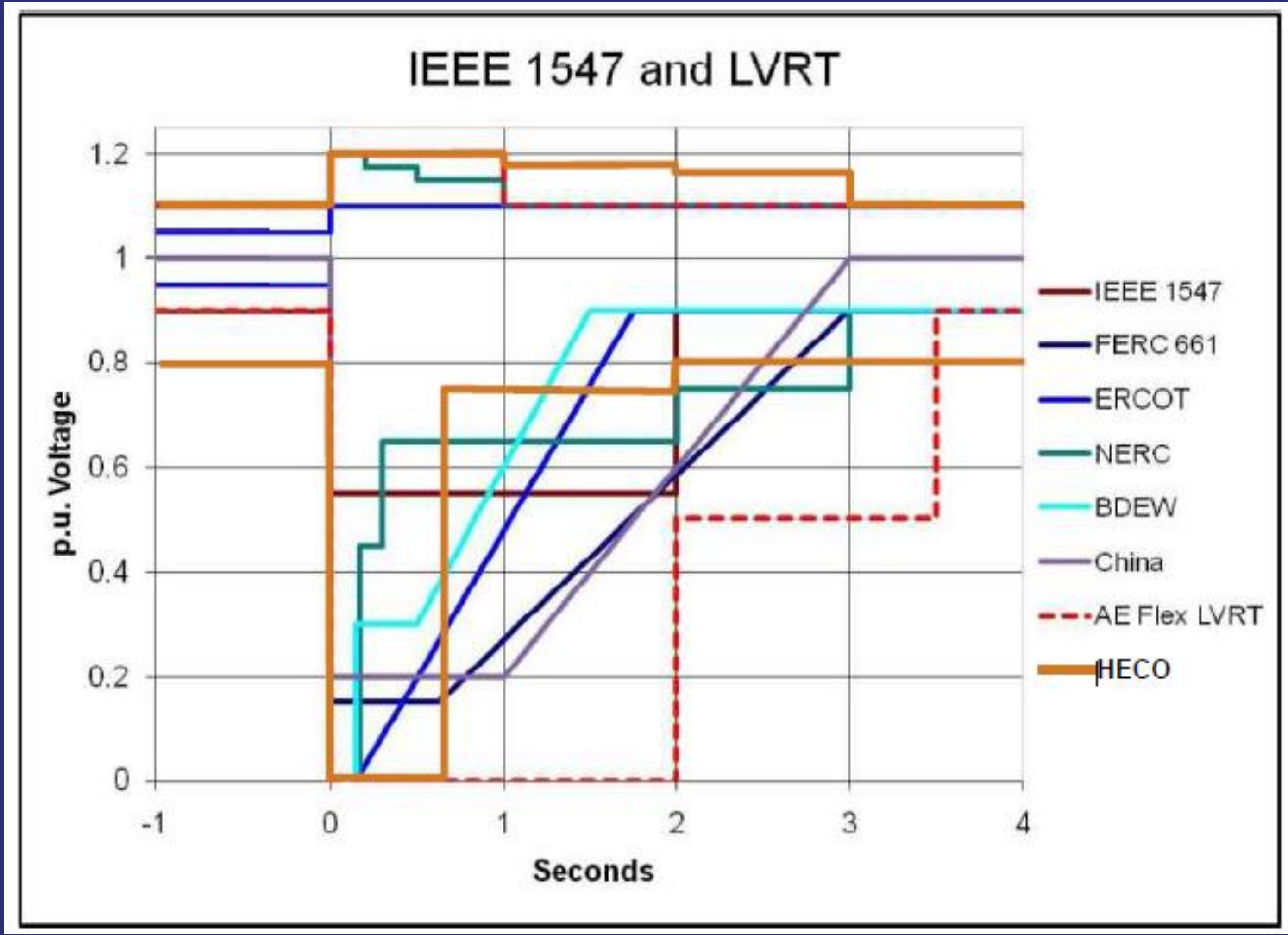
DG Behavior during Disturbances Impacting System Security

- Connecting DG are now required to use 57 Hz trip setting
  - (but does not guarantee ride-through)
- Legacy DG trip at 59.3 Hz IEEE 1547 default
- Recent daytime generator trip on Oahu, 55-65 MW of PV tripped.
  - Estimates based on different methods; using solar data and system response
- **Increased largest contingency by 27-36%**
- Over frequency trip settings are also critical
  - Loss of PV occurring for transmission faults under normal clearing on Oahu, resulting in low-frequency

DG Behavior During Voltage Disturbances

- Undervoltage trip setting is also a concern
- Island systems experience momentary wide-spread low-voltages during faults and contingencies
- Aggregate loss of DER may exacerbate conditions when disconnecting for low voltage (effectively increasing load during low voltage)
- Need to determine the voltage ride-through requirement at distribution level
- **Ride-through requirements will help mitigate system impacts but may require mitigation of risk for circuit island detection – settings must be a balance of circuit and system needs**

Voltage Ride-Through



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DG Impact on Underfrequency Loadshed Effectiveness

- Island systems rely heavily on underfrequency load-shed (UFLS) for loss of generation contingencies
- Distributed Solar PV cause circuit load to vary significantly throughout the day
- DER loss offsets effective load reduction from shedding UFLS circuits
- Illustrated on next slide

Impact on Underfrequency Loadshed Scheme

- More circuits (and customers) being shed than in the past for the same generator contingency
  - For higher levels, scheme may be insufficient to prevent system failure
  - Dynamic scheme may be necessary to reflect impact of DG on amount of load available
  - Need to determine largest contingency including contribution from DER
    - Requires aggregate estimate of DER production
  - UFLS relays be would set based on actual circuit net demand
- Some circuits may export during high PV production
  - UFLS need to be blocked when circuit exporting

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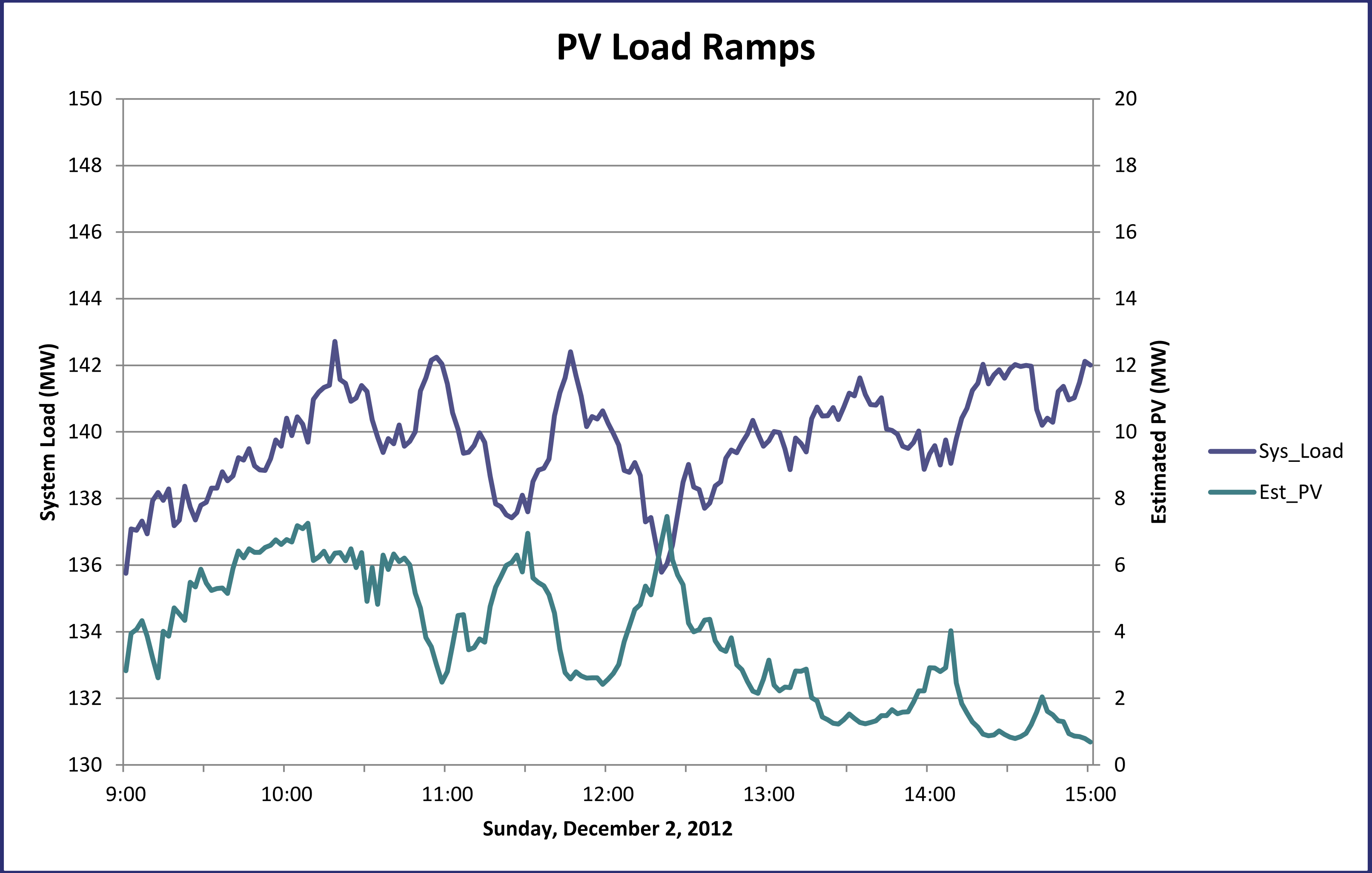
Operations Impacts from Changes in Net Demand

- Net demand more variable, less predictable
  - Beginning to integrate wind and solar forecasting into operations
- Two peaks (morning and evening) with valley in the middle caused by increased distr. PV
- Changes types of units needed
  - Cycling, quick start, fast ramping, able to operate short periods (small minimum up / down times)
  - Units historically operated continuously may need to cycle offline to avoid excessive costs by operating at inefficient levels
    - Cycling capabilities and costs being studied

Demand Forecasting

- Wind and Solar Impacts on Demand
  - Less predictable net demand makes it difficult for operators to decide when to start up and shutdown generators – increases costs
  - Forecasting is more critical as more units historically operated continuously are cycled offline
  - Island systems must balance system at all times – imbalance = frequency error
- Today: Adjusting commitment using existing tools
  - Adjust online reserves for real-time observed variability
  - Solar models incorporating connected PV are being tested
  - Wind forecast models were constructed for specific windfarm sites and are also being tested by operations
- Future: Improve weather forecasting models and tools
  - Need to develop day-ahead unit commitment tools to incorporate the forecasts to facilitate offline cycling
  - Real-time production and availability data would improve forecasts

PV Ramp Event – Impact on Net Demand



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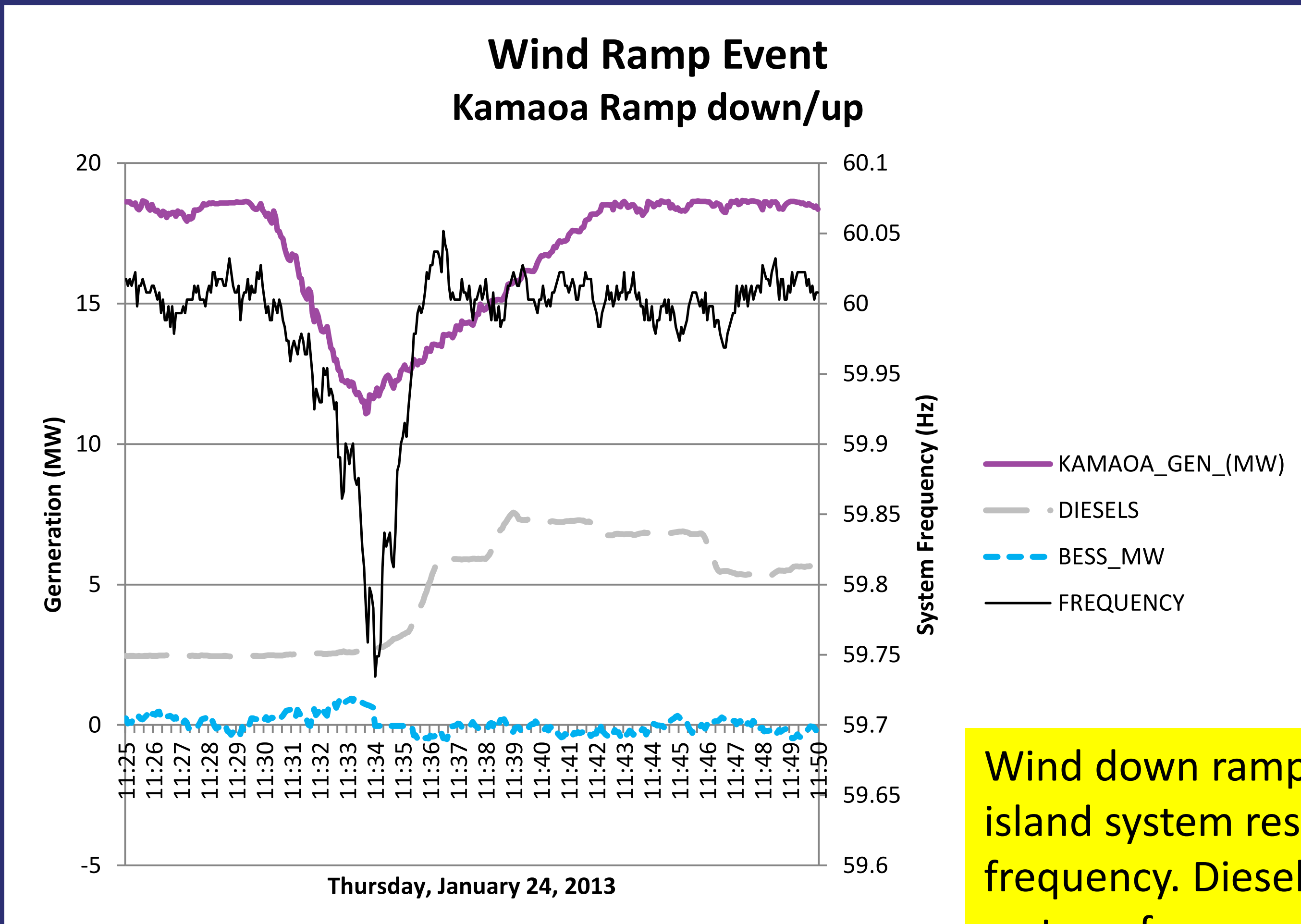
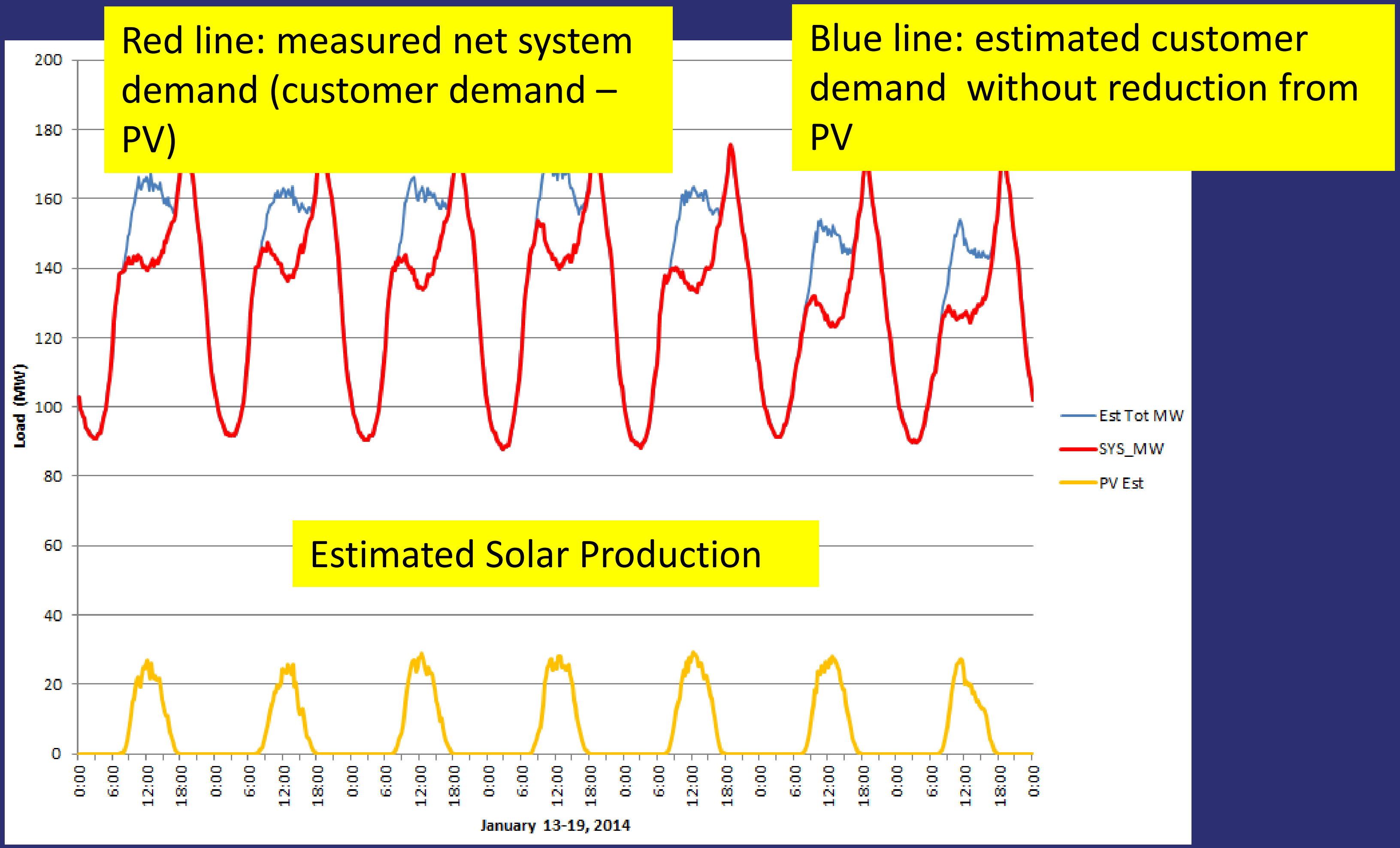
Wind Variability



Wind down ramp on the Hawaii island system resulted low frequency. Diesels were used to restore frequency. Wind ramped back up following the event.

Daily PV Impact on Net Demand – Monday Through Sunday - Hawaii Island



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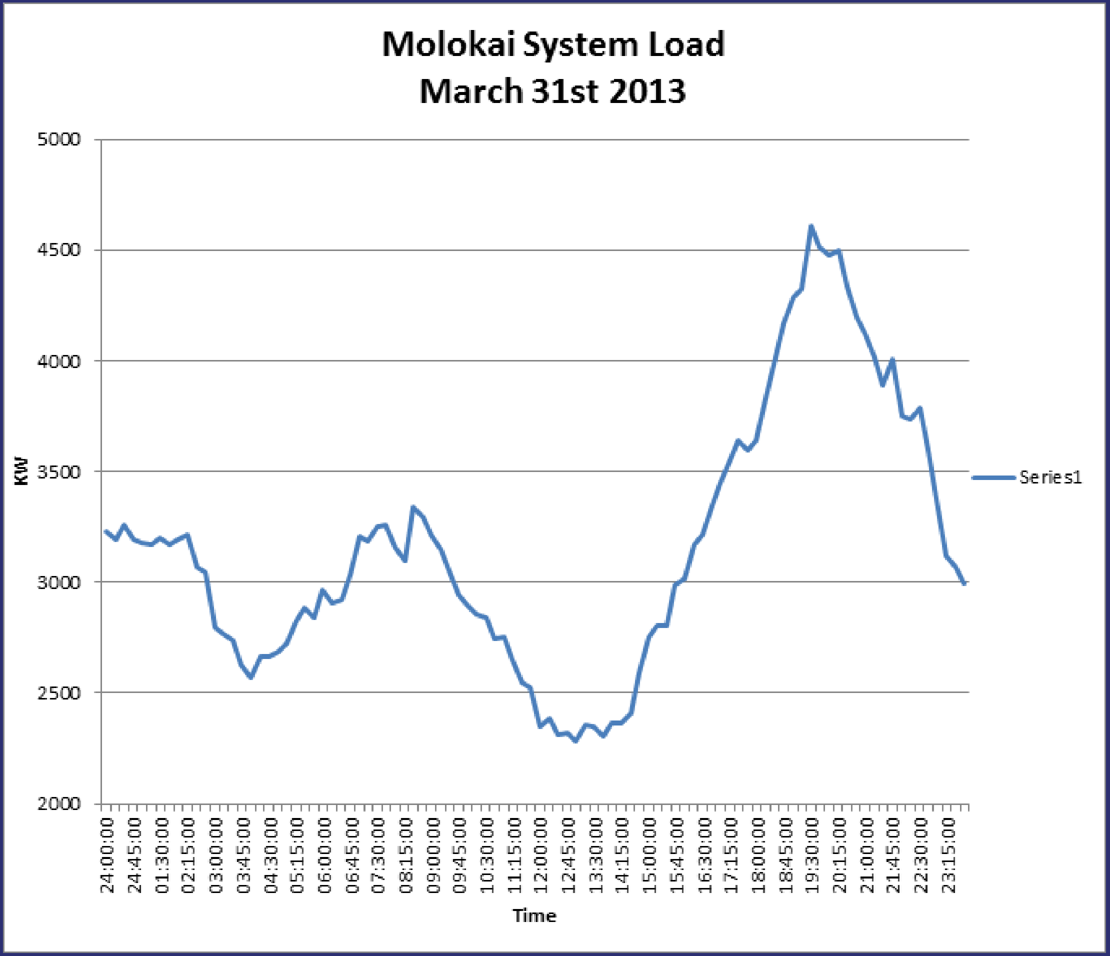
Molokai – Day Demand Lower Than Night Minimum Due to PV



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Estimating PV Production

– Measured data from production required to "tune" solar production forecasting and for operators to understand changes in net demand
– Approximation technique is being used based on solar irradiance monitors, scale by nearby capacity
– This method has improved visibility
– This method creates administrative burden to update rapidly increasing installed capacity

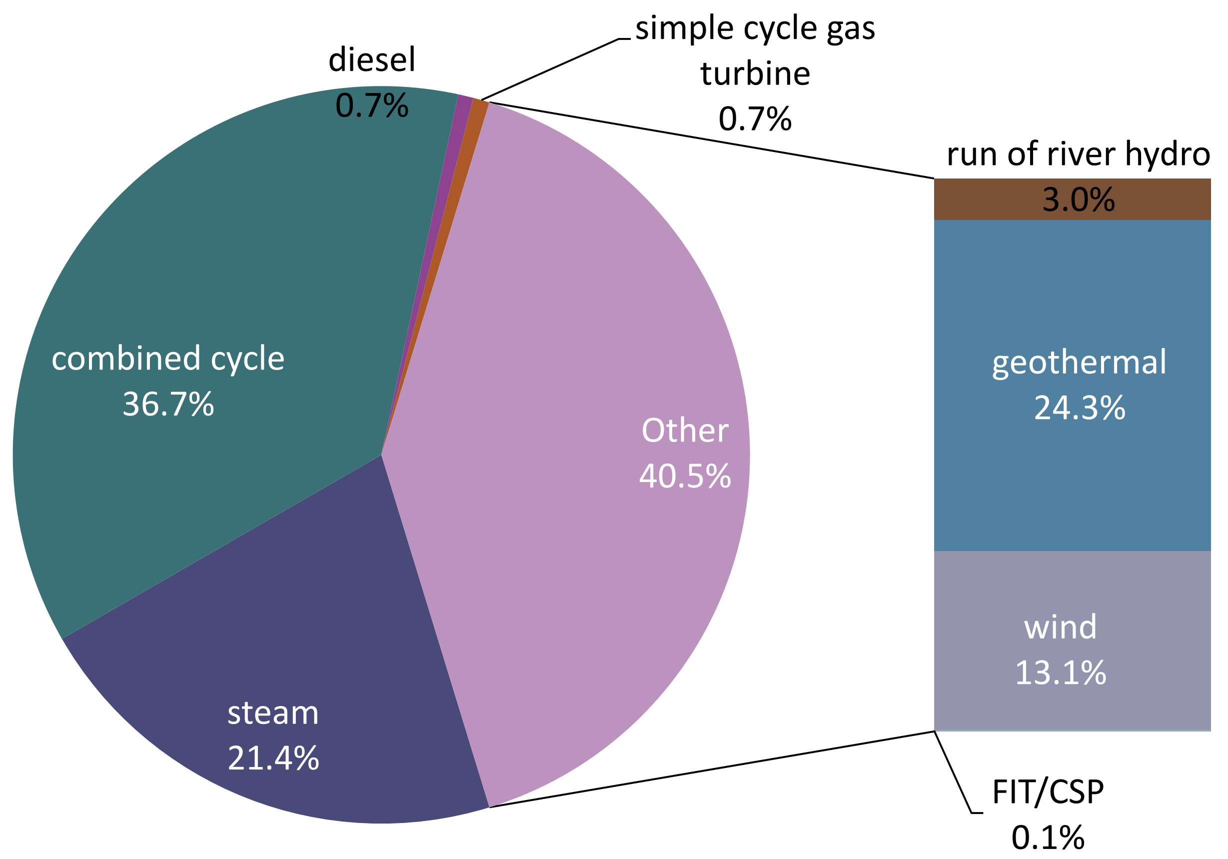
Recent snap-shot of Hawaii Island overview display. Colored circles indicate PV level.

PV estimated to provide 17% of total demand (161.2 MW)

Summary of Actions

- Challenges of distributed generation are more difficult than transmission-connected generation due to 1547 rules and large number of small participants
- Planning for Operational Configurations to Maintain System Security
  - Include DG in system planning models
    - Need for tools to allow rapid updates
  - Identify combinations of generation that should be able to provide acceptable system security through network security analysis
  - Implement system changes such as modified UFLS scheme, dynamic UFLS scheme
- Interconnection Requirements to maintain System Security and Operability
  - Active power control
  - Ride-through
  - Voltage control
  - Needed for Distributed Generation as amounts are equivalent or exceed largest transmission generator
- Develop Operator Controls and Tools
  - Identify the minimum online generation for system security
  - Forecasting tools and Unit commitment incorporating forecast uncertainty (day ahead, updates)
  - Real-time Visibility and Control for Aggregate Variable and Distributed Gen
  - Flexible Generation: Fast starting Generation and/or Demand Response, faster ramp rates, cycling capability, larger dispatch range
- Review system behavior post-disturbance, identify any new concerns or problems and improve system models (PMU data useful) – studies cannot identify all potential issues! Need operational experience.

Hawaii Island 2013 Total Generation by Type (Does not include self-generation from NEM, load offset)



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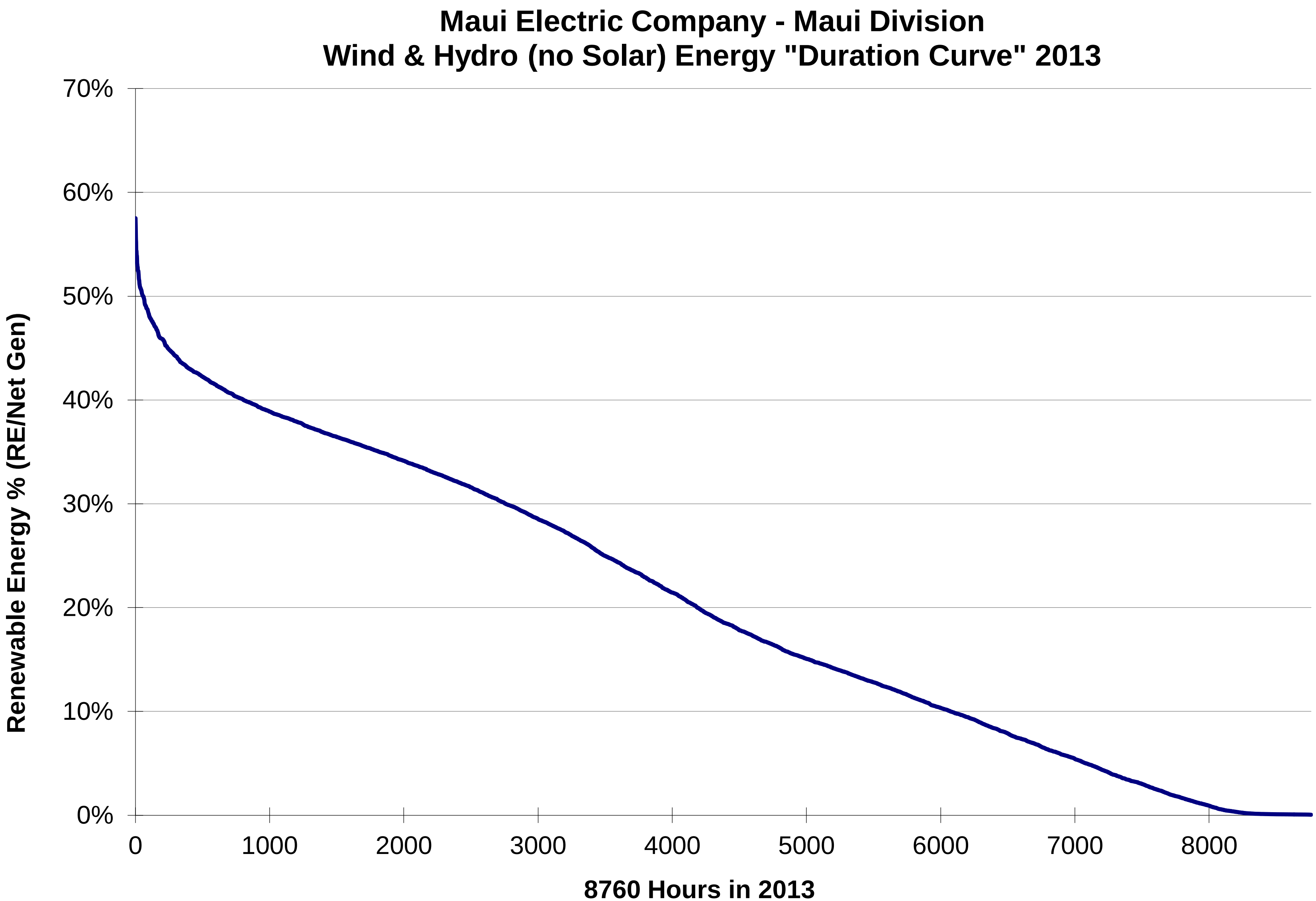

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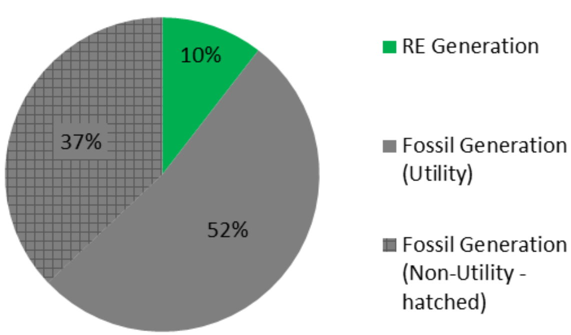
DG Exponential Growth: Engineering/Planning Challenge

- Standard Distribution Interconnection Process
  - Screening focuses on distribution feeder-level issues
  - No trigger for system level/ area level network analysis based on aggregate impacts
  - No defined mechanism to disallow projects contributing to area or system level reliability problems
- Growth is faster than system studies and development of mitigation measures and operator tools

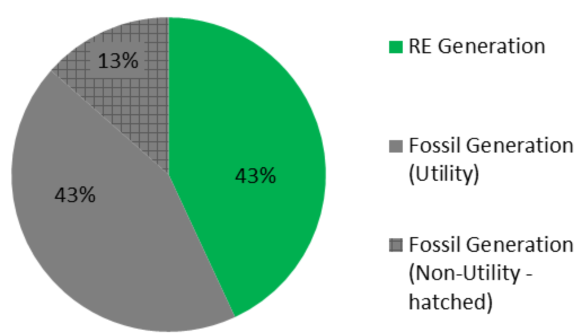
% Renewable Generation – Through November 2013

PPL Electric Exhibit SW-2

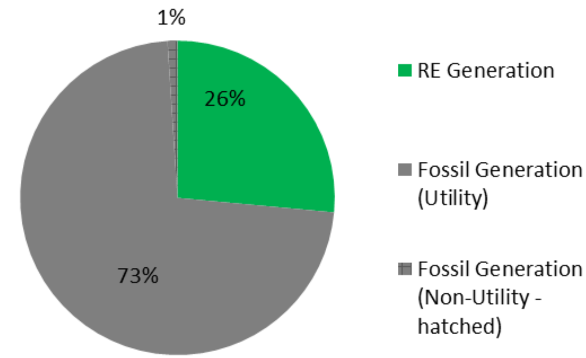
Oahu



Hawaii

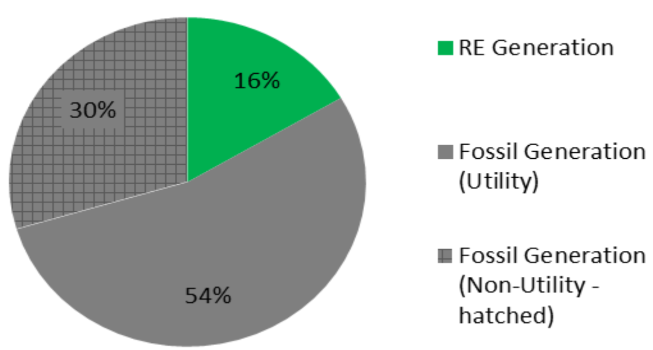


Maui County



Consolidated

RE Generation includes non-utility self-generation from FIT, NEM, and Rule 14H.



VERIFICATION

I, STEPHEN WHITLEY, being a Consultant at Stephen Whitley LLC, hereby state that the facts above set forth are true and correct to the best of my knowledge, information and belief and that I expect PPL Electric Utilities Corporation to be able to prove the same at a hearing held in this matter. I understand that the statements herein are made subject to the penalties of 18 Pa.C.S. § 4904 relating to unsworn falsification to authorities.

Date: 12-9-2019

Stephen Whitley

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