Renewable Energy Grid Integration

GridSTART

Grid System Technologies Advanced Research Team

Hawai‘i Natural Energy Institute
School of Ocean & Earth Science & Technology
University of Hawaii at Manoa
1680 East-West Road, POST 109
Honolulu, Hawaii 96822

HNEI
Hawai‘i Natural Energy Institute

UNIVERSITY of HAWAI‘I MANOA

APEC EGNRET
Capacity Building on Renewable Energy

March 20, 2018
Honolulu, Hawai‘i

GridSTART

Hawai'i Natural Energy Institute | University of Hawai'i

Grid System Technologies Advanced Research Team

Established to develop and test advanced grid architectures, new technologies and methods for effective integration of renewable energy resources, power system optimization and enabling policies.

- Serves to integrate into the operating power grid other HNEI technology areas: biomass and biofuels, fuel cells and hydrogen, energy efficiency, renewable power generation
- Strong and growing partnerships with national and international organizations including Asia-Pacific nations.

Lead for many public-private demonstration projects

GridSTART
Grid System Technologies Advanced Research Team

Core Team Members:

❖ Richard Rocheleau	*Director, HNEI*
❖ Leon Roose *	*Specialist & Chief Technologist*
❖ Mark Glick *	*Specialist, Energy Policy*
❖ Marc Matsuura *	*Senior Smart Grid Program Manager*
❖ Kanoa Jou *	*Power Systems Engineer*
❖ Staci Sadoyama *	*Power Systems Engineer*
❖ Thai Tran	*Junior Power System Engineer*
❖ Silas Oliviera de Toledo	*Junior Power System Engineer*
❖ Brian Chee	*Communications & IT System Analyst*
❖ John Cole *	*Senior Policy Strategist*
❖ James Maskrey *	*Energy Efficiency Program Manager*
❖ Dax Mathews	*Renewable Energy Resources Forecasting*
❖ Sharon Chan	*GIS Specialist*
❖ Kevin Davies	*Assistant Researcher*
❖ Saeed Sepasi	*Assistant Researcher*
❖ Abdul Motin Howlader	*Post-Doctoral Fellow*
❖ Sharif Muhammad Uddin	*Post-Doctoral Fellow*

Team members combine for 75+ years of utility, policy and regulatory experience

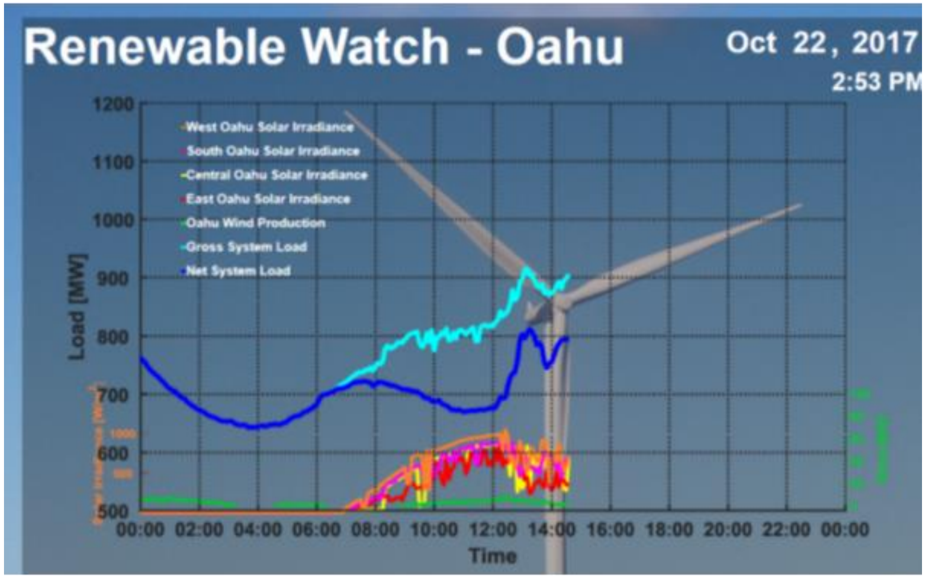
* Prior electric utility company senior management and staff (green)

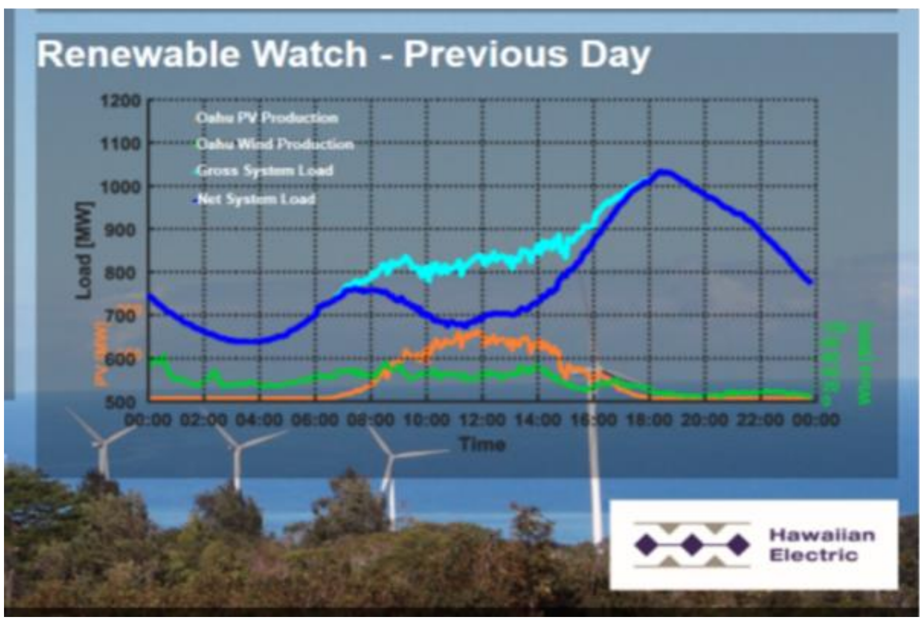
* Prior Commissioner of the Hawaii State Public Utilities Commission (blue)

* Prior Administrator of the Hawaii State Energy Office (yellow)

HNEI Hawai'i Natural Energy Institute

Hawaii’s Nene Curve

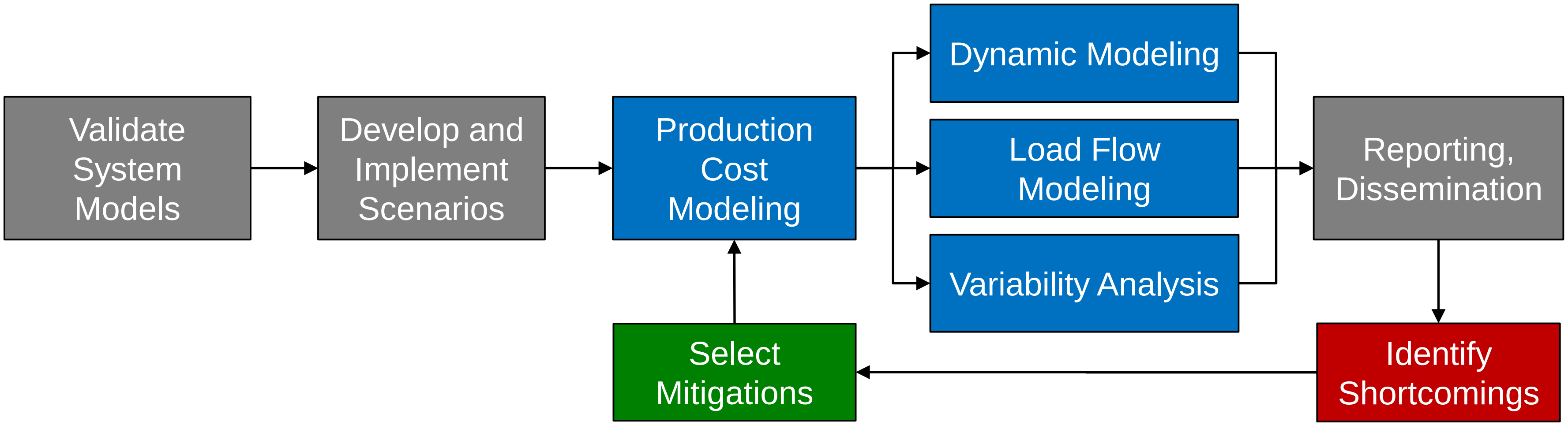




Types of Renewable Studies

- System Integration Study
  - Analysis of various renewable energy and system scenarios, considering:
    - Economics: production cost and curtailment risk
    - Reliability: loss of load expectation (LOLE), reserve requirements, mitigation strategies
    - System-level physics: voltage strength and frequency stability
- Interconnection Requirement Study (IRS)
  - Project-specific analyses – Protection schemes, ground fault overvoltage, power flow, etc.
- Distribution Hosting Capacity Study

System Integration Studies



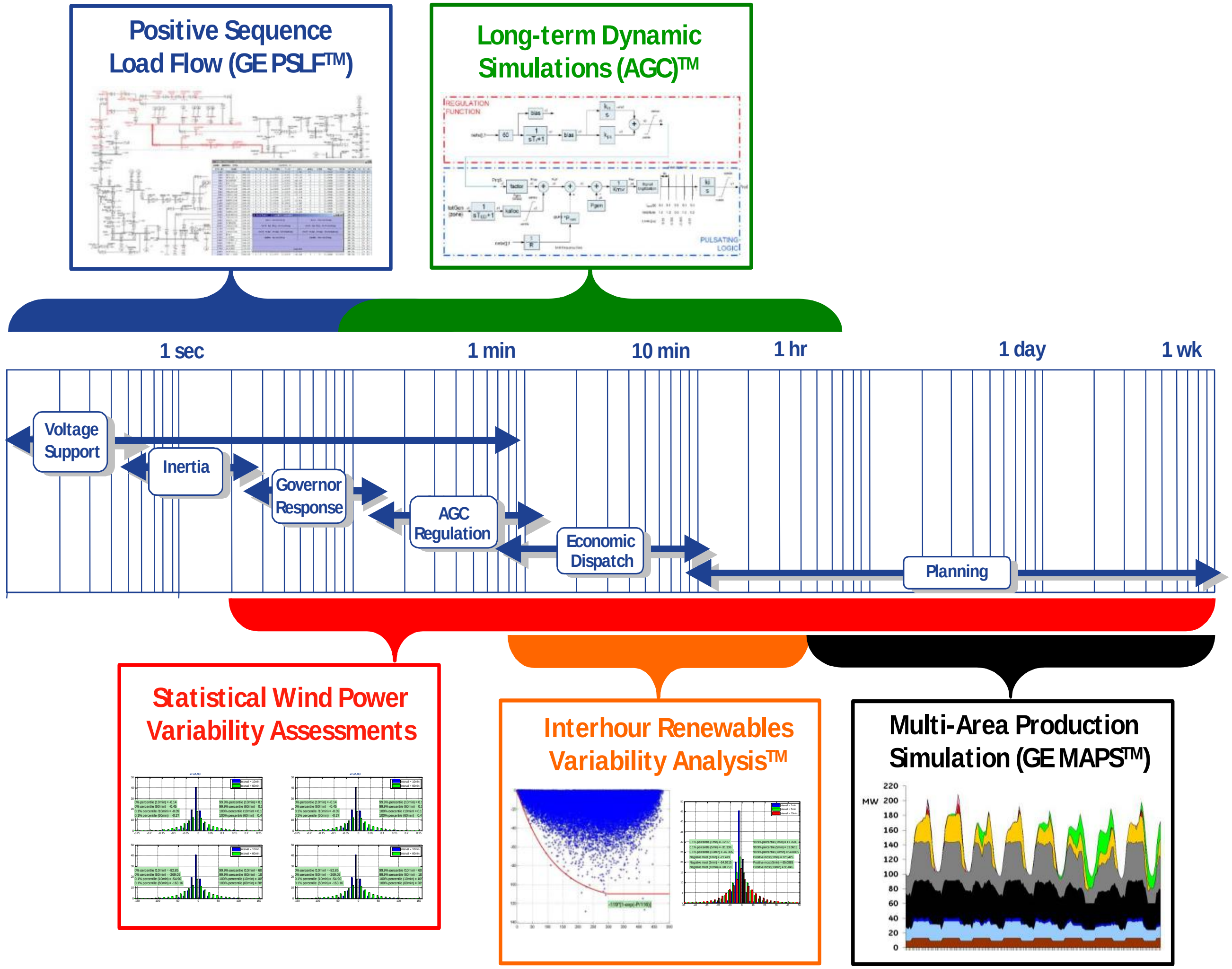
Evaluate high renewable options to identify technology and cost drivers

- Different resource mixes (wind, central & distributed solar, biomass, other)
- Different grid configurations (independent or connected, micro and smart grids)
- Alternative fuels (LNG, hydrogen)
- Changes in loads (energy efficiency, demand response, EVs, storage)
- Changes in grid operation (unit cycling, reduced min run)
- Changes in generation mix (unit retirement, new units, new technology)

Robust analysis to identify optimal operations and inform policy

Renewable Energy Grid Integration Studies

- Develop rigorous analytic models of electricity grids
- Analyze impact of new energy systems including renewable generation, end-use energy efficiency, and transportation systems
- Analyze solutions to address system integration issues
  - Advanced controls
  - Forecasting
  - Demand control
  - Storage
  - Smart grids



Tools are used together to assess the challenges and provide information needed for advanced energy solutions

HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

Why is Hawaii Unique?

A shared experience with other islanded power systems

Large Single Contingency

Must be prepared for the loss of AES coal plant, which can be up to 30% of the grid's supply

Low Number of Synchronous Generators

Oahu has few synchronous generators online and available to provide primary frequency response

Isolated grids

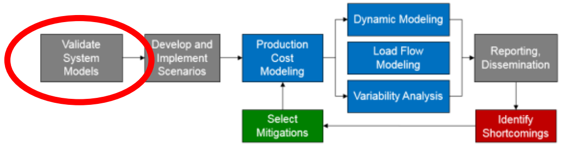
Islands cannot rely on neighbors during emergency events for support

High Level of Renewable Penetration (DPV especially)

High renewable penetration displaces conventional generation and some of the ancillary services they provide.

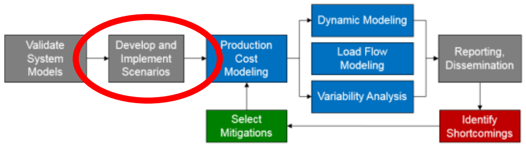
Novel solutions are required to maintain grid stability with high wind and solar penetration

System Integration Tasks
Data Requirements



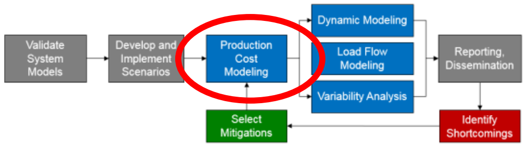
- **Existing infrastructure:**
  - **Thermal fleet:** heat rate curves, min/max operation, ramp rates and startup/shutdown time, maintenance intervals and outage rates
  - **Transmission and distribution:** topology, thermal limits, efficiencies
  - **Supporting equipment:** synchronous condensers, energy storage, etc.
- **Existing plans:** Capacity expansion and decommissioning
- **Loads:** Typical profiles and ramp rates, uncertainty, and annual growth
- **Renewable energy:** Typical metrological year (TMY) profiles, uncertainty, and annual variability (all location dependent)
- **Commitment and dispatch:** Operating constraints and strategies (reserves, PPAs, etc.), SCADA data
- **Economics:** Current and projected cost of fuel, renewable energy, and supporting technology

System Integration Tasks
Scenario Development

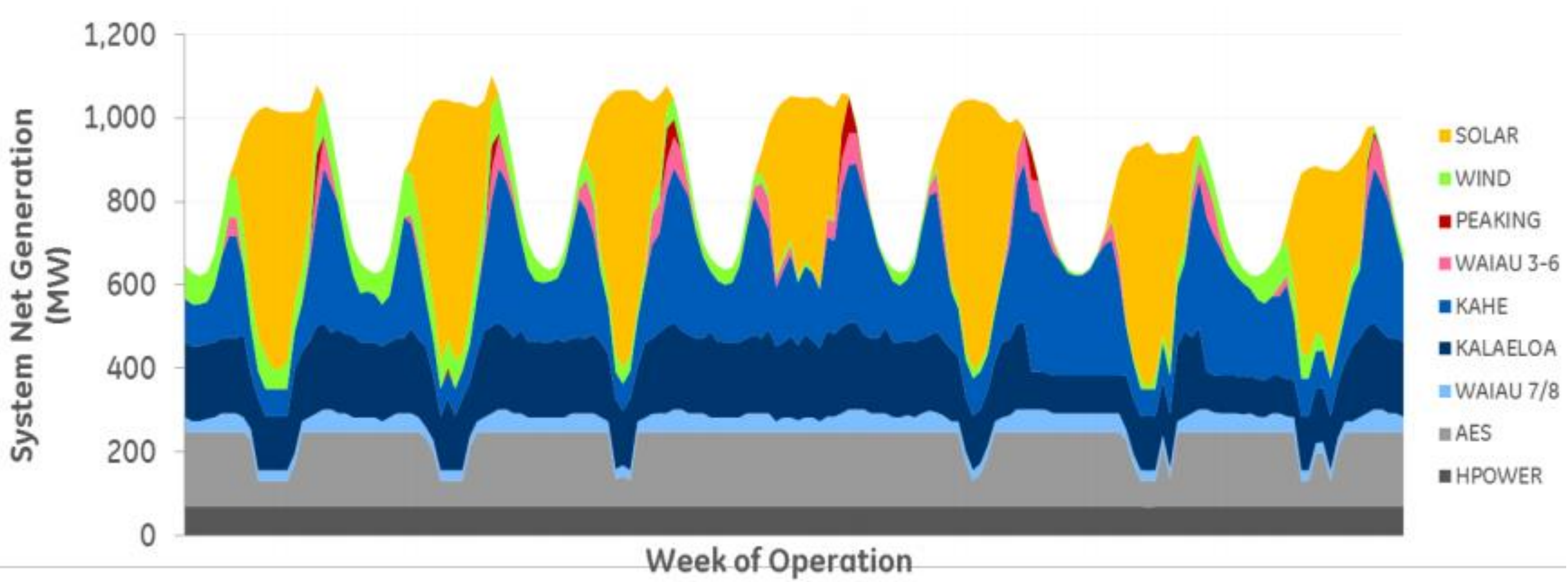


- Driven by society/political goals, available and future technology, and economics
- Iterative process – changes in driving factors
- Should involve all stakeholders – policymakers, utility, developers, public representatives – but let the data drive the outcomes
- Balance between the current and ideal future state of the grid

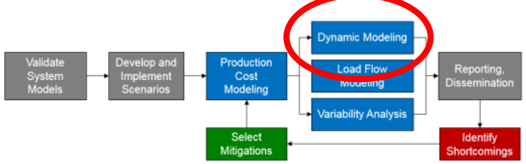
System Integration Tasks
Production Cost Modeling



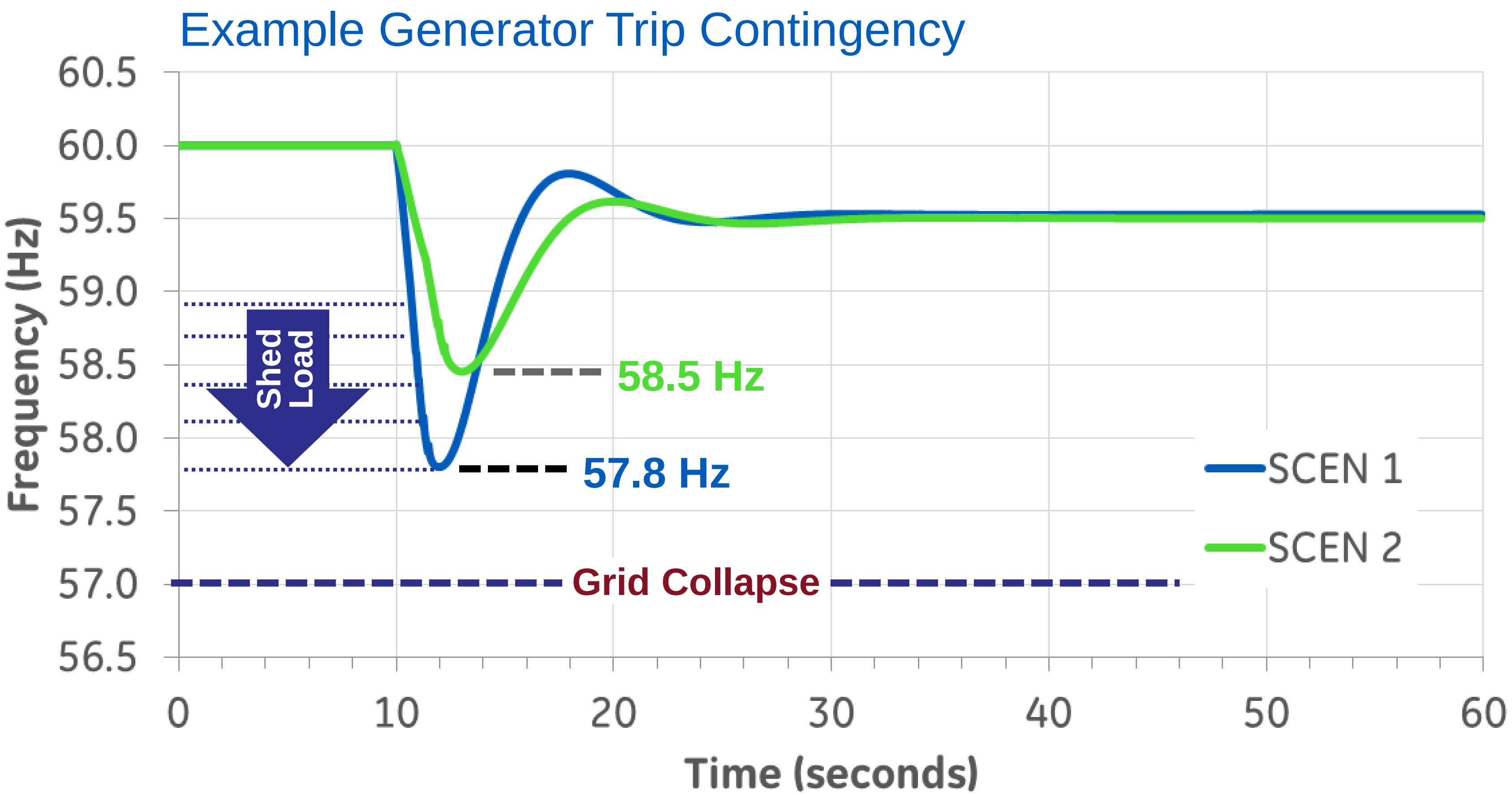
- Sub-hourly optimal commitment and dispatch, subject to operational constraints
- Initially, validate against existing operations
- Then, evaluate system operations and economics with increasing levels of wind, solar, and energy storage



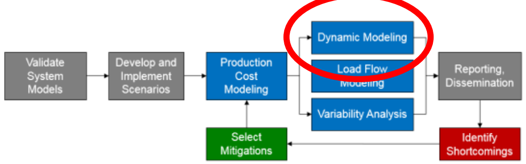
System Integration Tasks
Dynamic Modeling



- Used to analyze frequency stability under contingency events

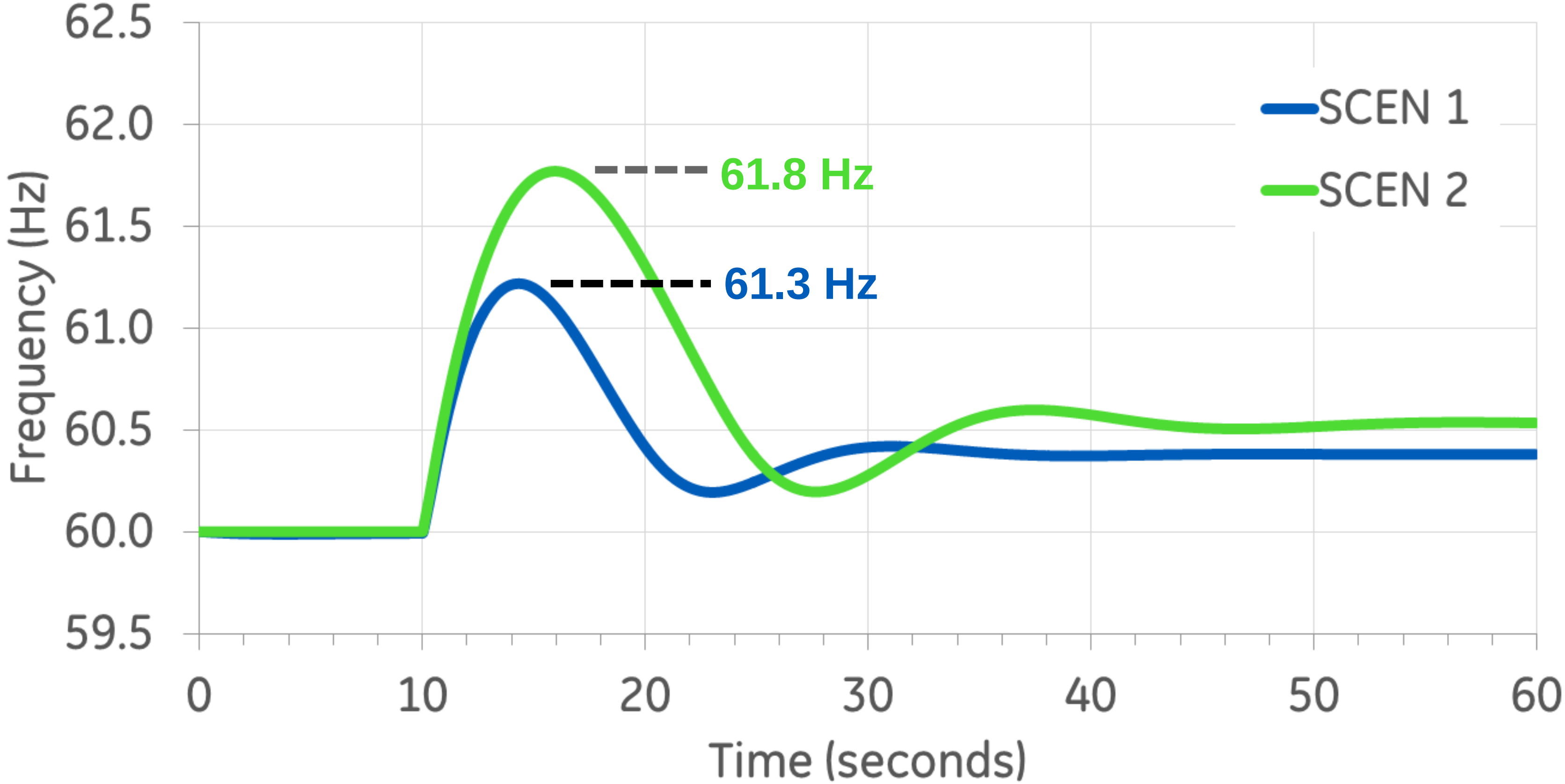


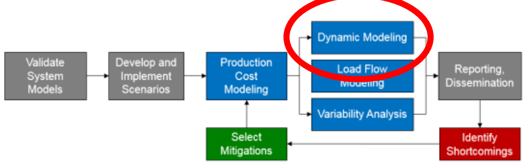
System Integration Tasks
Dynamic Modeling



- Over-frequency can also occur due to load rejection

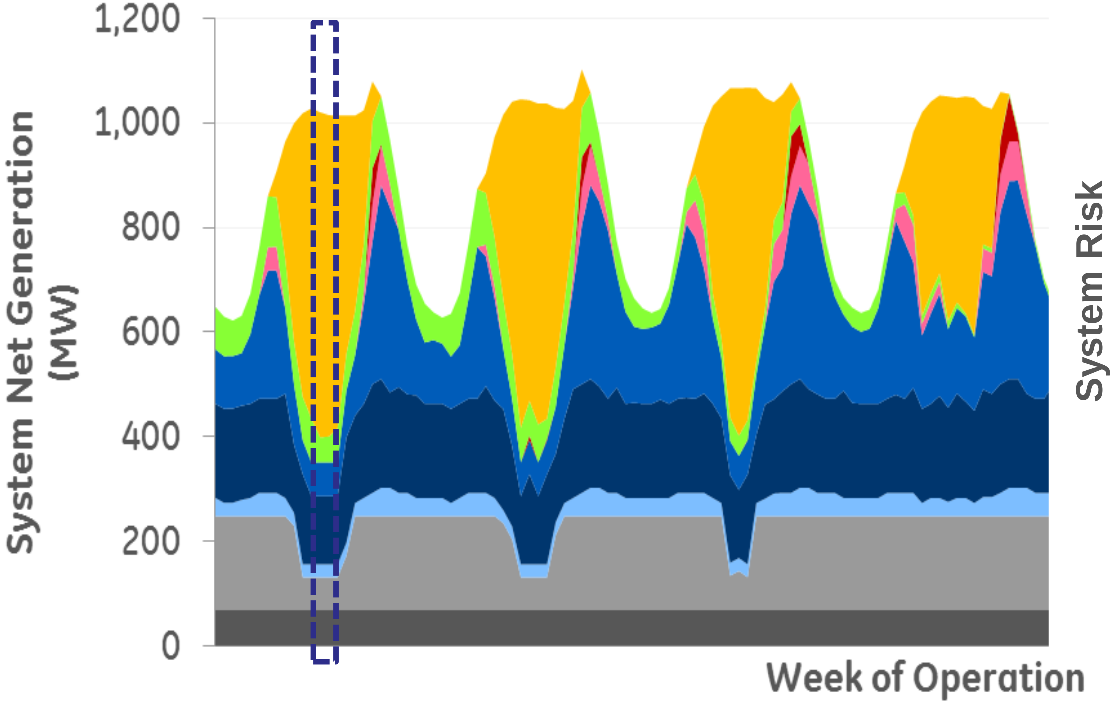
Example Load Rejection Contingency

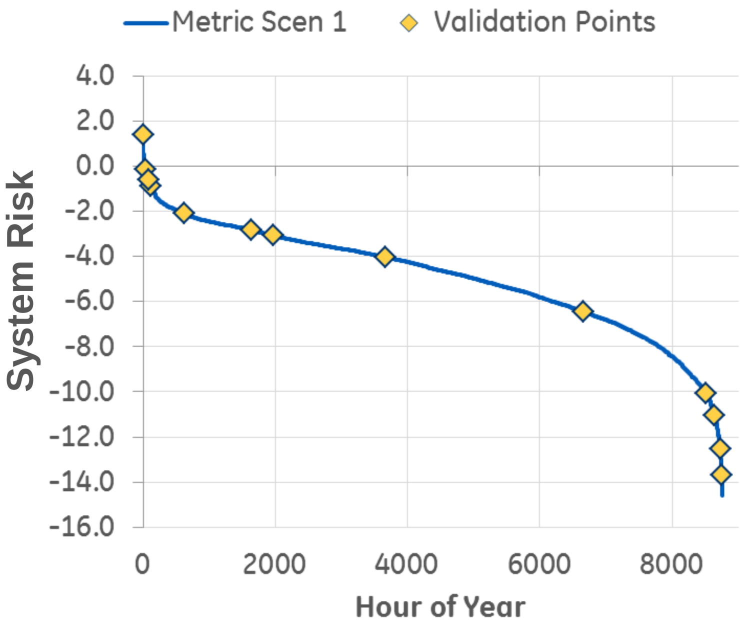




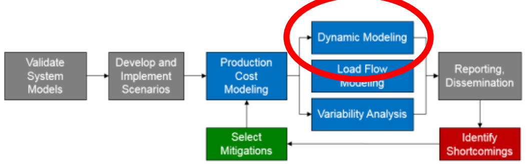
System Integration Tasks
Dynamic Modeling

- Dynamic simulation requires more effort than production cost simulation, so we use production cost to select challenging periods to evaluate further
- We fit and validate a metric that quantifies system risk based on multiple factors: thermal unit commitment, largest generator contingency, legacy DPV, and up reserves online



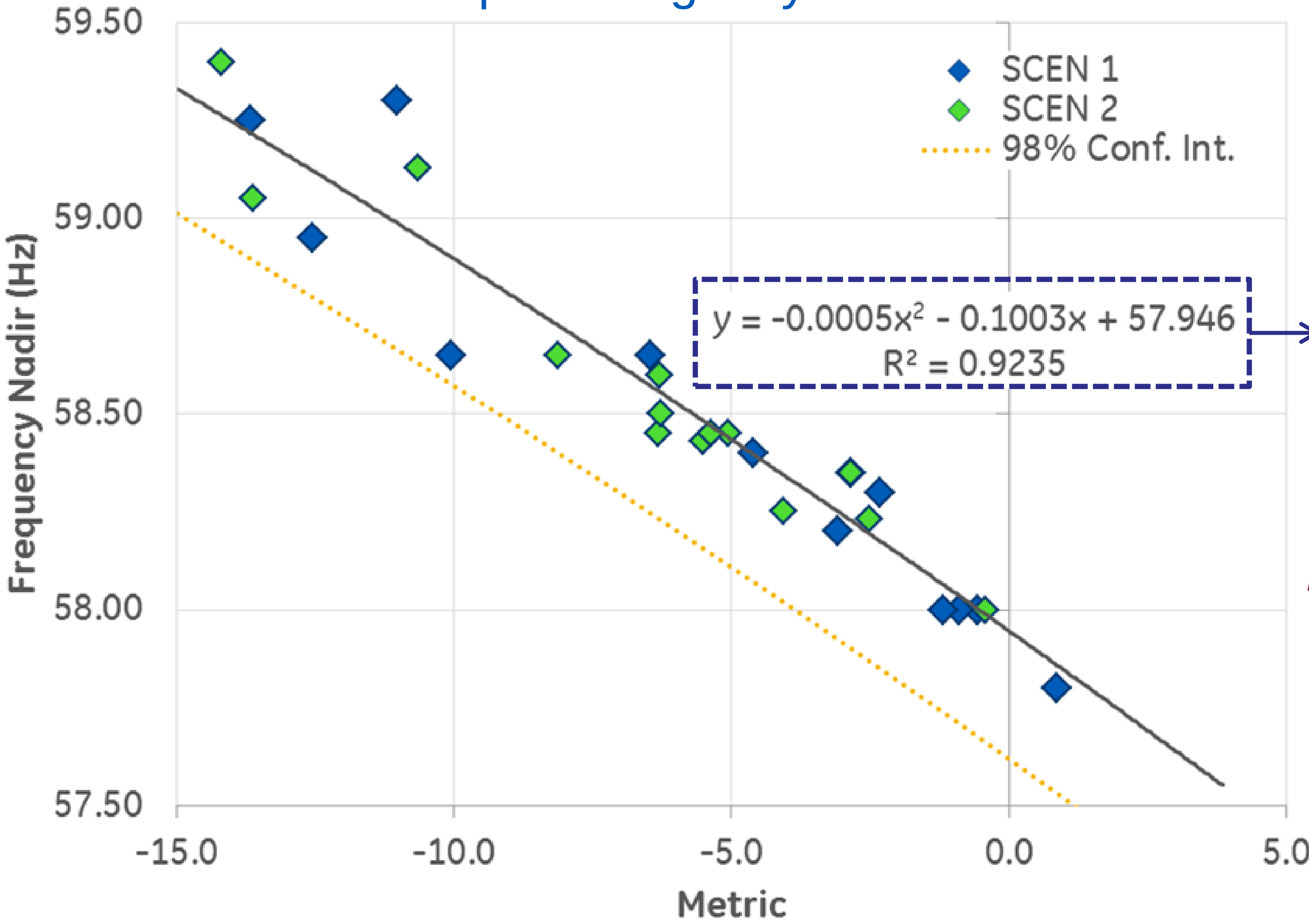


HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa



System Integration Tasks
Dynamic Modeling

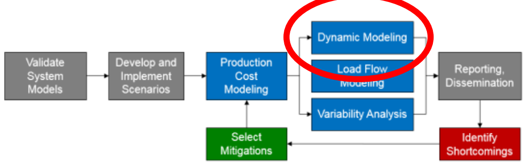
Generator Trip Contingency



Use this equation to estimate frequency response throughout the year

Process repeated for load-rejection contingencies

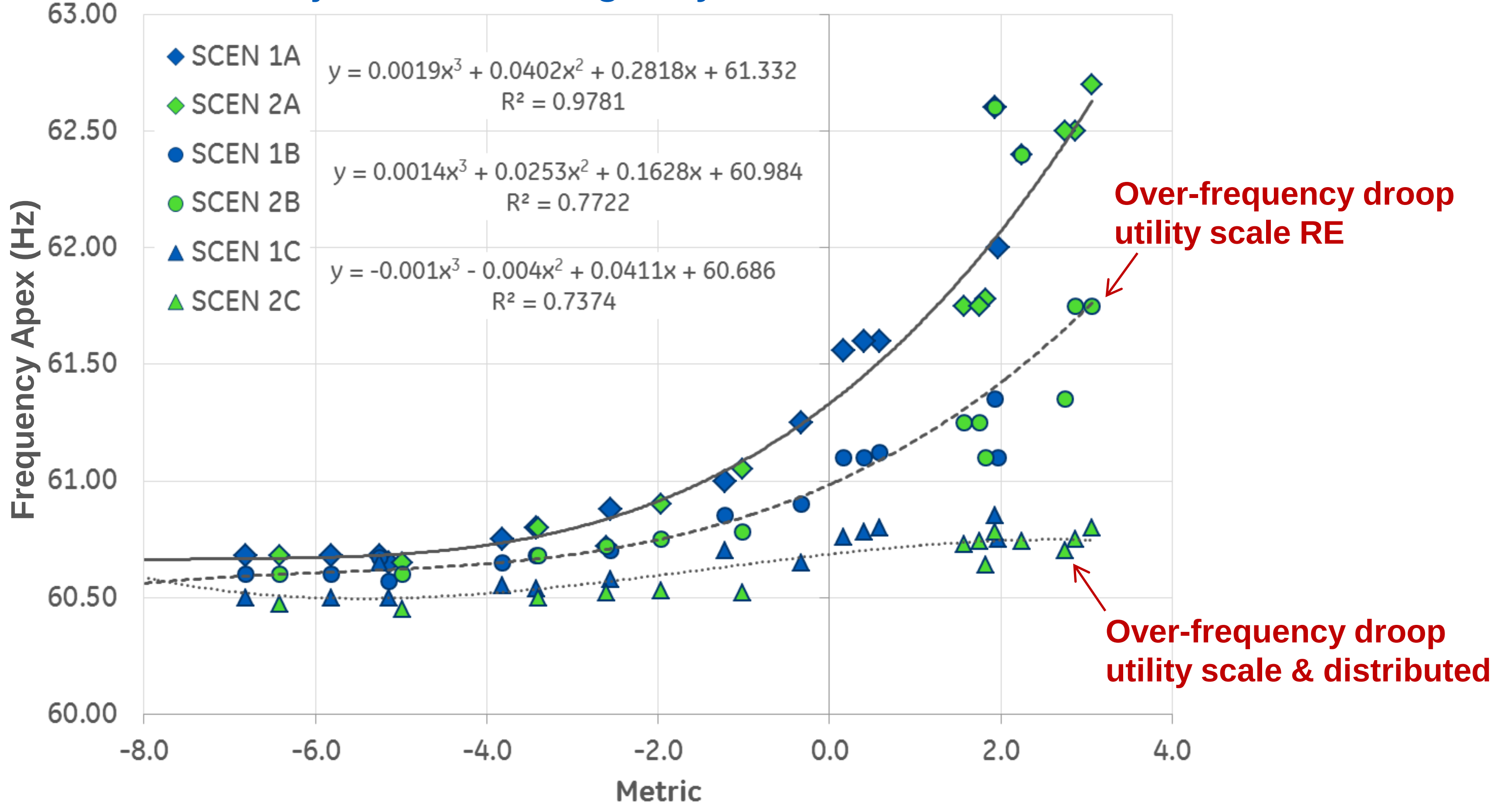
HNEI



System Integration Tasks

Dynamic Modeling

Load Rejection Contingency



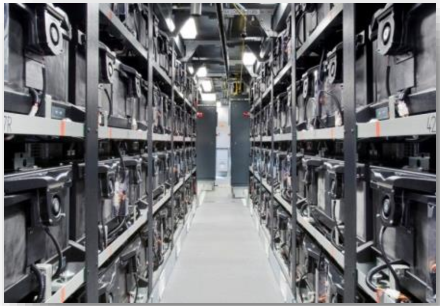
System-Level Mitigating Technologies

- Selecting the right type of new generation technology for expected load growth
- Upgrades to existing thermal fleet: Reduced minimum operating levels, improved ramp rates and efficiencies
- Energy storage technologies:
  - Wide range from high power, low energy (synchronous condensers, flywheels) to low power, high energy (pumped hydro, hydrogen); batteries are somewhere in the middle depending on chemistry and design
  - Depending on technology, implementation, and controls, can provide a variety of services: fast frequency response (FFR), operative reserves, energy shifting, etc.
- Demand response and distributed energy resource (DER) controls: can provide FFR, reserves, and energy shifting just like energy storage technologies
- Improved communications, controls, visibility, and prediction:
  - Particularly needed for DER (e.g., rooftop PV)
  - Wind and solar forecasting can optimize reserve requirements by predicting resource availability over multiple time horizons from seconds to days

Grid Scale BESS Projects (HNEI)

Demonstrate optimized BESS operating strategies for high value grid applications

photos courtesy of Altairnano



Upolu Point, Hawaii Island (1MW, 250kWh)

- Modeling showing benefit completed in 2007
- Frequency regulation and wind smoothing
- 3.3 GWh over 3yrs, > 6000 full cycles

Molokai Secure Renewable Microgrid (2MW)

- Operating reserves (fault management), frequency regulation,
- Fast response decision and control (<50ms response)

Campbell Park industrial feeder with high penetration (1MW)

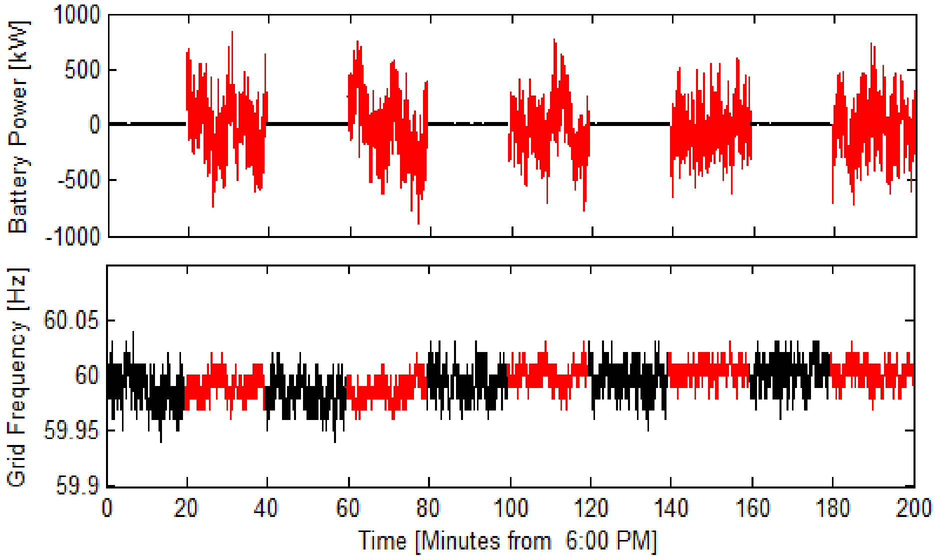
- Power smoothing, voltage and VAr support, and frequency regulation

Laboratory testing of single cells

- Novel technique to characterize state-of-health
- Performance models to predict lifetime of grid scale BESS

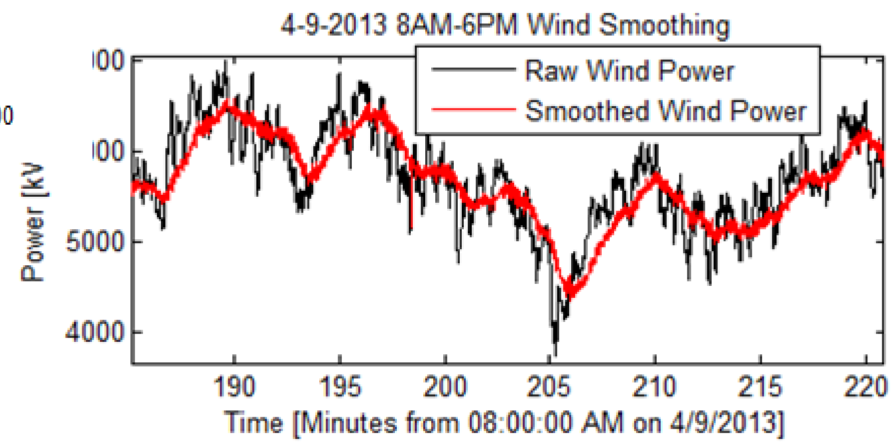
Grid Scale BESS Projects (HNEI)

Select Results



1MW BESS reduces Big Island frequency variability up to 40%

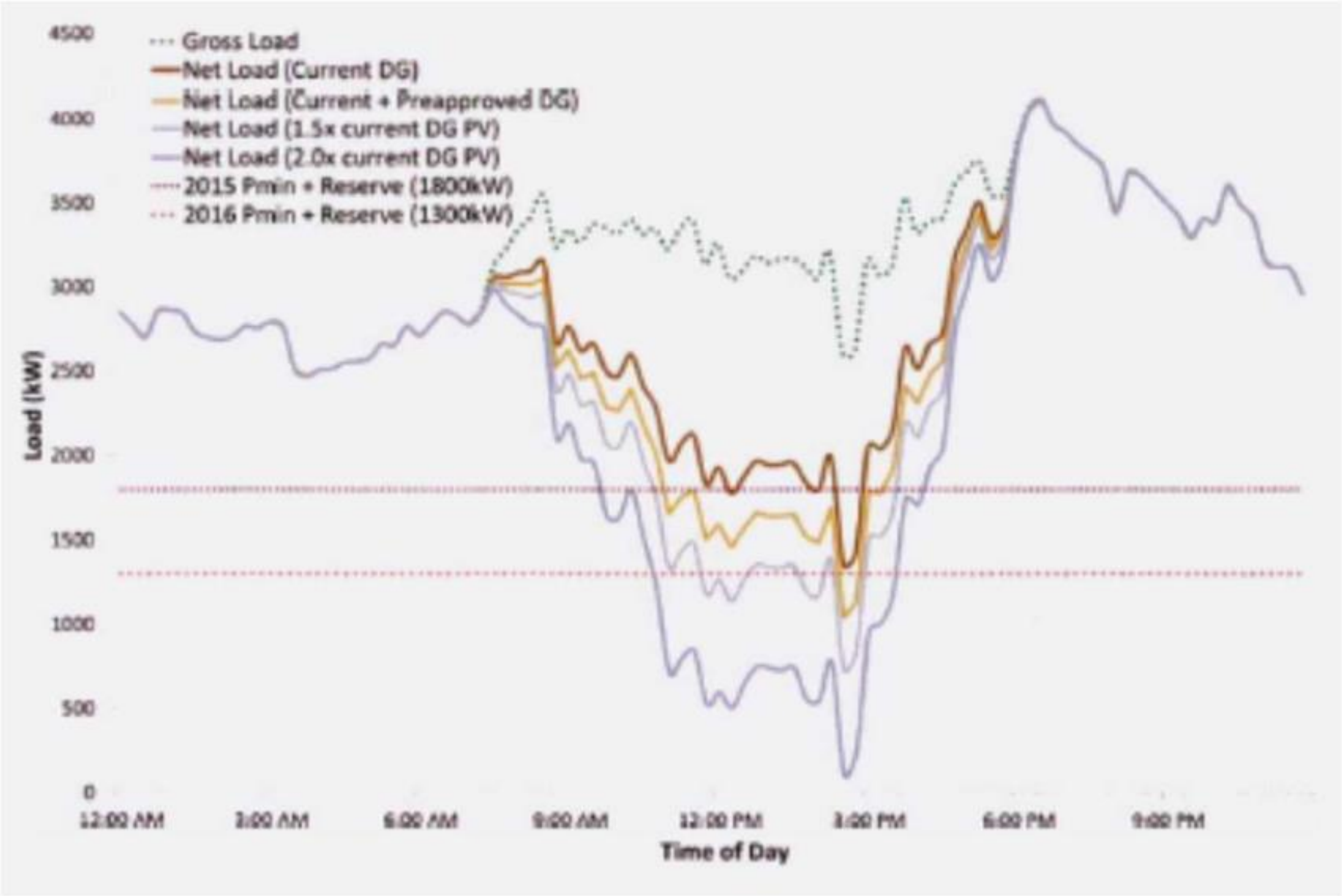
Wind smoothing:
Significant reduction 1 min ramp rates



- Reduce battery cycling while maintaining grid benefit
- Integrate with other technologies for longer events
- Analysis of utility value

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

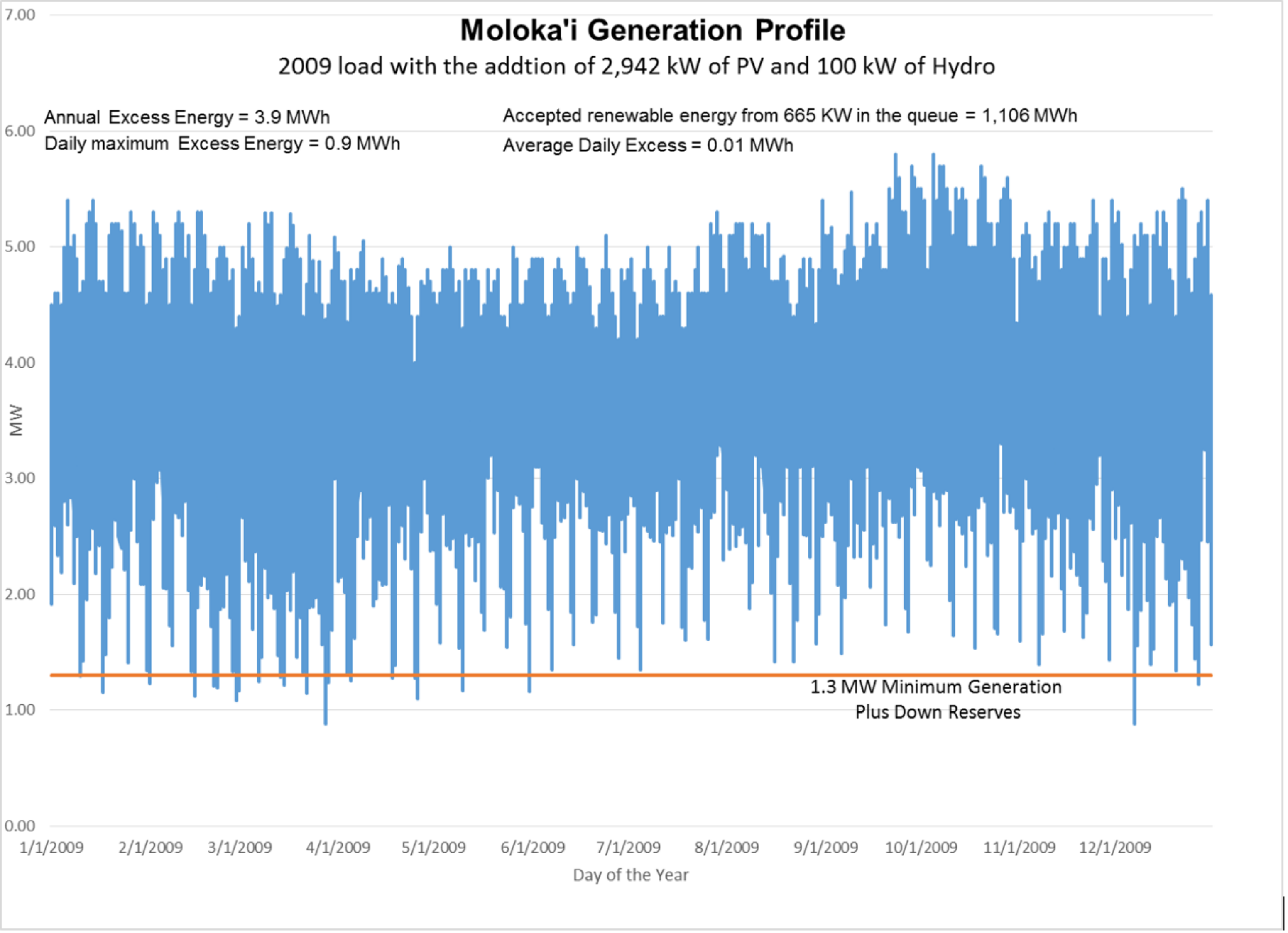
Molokai Excess Energy Issue



Source: E3 Interconnection Potential Analysis – Molokai, October 8, 2015 [1].

HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

Molokai Excess Energy Issue



Maui Wind Integration Study Scenarios

- Scenario 1

  30 MW, Plant 1 (Existing)

- Scenario 2

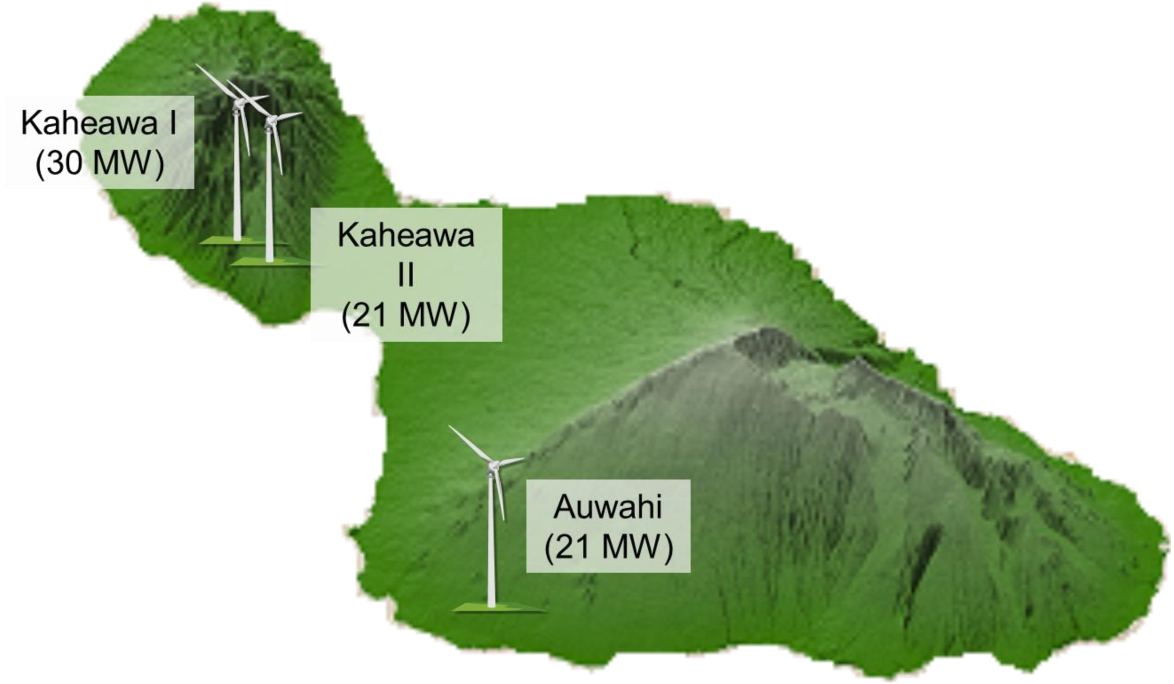
  30 MW, Plant 1
  22.5 MW, Plant 2

- Scenario 3

  30 MW, Plant 1
  21 MW, Plant 3

- Scenario 4

  30 MW, Plant 1
  22.5 MW, Plant 2
  21 MW, Plant 3



Wind Delivered With MECO System "As-Is" Today

Available and Delivered Wind Energy

		Plant 1		Plant 2		Plant 3	
Scenario	Wind Data	Available (GWh)	Delivered (GWh)	Available (GWh)	Delivered (GWh)	Available (GWh)	Delivered (GWh)
Plant 1	Historical*	138	135				
Plant 1 and 3	Historical*	138	135			97	59
Plant 1 and 2	Estimated**	133	129	108	78		
Plant 1,2 and 3	Estimated**	133	129	108	78	93	25

Delivered Energy for Plant 3 was insufficient to finance the project

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Candidate Mitigation Strategies

Table 2 Summary of strategies to increase wind energy delivered

#	Operational Change / Additional Equipment	Expected advantage	Risk	Observation
1	Reduce up reserve requirement	Reduce unit commitment in moderate/high load level. Reduce minimum power & cutailment	System frequency performance. Wind drop off events with insufficient reserve	Potentially most increased production benefit to WFs later in the curtailment order.
2	Reduce minimum operating power of thermal units carrying 6 MW of down reserve.	Increase WF production by 6MW during load low hours	Risk of units continuosly operating close to trip conditions	Depending on WF performing controls, most increased production benefit to WFs later in the curtailment order.
3	Storage (high energy)	Shifting injection of Plant 3 wind power	High energy/power ratings of storage	Limited number of hours in high wind days when additional power can be injected
4	Storage (lower energy) to provide up reserve	Reduce unit commitment in moderate/high load level	High energy/power ratings of storage	Potentially most increased production benefit to WFs later in the curtailment order.
5	Reduce system MR commitment rules	Increase WF production during low load hours	Insuffient MR to meet reliability requirements. Limitations to reliably cycle units.	Potentially most increased production benefit to WFs later in the curtailment order.
6	Additional fast start generation to reduce rotating reserve requirements	Reduce unit commitment in moderate/high load level	Permitting difficulties for thermal generation (biofuel may be option). Time required for implementation. Frequency performance for fast wind power variations (<10min)	Potentially most increased production benefit to WFs later in the curtailment order.
7	Wind production forecast			
8	Demand Side Management			

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Effectiveness of Mitigation Measures to Increase Wind Energy Delivered

	Wind Energy Delivered (GWh)						
	Scenario 1H	Scenario 2	Scenario 2B	Scenario 1E	Scenario 3	Scenario 4	Scenario 4B
	Historical Wind Data			Estimated Wind Data			
	Plant 1	Plant 1 + 3	Plant 1 + 3 (Mitigations)	Plant 1	Plant 1 + 2	Plant 1 + 2 + 3	Plant 1 + 2 + 3 (Mitigations)
Plant 1	135	135	136	131	131	129	132
Plant 2	0	0	0	0	79	78	91
Plant 3	0	59	77	0	0	25	42

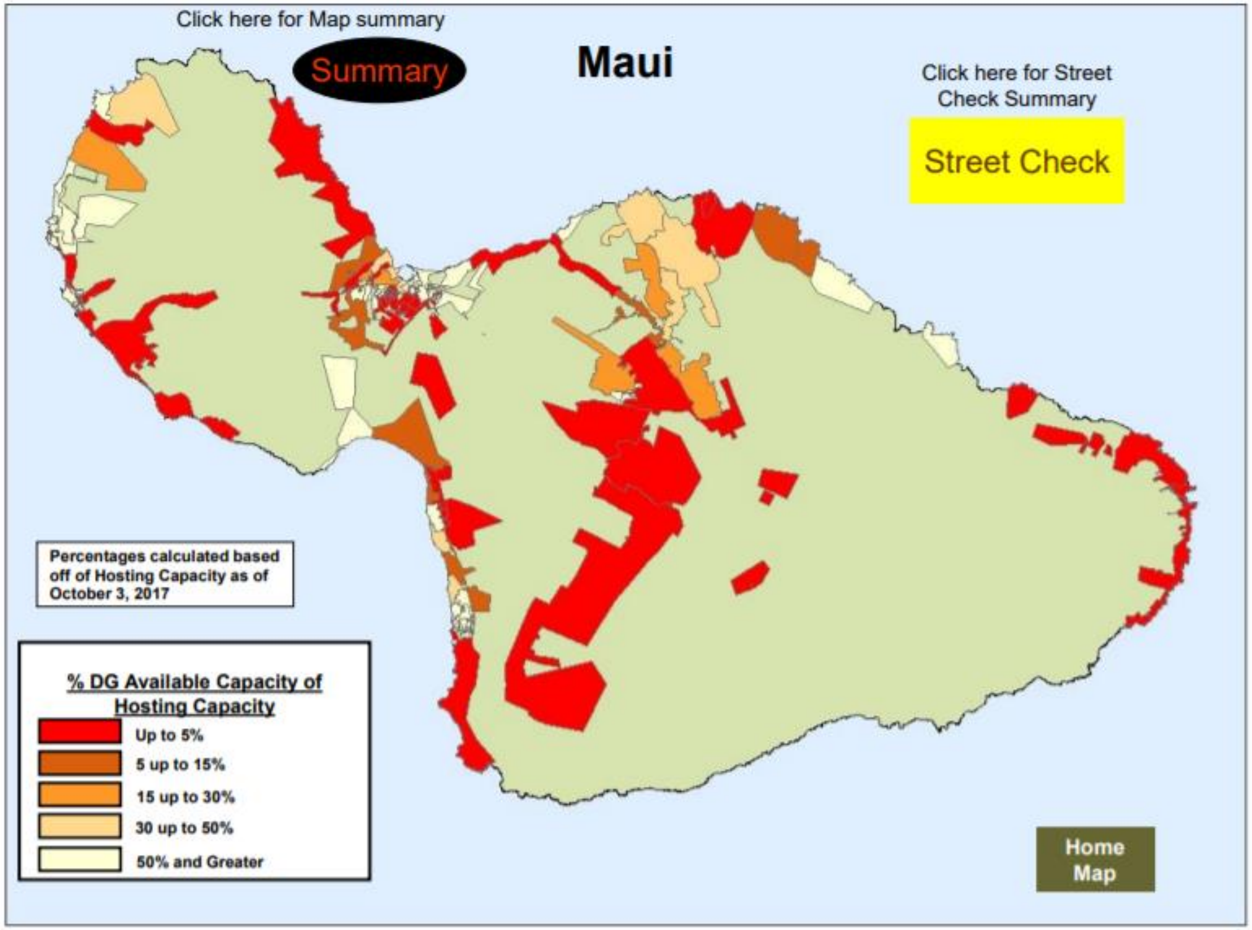
<u>BESS Function</u>

- 10MW / 20MWh
- Manual and AGC Dispatch
- Aggressive Overfrequency Response
- Ramp Rate Limit within a limited SOC Range

<u>MECO Operations</u>

- Include 10MW of BESS in Up Reserve
- Reduce Down Reserve of M14 & M16 by 1.5MW
- Reduced Operation of K1 and K2
- 50MW Up-Reserve Limit

Interconnection Requirements and Distribution Circuit Hosting Capacity



DG PV Interconnection Requirements

- IEEE 1547a-2014 / UL1741 Certification
- Active anti-islanding
- Transient overvoltage mitigation
- Low/High voltage ride-through
- Low/High frequency tide-through
- Advanced Inverter Functions
  - Volt-watt
  - Frequency-watt
  - Volt-var
  - Fixed power factor
  - Ramp rate – normal and soft start
  - Remote disconnect capability

Anti-Islanding

- Active anti-islanding schemes typically drive frequency out of the ride-through region when disconnected from the grid.
- With active anti-islanding, islanding has not proven to be an issue, even at high penetration levels using standard anti-islanding techniques.
- Studies done by Sandia National Lab determined that if there is a mismatch of more than 1% between the VAR load and the VAR sources on the circuit, the inverters will not form an island.

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Transient Overvoltage

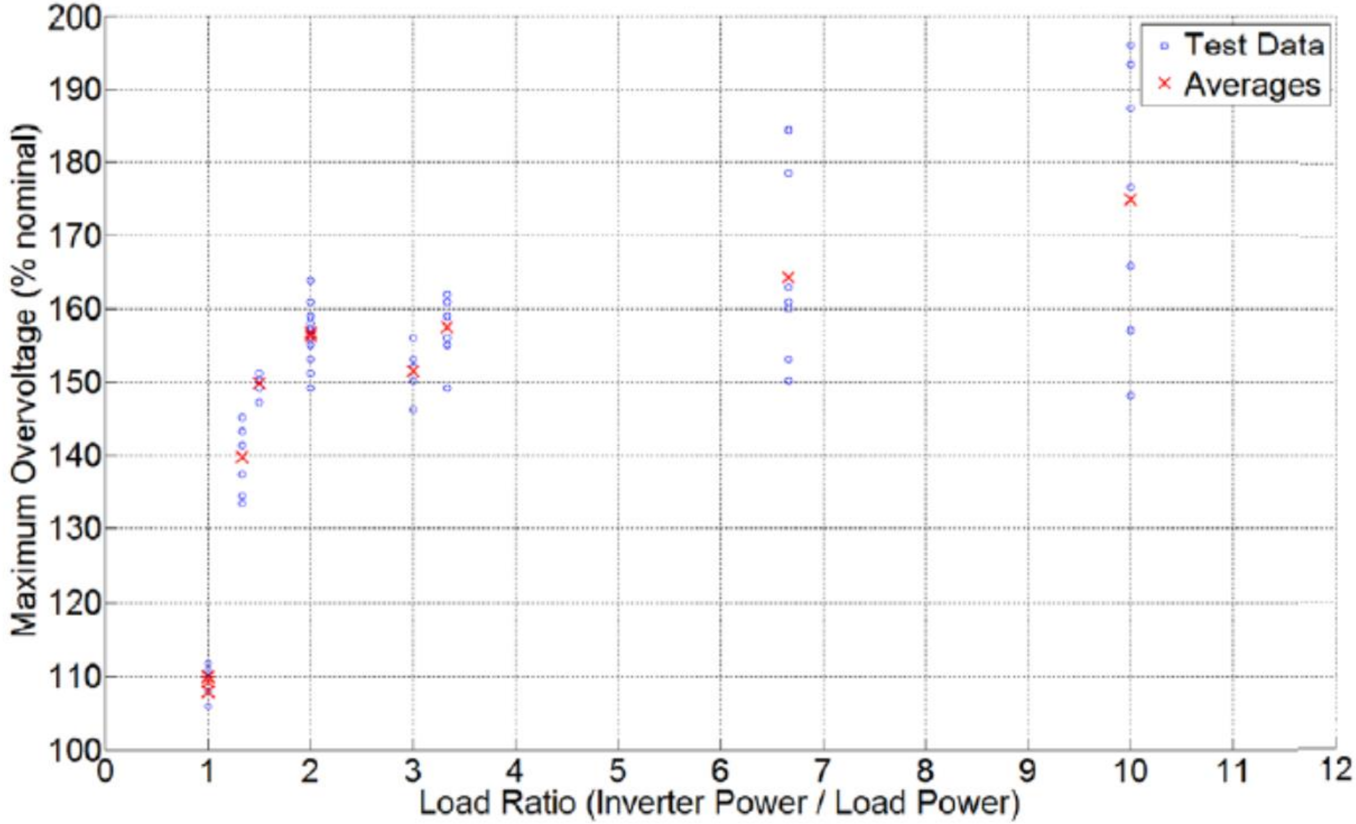
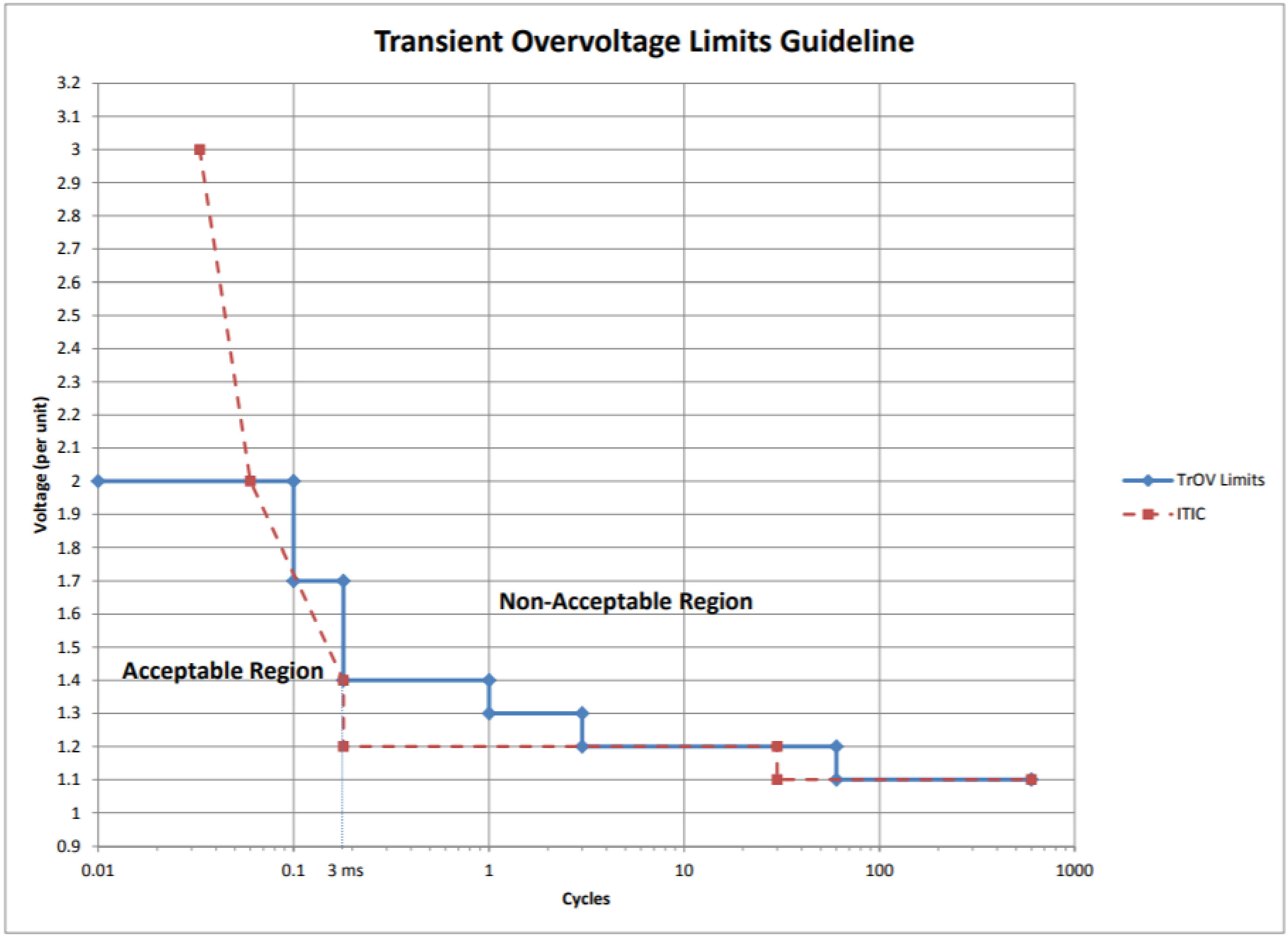


Figure 18: Maximum instantaneous over-voltage vs. load ratio for Inverter 5

Source: “Inverter Load Rejection Over-Voltage Testing”, NREL & SolarCity Corporation, NREL/TP-5D00-63510, Feb 2015

Avoiding Transient Overvoltage Conditions

Hawaiian Electric
Maui Electric
Hawai‘i Electric Light



HNEI
Hawai‘i Natural Energy Institute
University of Hawai‘i at Mānoa

Frequency Ride-Through

Table 4a.h: Frequency Ride-Through Table (Oahu, Maui, Hawai'i Island)

Operating Region	System Frequency Default Settings (Hz)	Minimum Range of Adjustability	Ride-Through Until	Operating Mode	Maximum Trip Time
Over-Frequency 2 (OFR2)	f > 64.0	60.1 - 65	No Ride Through	Permissive Operation (Freq-Watt)	0.16 seconds
Over-Frequency 1 (OFR1)	64.0 ≥ f > 63.0	60.1 - 65	20 seconds	Mandatory Operation (Freq-Watt)	21 seconds
Normal Operation High (NORH)	63.0 ≥ f > 60.0	Not Applicable	Indefinite	Continuous Operation (Freq-Watt)	Not Applicable
Normal Operation Low (NORL)	60.0 ≥ f ≥ 57.0	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Under-Frequency 1 (UFR1)	57.0 > f ≥ 56.0	57 - 59.9	20 seconds	Mandatory Operation	21 seconds
Under-Frequency 2 (UFR2)	56.0 > f	53 - 57	No Ride Through	Permissive Operation	0.16 seconds

Table 4a.h: Frequency Ride-Through Table (Molokai, Lanai)

Operating Region	System Frequency Default Settings (Hz)	Minimum Range of Adjustability	Ride-Through Until	Operating Mode	Maximum Trip Time
Over-Frequency 2 (OFR2)	f > 65.0	60.1 - 65	No Ride Through	Permissive Operation (Freq-Watt)	0.16 seconds
Over-Frequency 1 (OFR1)	65.0 ≥ f > 63.0	60.1 - 65	20 seconds	Mandatory Operation (Freq-Watt)	21 seconds
Normal Operation High (NORH)	63.0 ≥ f > 60.0	Not Applicable	Indefinite	Continuous Operation (Freq-Watt)	Not Applicable
Normal Operation Low (NORL)	60.0 ≥ f ≥ 57.0	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Under-Frequency 1 (UFR1)	57.0 > f ≥ 50.0	57 - 59.9	20 seconds	Mandatory Operation	21 seconds
Under-Frequency 2 (UFR2)	50.0 > f	50 - 57	No Ride Through	Permissive Operation	0.16 seconds

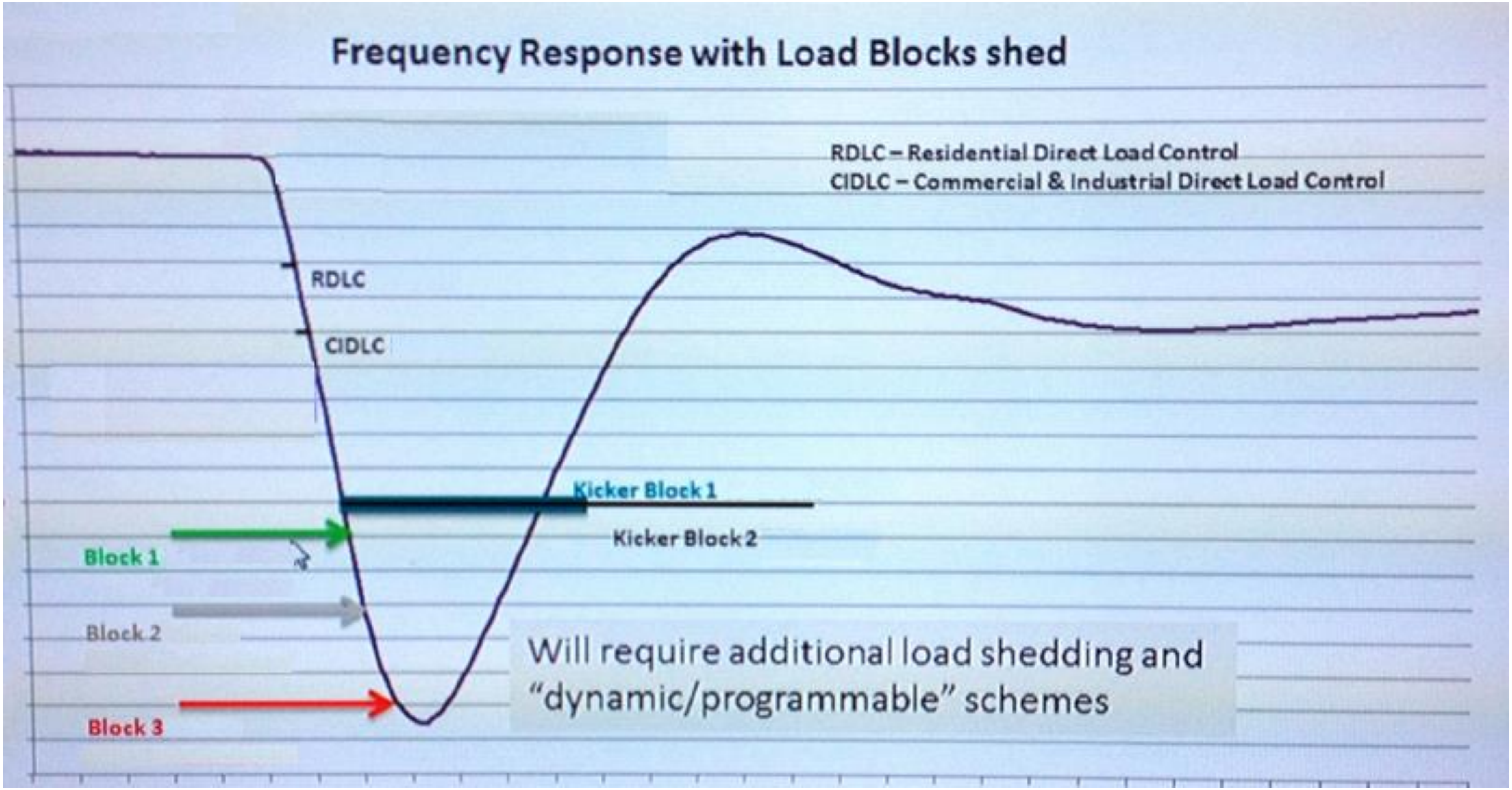
Voltage Ride-Through

Table 4a.g: Voltage Ride-Through Table

Operating Region	Voltage at Point of Interconnection (% Nominal Voltage)	Ride-Through Until	Operating Mode	Maximum Trip Time	Return To Service - Trip Criteria (V)	Time Delay (s)
Over-Voltage 2 (OVR2)	V > 120	No Ride Through	Cease to Energize	0.16** seconds	110 ≥ V ≥ 88	300 - 600*
Over-Voltage 1 (OVR1)	120 ≥ V > 110	0.92 seconds	Mandatory Operation	1 second	110 ≥ V ≥ 88	300 - 600*
Normal Operation High (NORH)	110 ≥ V > 100	Indefinite	Continuous Operation (Volt-Watt)	Indefinite	Not Applicable	Not Applicable
Normal Operation Low (NORL)	100 > V ≥ 88	Indefinite	Continuous Operation	Indefinite	Not Applicable	Not Applicable
Under-Voltage 1 (UVR1)	88 > V ≥ 70	20 seconds	Mandatory Operation	21 seconds	110 ≥ V ≥ 88	300 - 600*
Under-Voltage 2 (UVR2)	70 > V ≥ 50	10-20* seconds	Mandatory Operation	11-21* seconds	110 ≥ V ≥ 88	300 - 600*
Under-Voltage 3 (UVR3)	50 > V	No Ride Through	Permissive Operation	0.5 seonds	110 ≥ V ≥ 88	300 - 600*

* May be adjusted within these ranges at manufacturer's discretion.
** Maximum trip time under steady state condition. Inverters will also be required to meet the Companies transient overvoltage criterion (TrOV-2).

Under Frequency Load Shedding Impacts

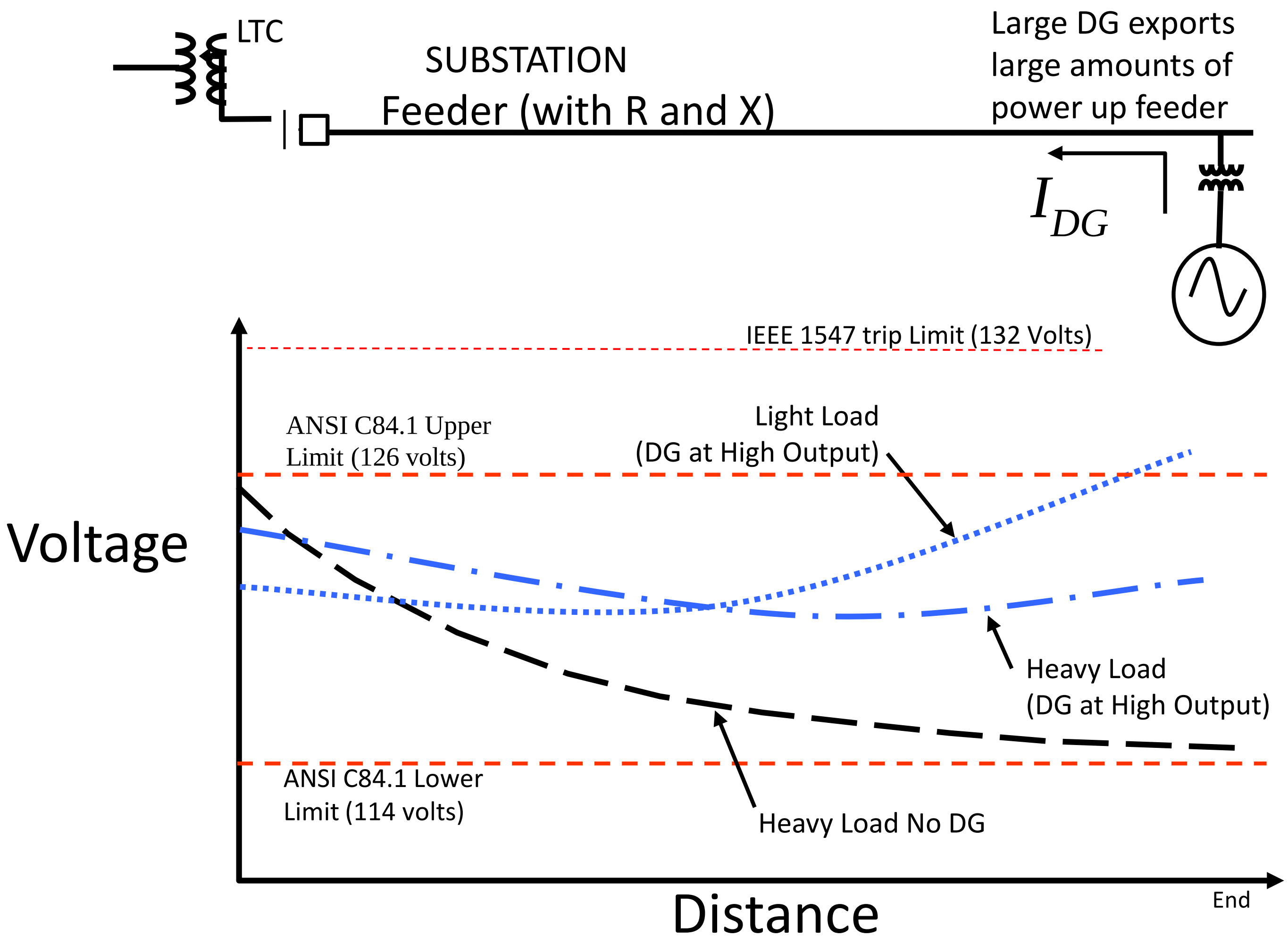


Distribution Hosting Capacity

- Assumes interconnection requirements are met
- Develop PV growth scenarios
- Assess circuit loading impacts
- Assess circuit voltage impacts
- Assess voltage flicker impacts

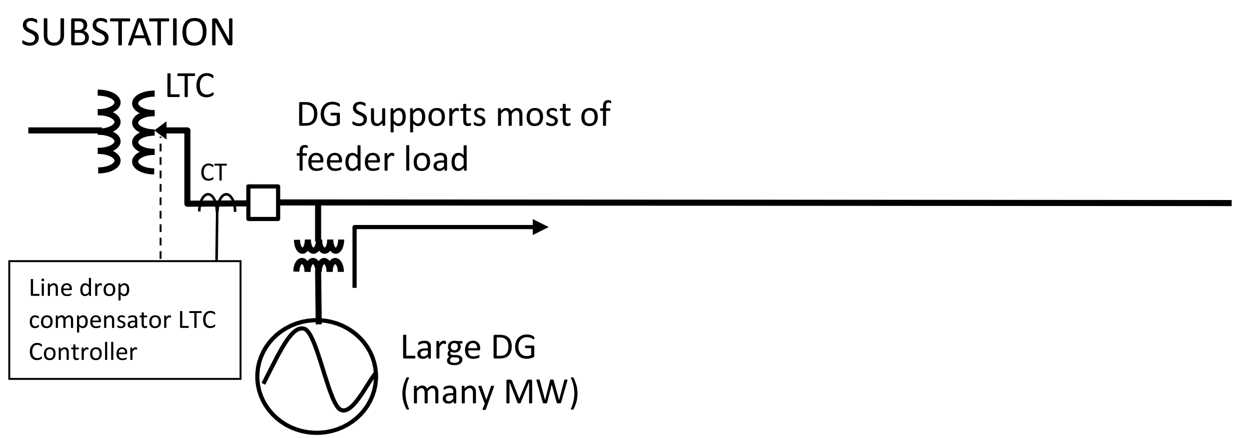
HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

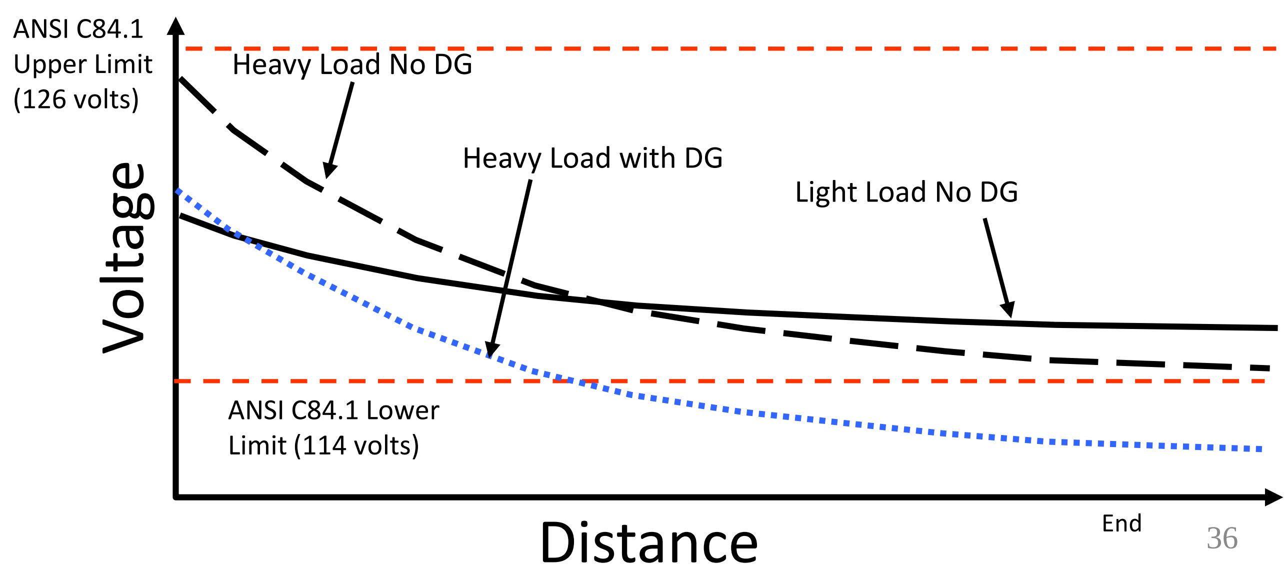
Circuit Overload and Voltage Impacts:
Location of DG Impacts Circuit Loading and Voltage



Circuit Overload and Voltage Impacts: Location of DG Impacts Circuit Loading and Voltage

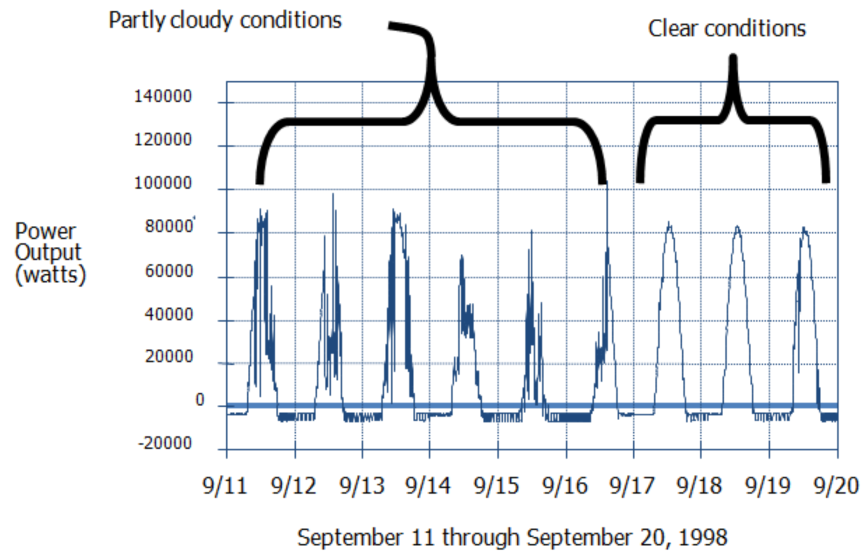
Exporting DG “shields” the substation LTC controller from the feeder current. The LTC sees less current than there is and does not boost voltage adequately.



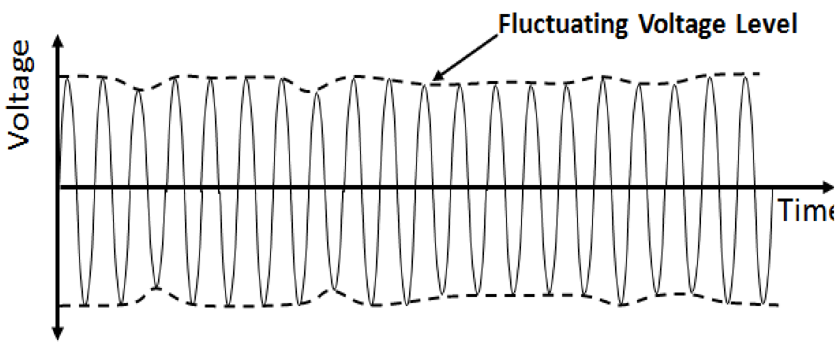


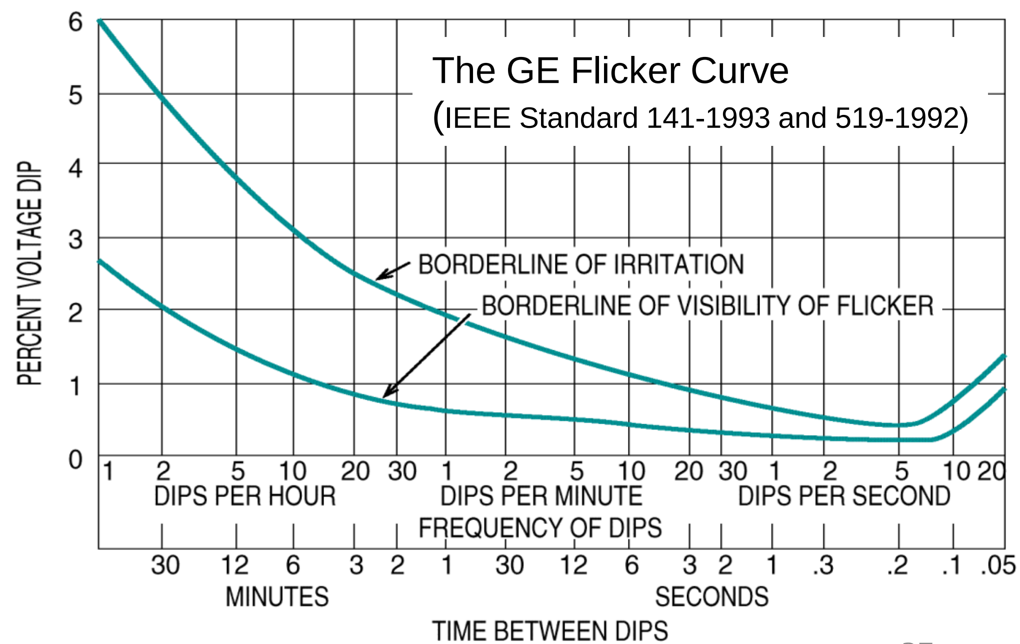
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

Power Quality - Flicker



Interconnecting a large amount of fluctuating generation such as PV (for example) on a circuit

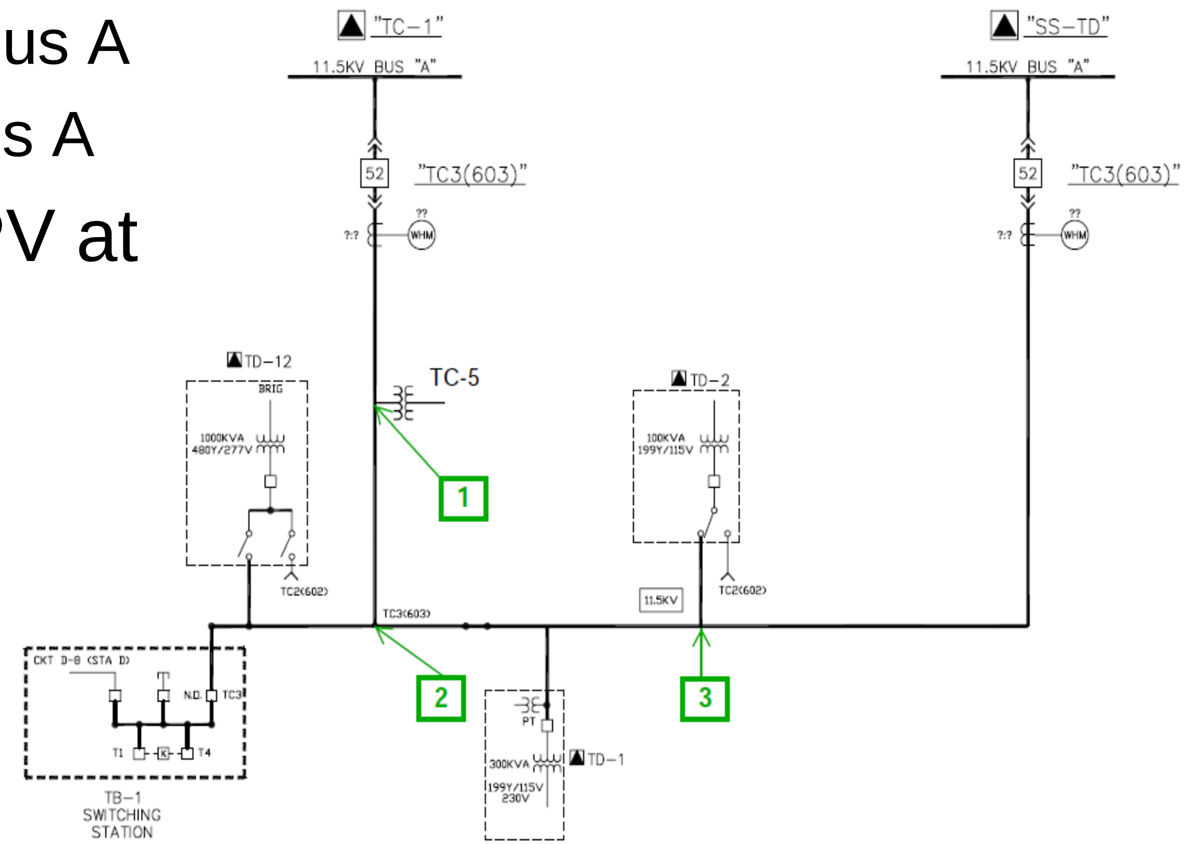




May result in power quality issues such as flicker at the circuit level

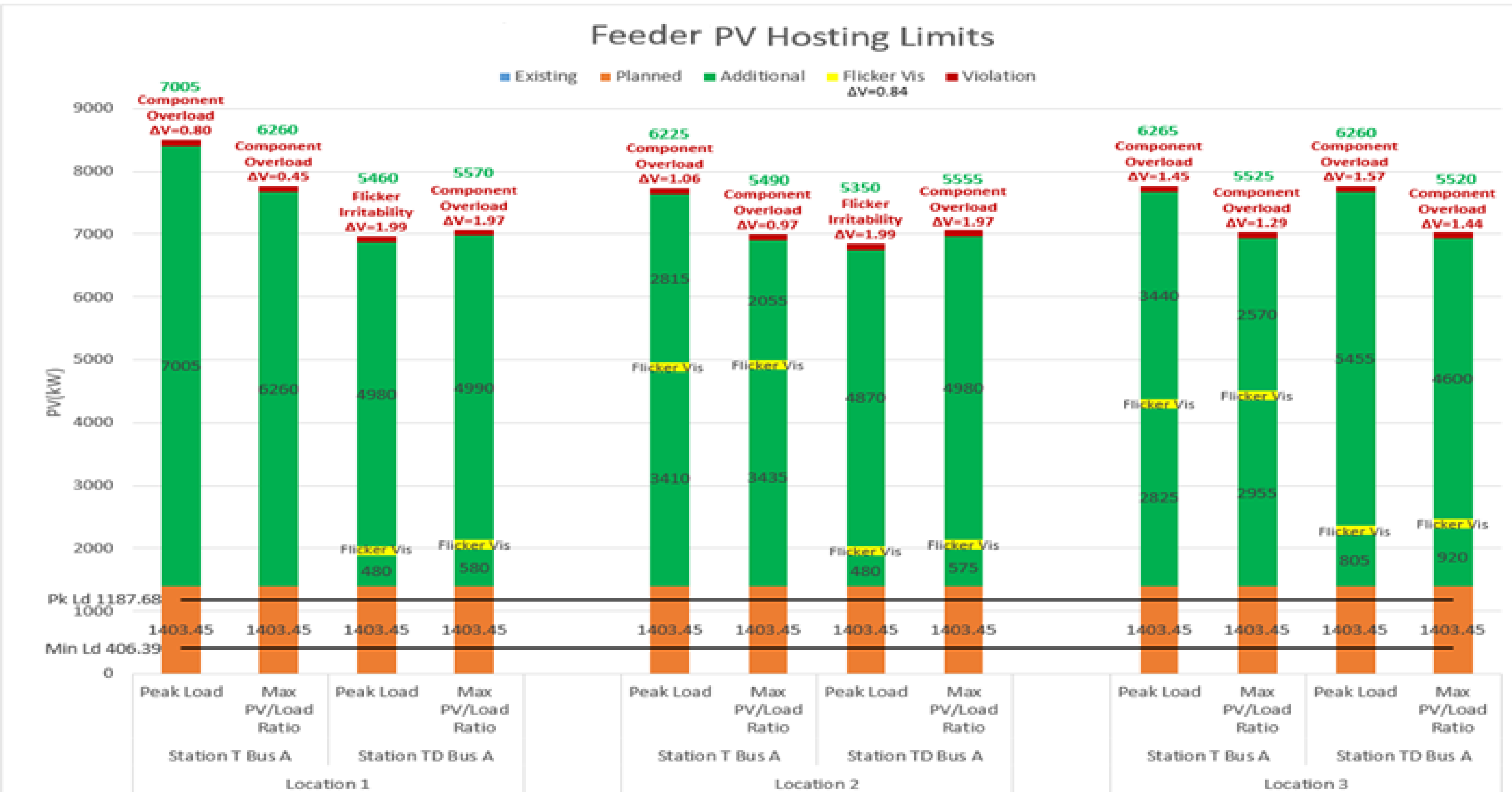
Feeder Hosting Ability

- Two Sources
  - Station TC1 Bus A
  - Station TD Bus A
- Incremented PV at three different locations

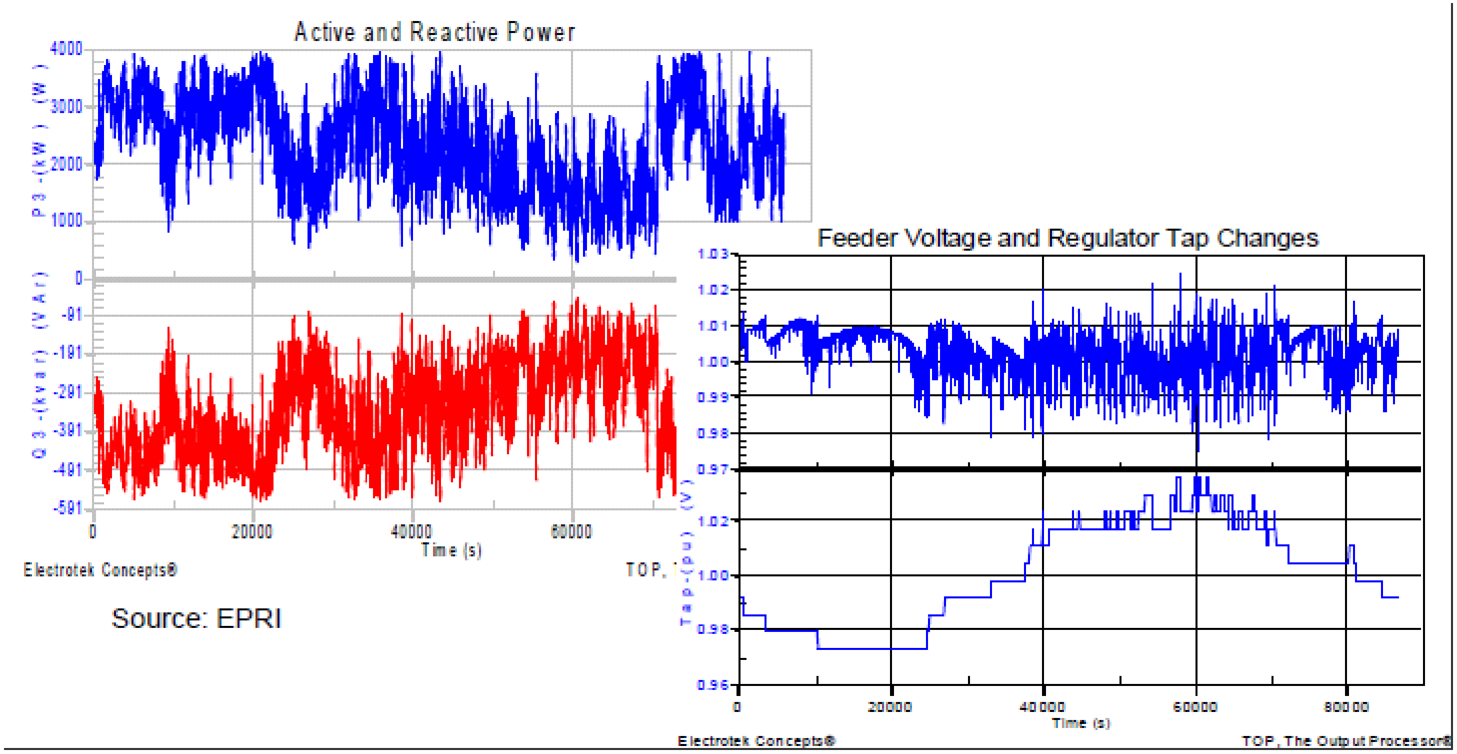


Example - Feeder Hosting Results

- Existing PV: 0 kW
- Planned PV: 1403.5 KW

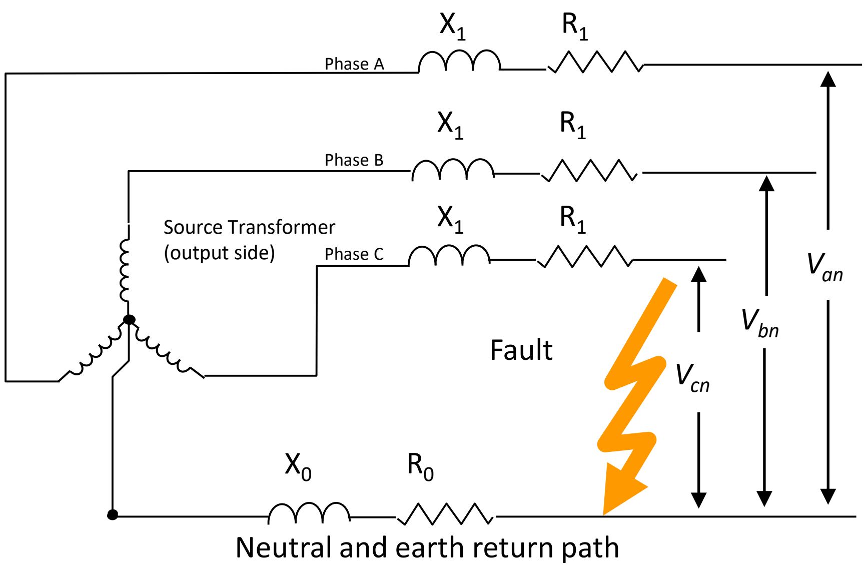


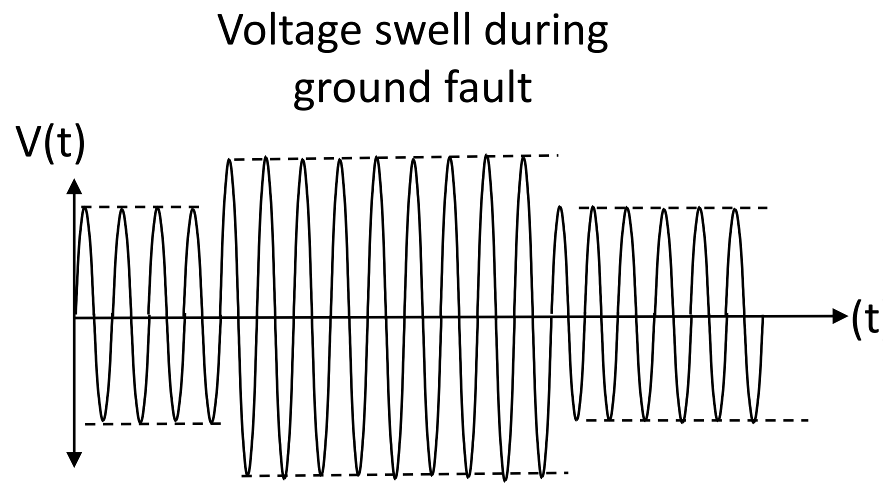
Voltage Control: Excessive voltage regulator tap operations with variable DG

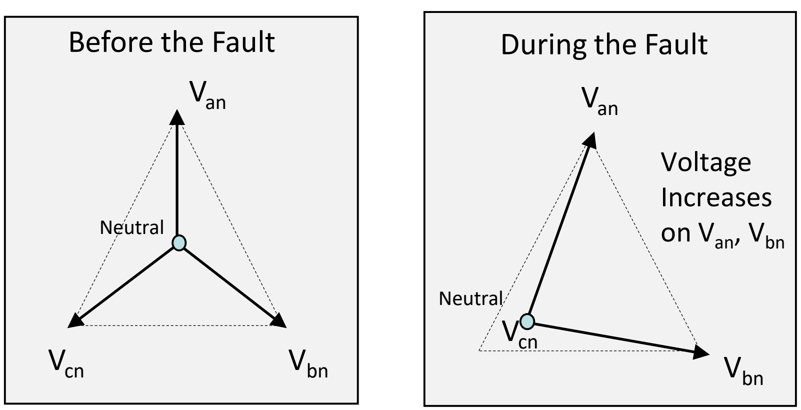


Source: EPRI

Ground Fault Overvoltage







Ground Fault overvoltage can result in damaging overvoltages on unfaulted phases of up to roughly 170% of the normal maximum system voltage!

Effective grounding limits the voltage rise on the unfaulted phases to about 125% of nominal during L-G fault on 4-wire multi-grounded neutral systems

HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

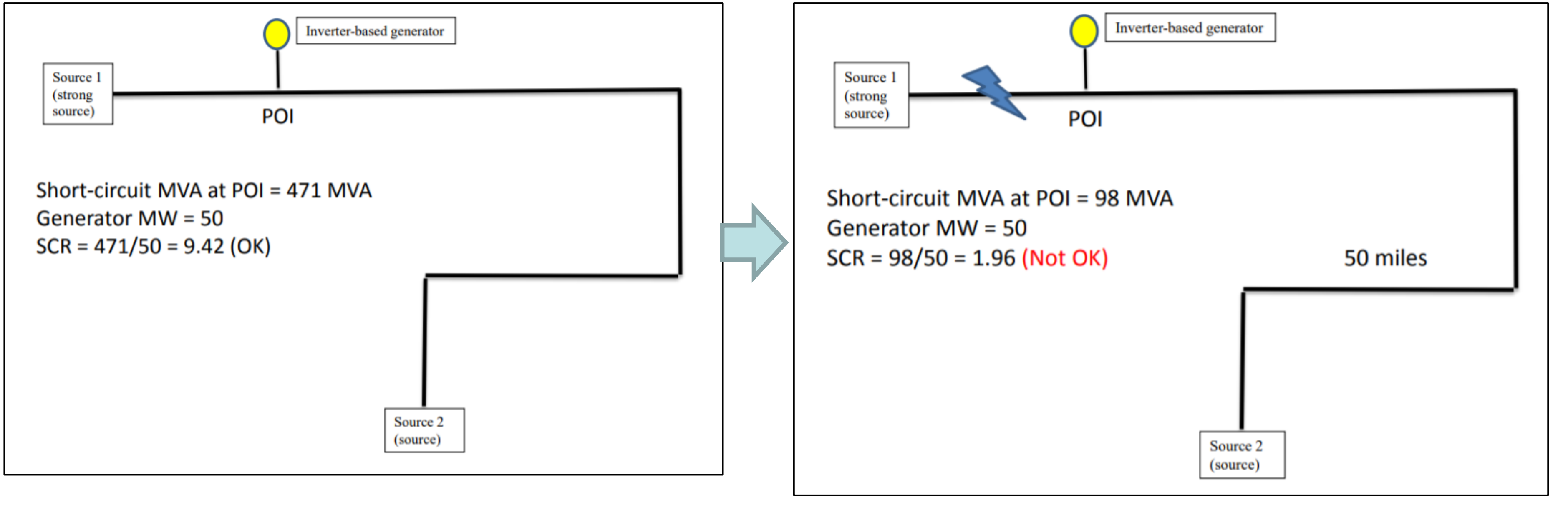
Short Circuit Ratio

The majority of inverter-based control systems rely on the voltage magnitude and angle at their terminals to not be largely affected by the current injection of the resource for stable operation. In this context, electrical system strength refers to the sensitivity of the resource's terminal voltage to variations of current injections. In a strong system, this sensitivity is low; in a weak system, this sensitivity is higher. The most basic and easily applied metric to determine the relative strength of a power system is short circuit ratio (SCR)

$$SCR_{POI} = \frac{SCMVA_{POI}}{MW_{VER}}$$

"Plain" SCR is a simple calculation, but does not account for multiple inverter interactions. An SCR of 3 is considered adequate. Some inverter manufacturers can operate with an SCR as low as 2.

Simple SCR Example



Source: MISO Planning Subcommittee August 15, 2017

Short Circuit Ratio Calculation Methods

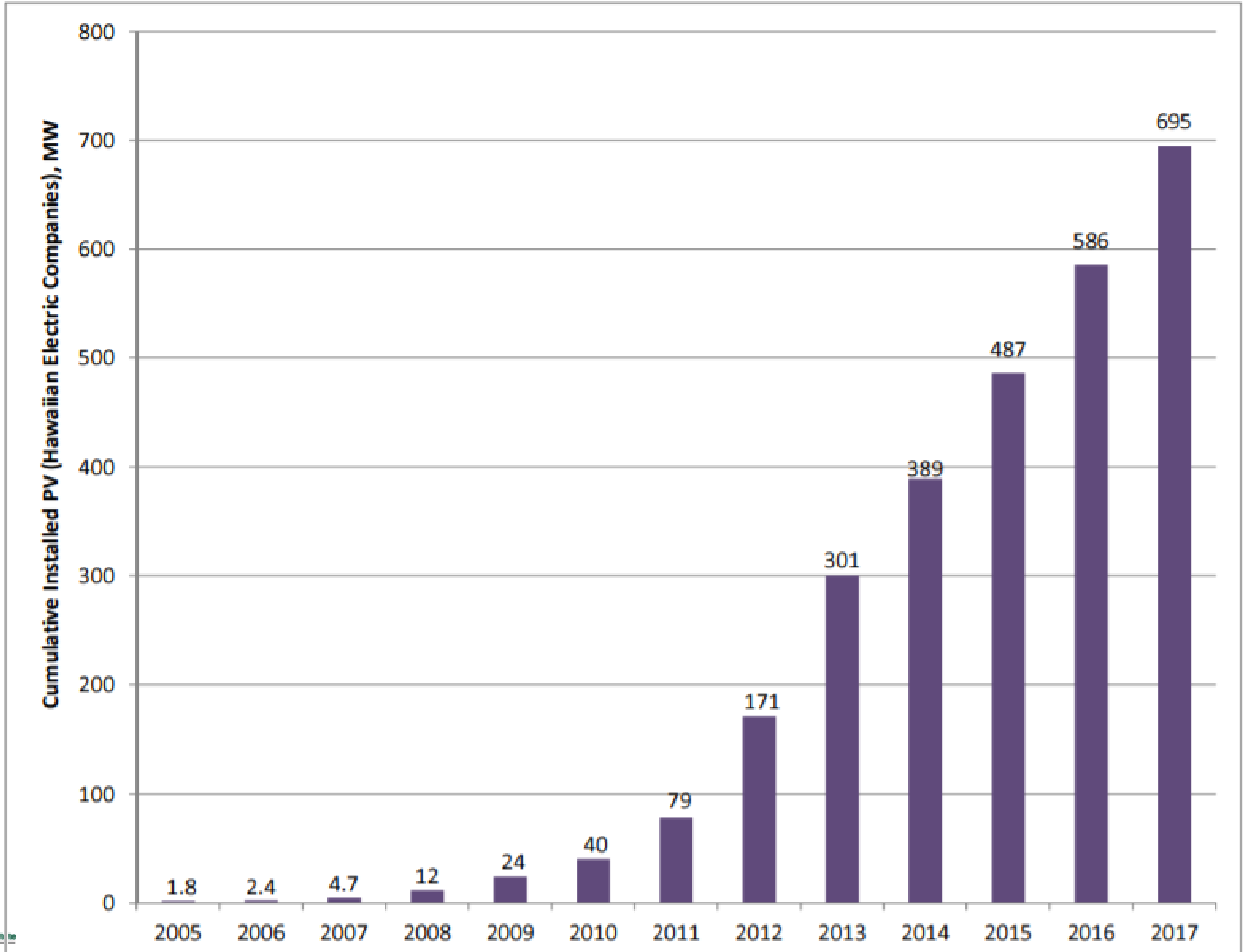
Table 2.1: Comparison of SCR Methods

Metric		Simple calculation using short circuit program	Accounts for nearby inverter based equipment	Provides common metric across a larger group of VER	Accounts for weak electrical coupling between plants within larger group	Considers non-active power inverter capacity*	Able to consider individual sub-plants within larger group
SCR	Short Circuit Ratio	★★	X	X	X	X	X
CSCR	Composite SCR	★	★★	★★	X	X	X
WSCR-MW	Weighted SCR using MW	★	★★	★★	★	X	X
WSCR-MVA	Weighted SCR using MVA	★	★★	★★	★	★★	X
SCRIF	Multi-Infeed SCR	X	★★	X	★★	★★	★★

* e.g., STATCOMs or partial power inverter-based resources

Source: "Integrating Inverter Based Resources into Weak Power Systems, Reliability Guideline", NERC, June 2017
http://www.nerc.com/pa/RAPA/rg/ReliabilityGuidelines/Reliabilty_Guideline_-_Integrating_VER_into_Weak_Power_Systems.pdf

Installed PV Capacity - HECO Companies
(2005 to 2017)

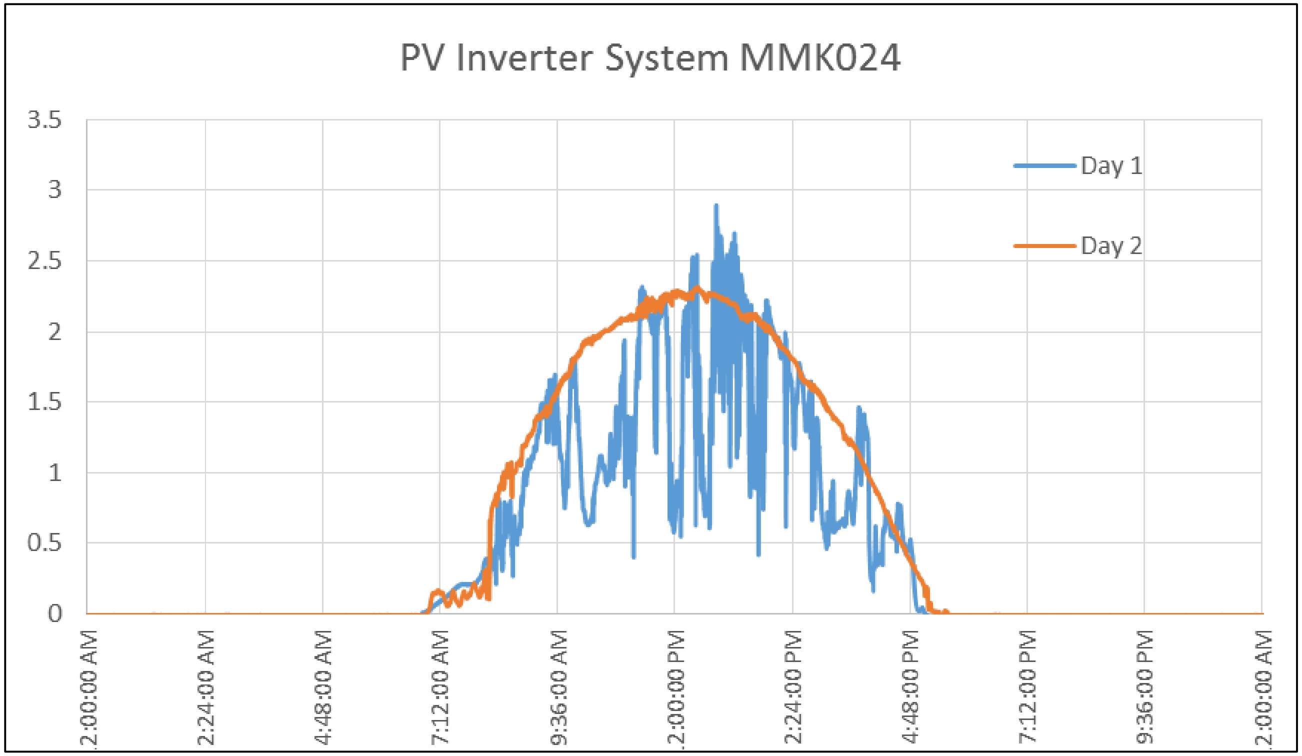


HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Complexity of DER Utilization

Circuit DER utilization potential depends on:

- Time of day and weather for PV
- Available resource capacity for Distributed Energy Resource (DER), i.e. BESS, EV, DR, etc.
- DER may also have competing use cases to consider



HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Maui Advanced Solar Initiative

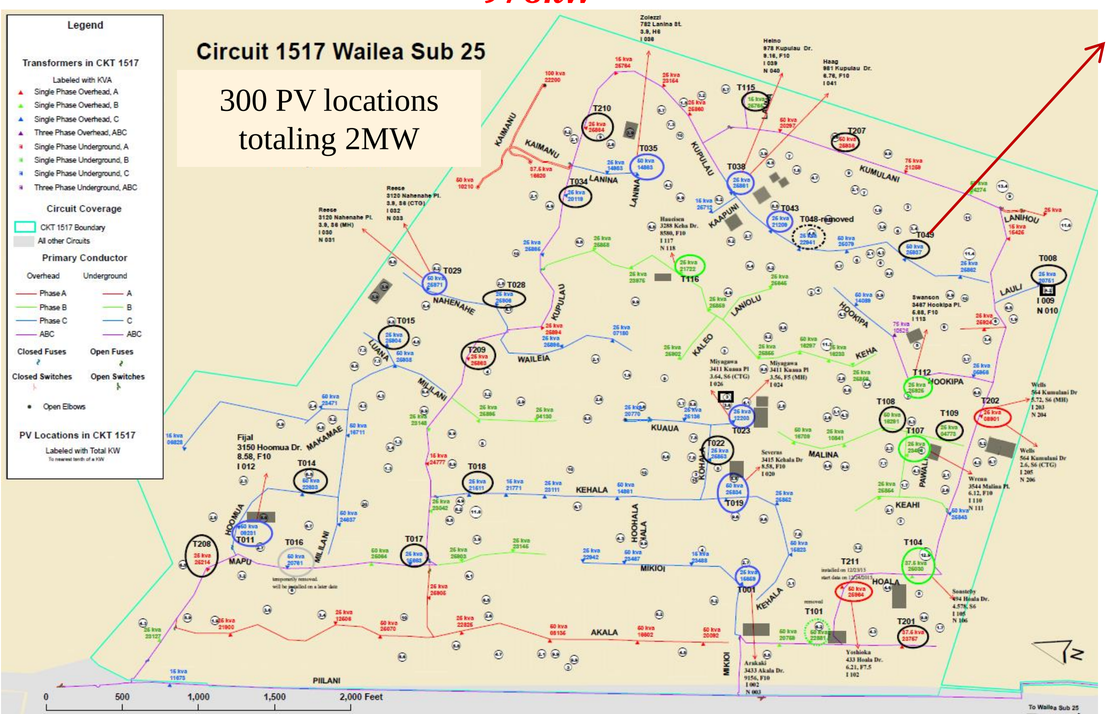
US DOE & ONR funded, <u>HNEI led</u> project to develop and demonstrate advanced PV inverter functionality in a smart grid environment

~800 customers

~300 PV systems = 2MW

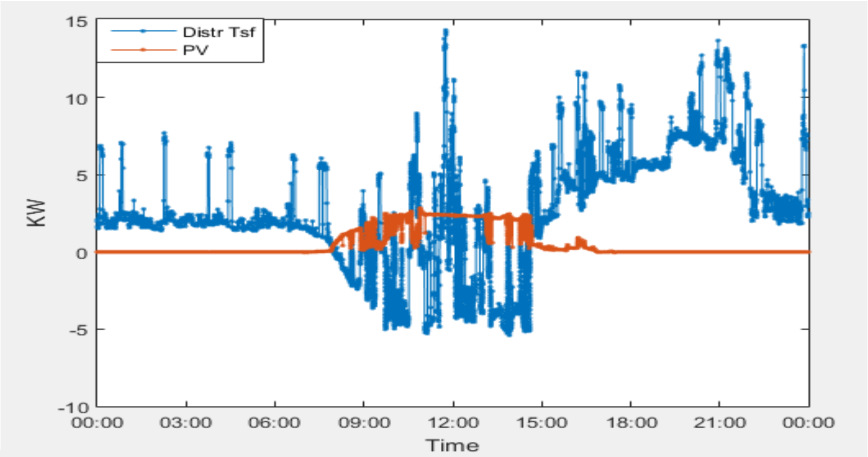
MDL = 976kW

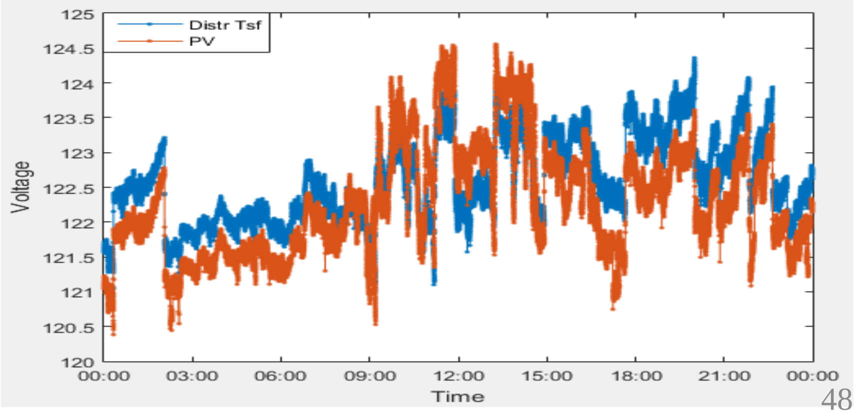
% Penetration = $\frac{2MW}{976kW} = 200\%$



HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Field Performance & Data Mining

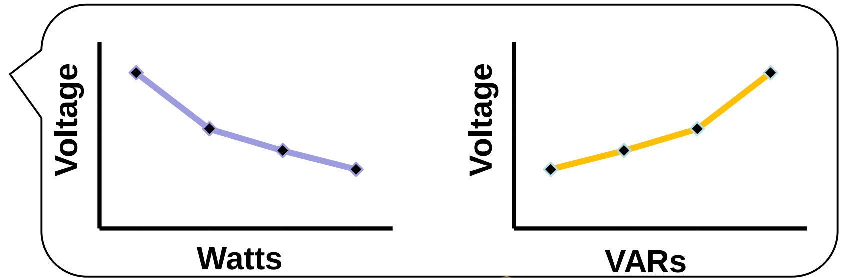


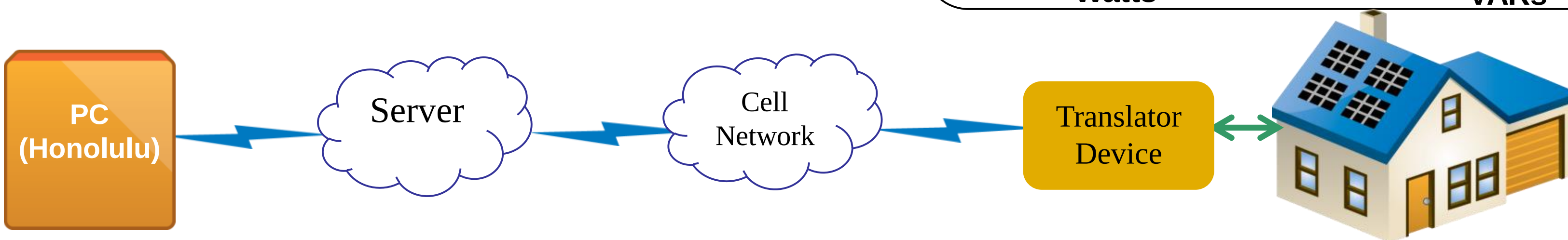


HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Software sends control curves to adjust inverter

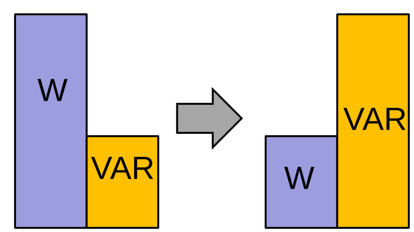
1 Sends Volt-VAR or Volt-Watt curve to Smart Inverter to adjust inverter VAR or Watt injections into the grid

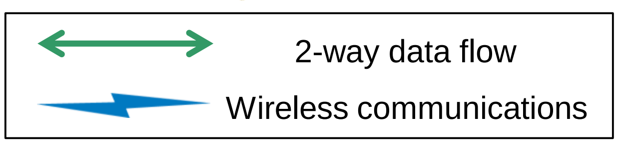




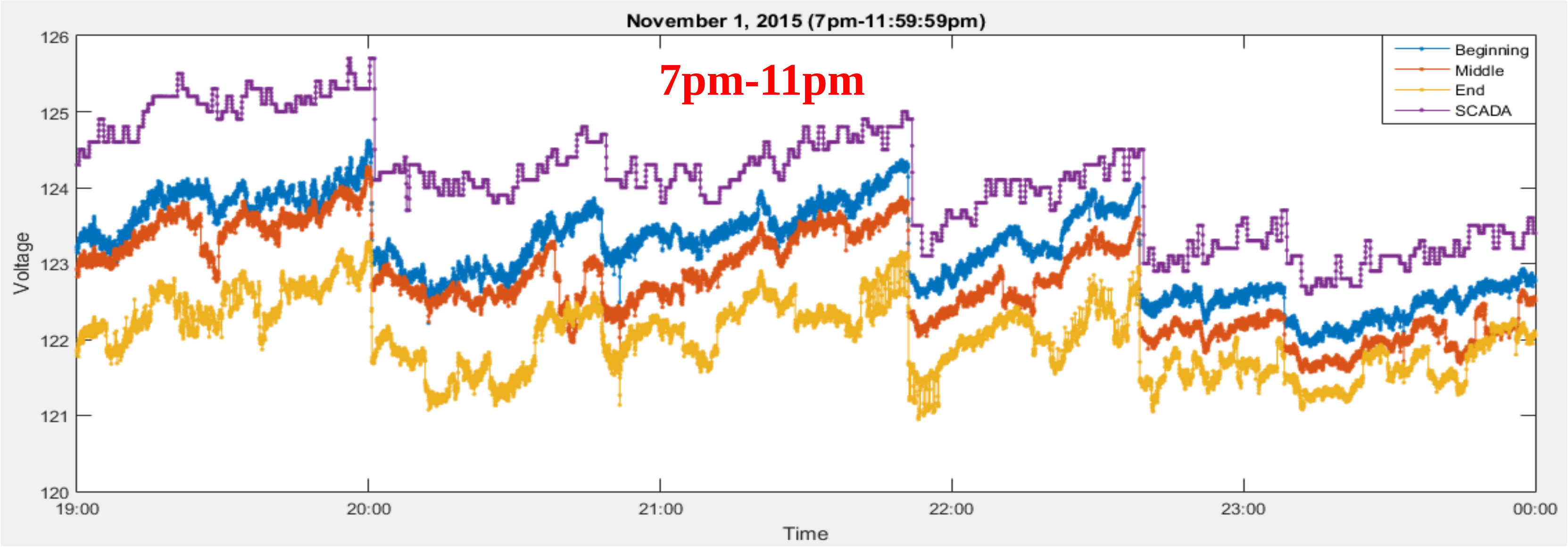
2 Smart Inverter receives curve, senses system voltage

3 Smart Inverter adjusts VAR or Watt output based on curves to respond to system voltage fluctuations

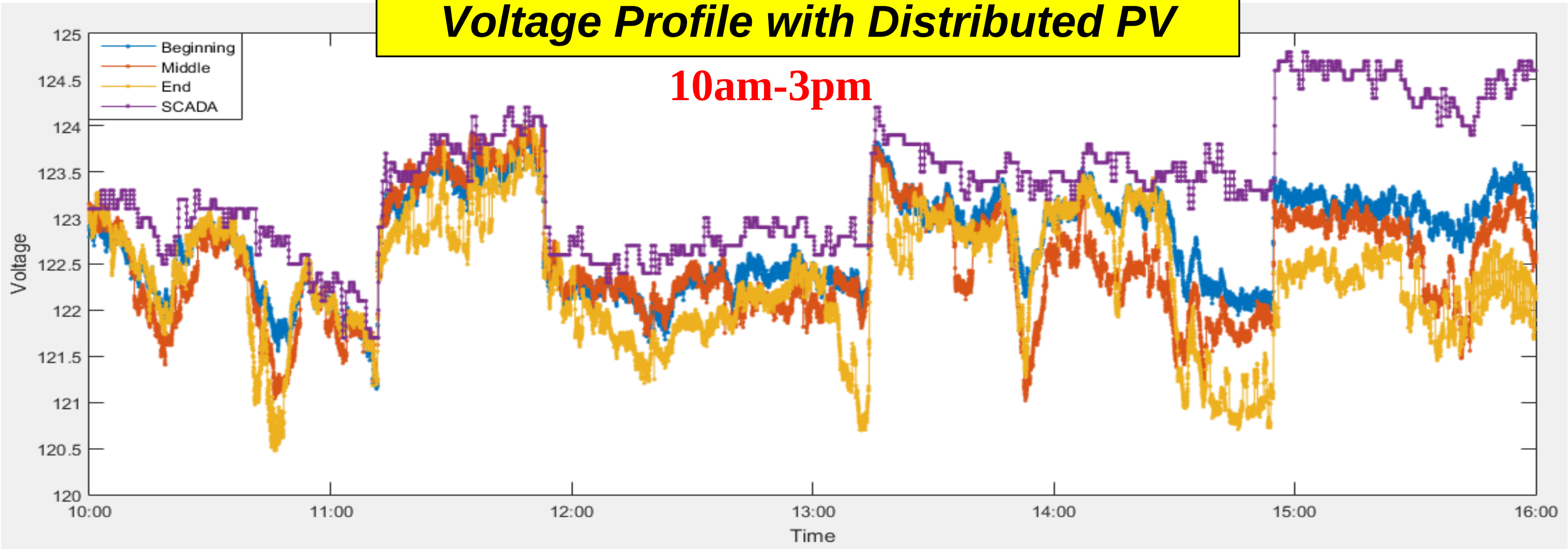




Voltage Along the Feeder



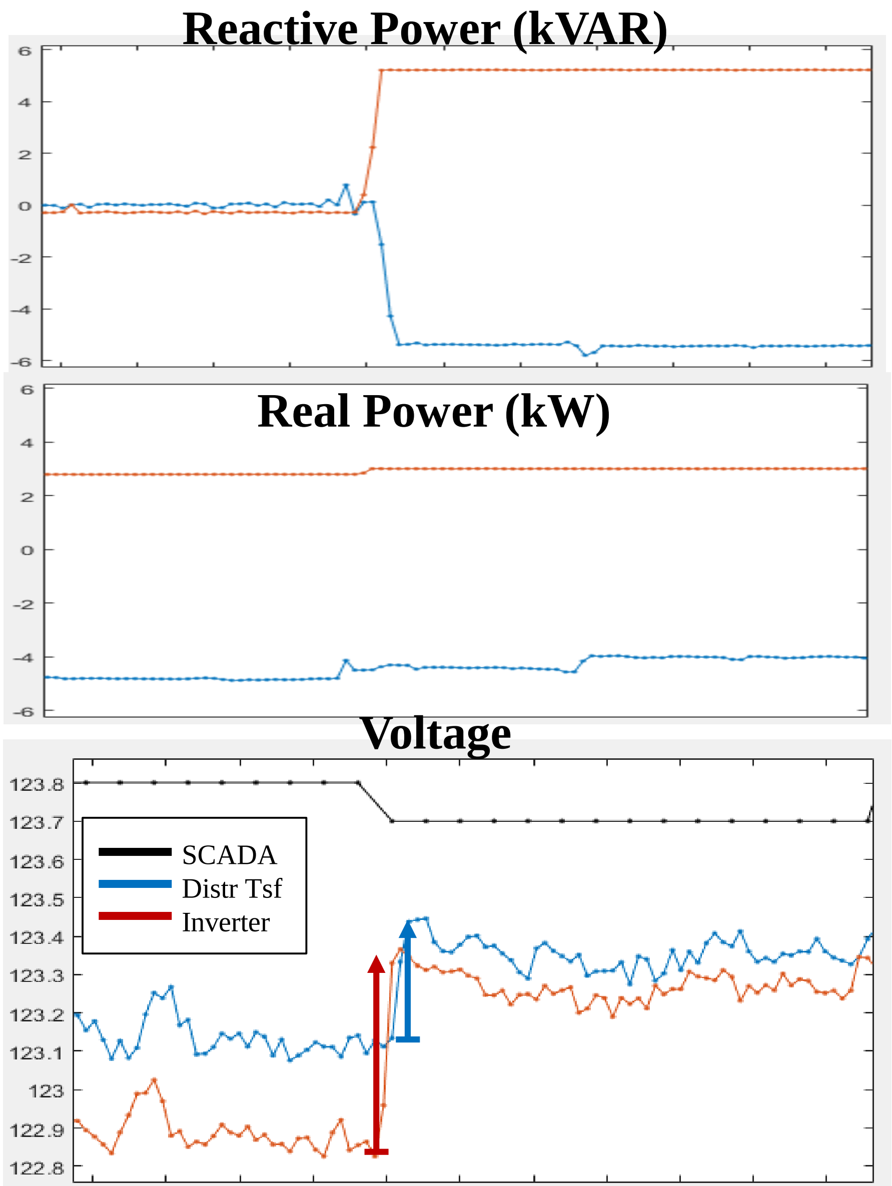
Voltage Profile with Distributed PV



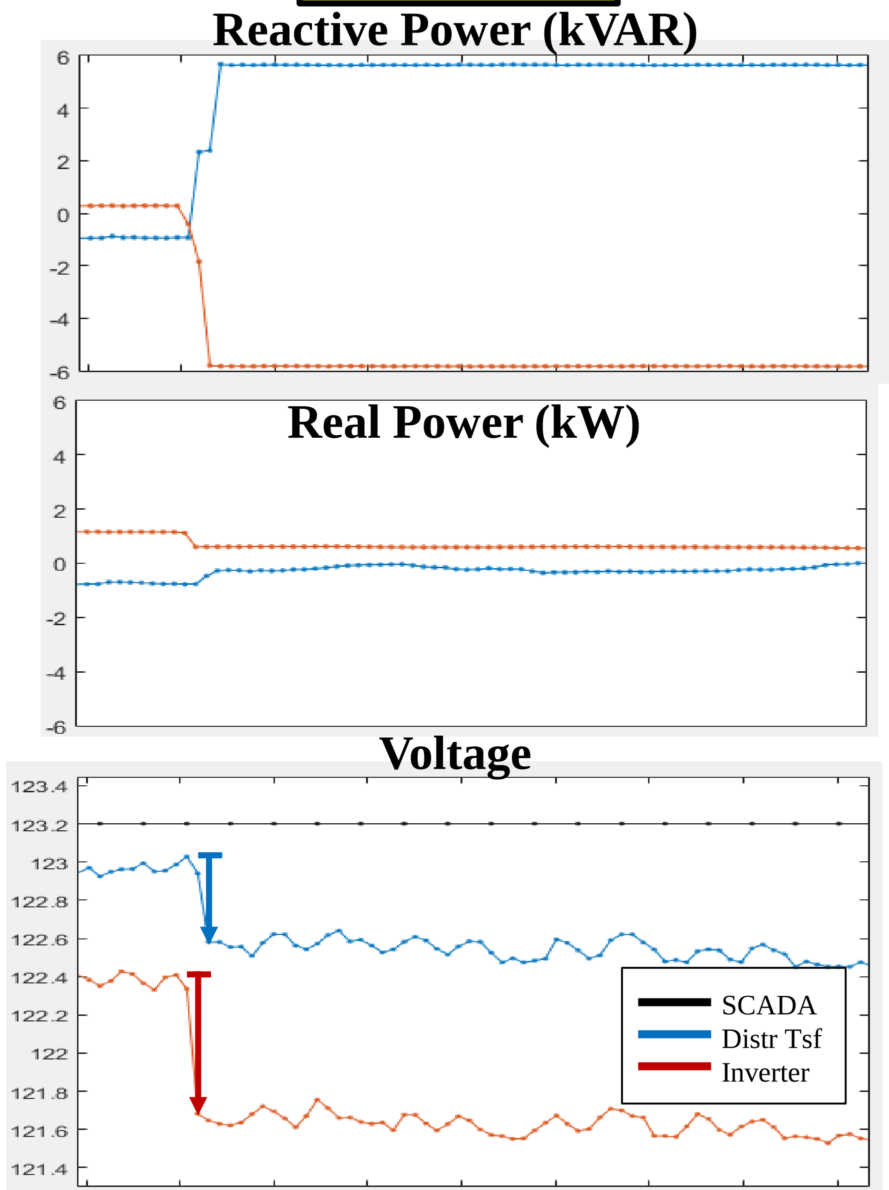
HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Reactive Power & Voltage

Capacitive

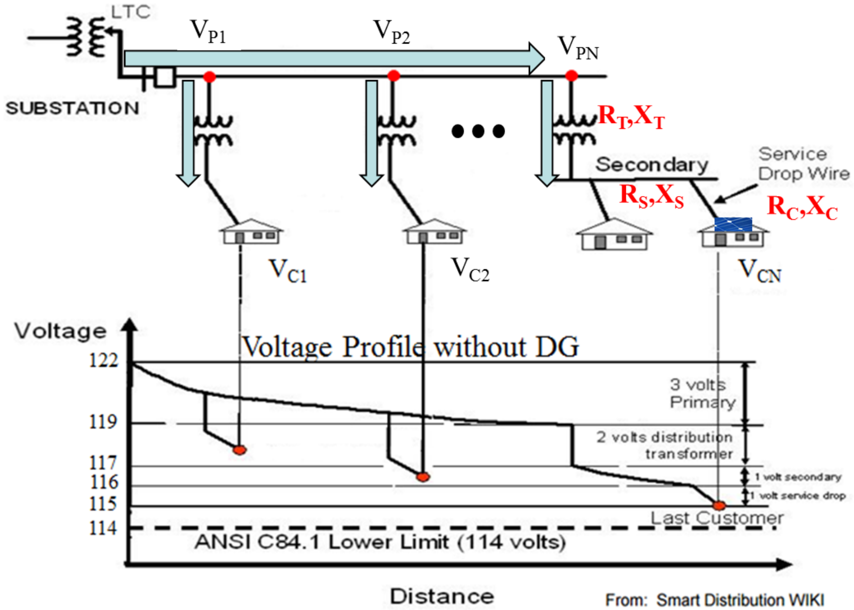


Inductive

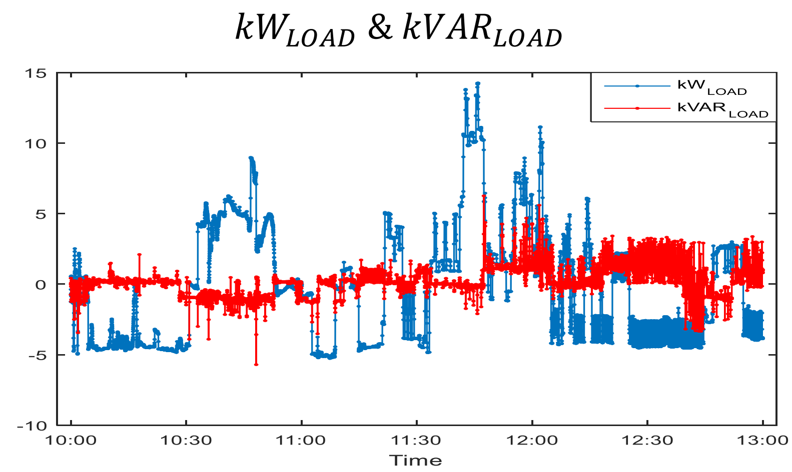


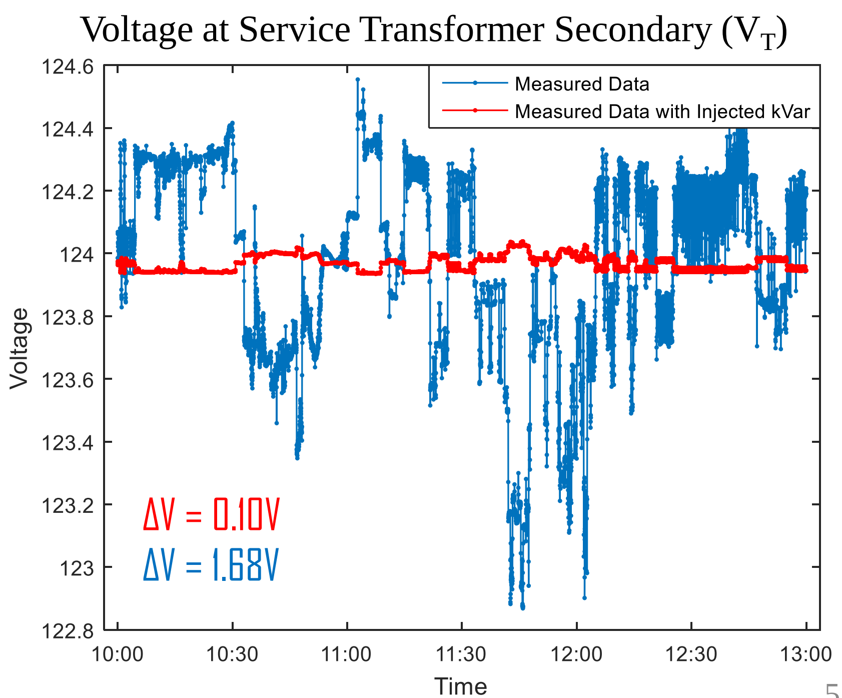
Reducing Voltage Fluctuations Across Distribution Feeder

Improves energy efficiency and reduces peak demand by lowering voltage (within ANSI limits) on the feeder lines that run from substations to end-use loads.

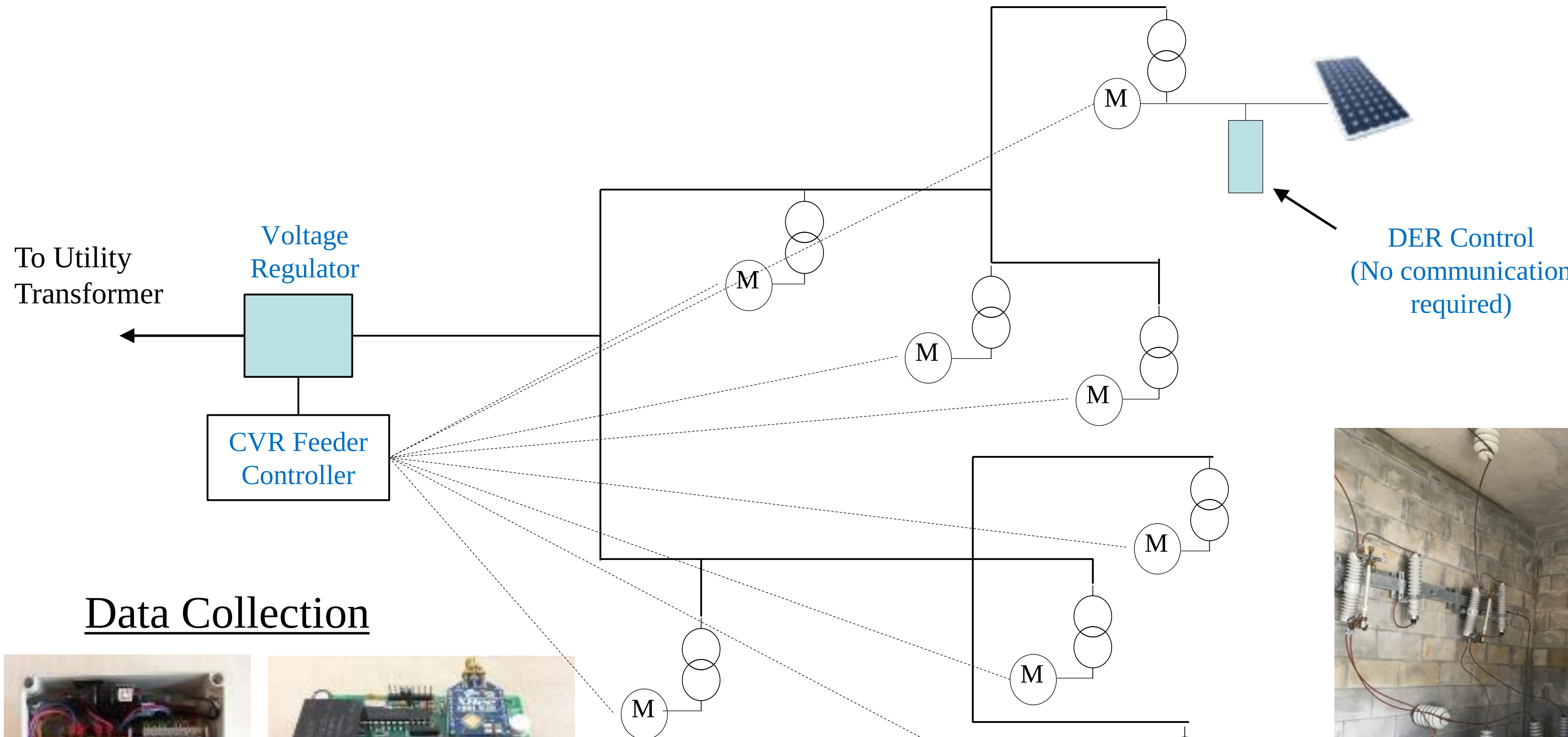


Smart inverters can be controlled to manage voltage





Advanced Conservation Voltage Reduction (CVR)
Field Demonstration



Data Collection

PQube

Custom

Collaborating with an international partner to provide equipment installation support

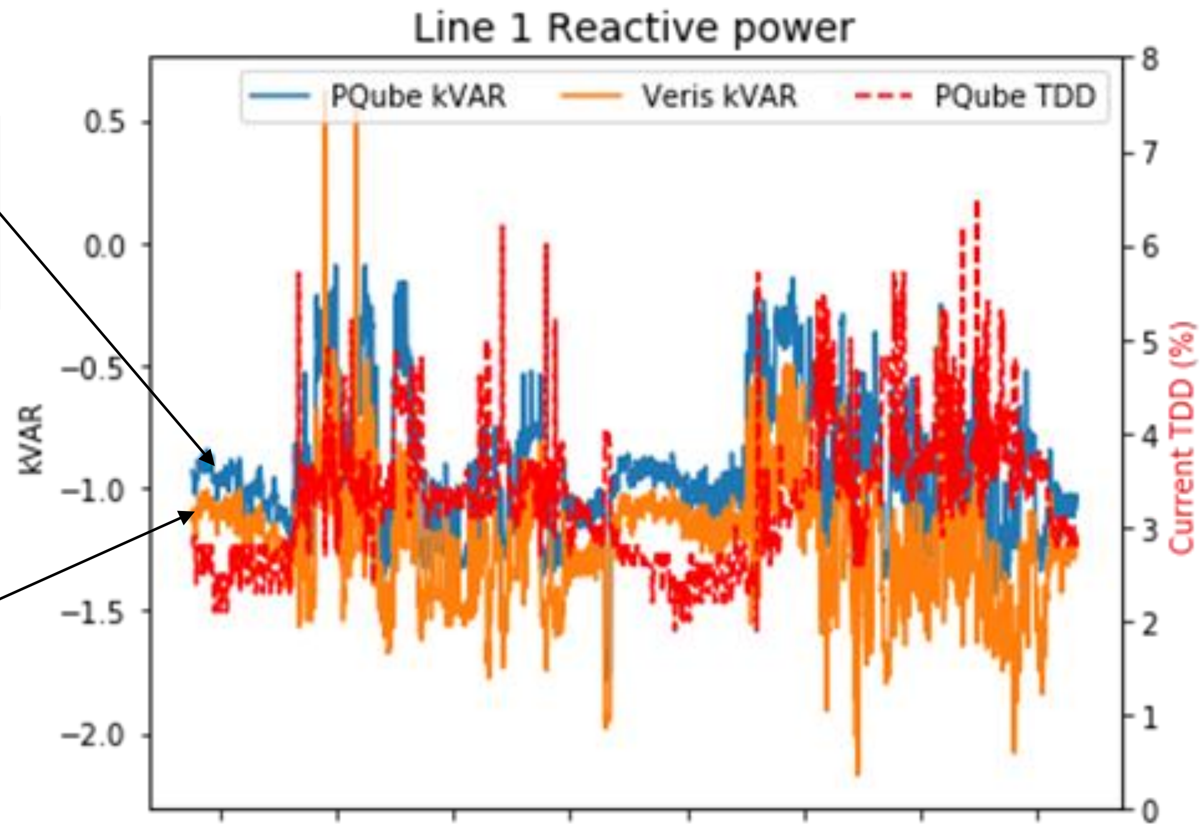
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

Understanding Power Meters

Computation of reactive power differs across meters

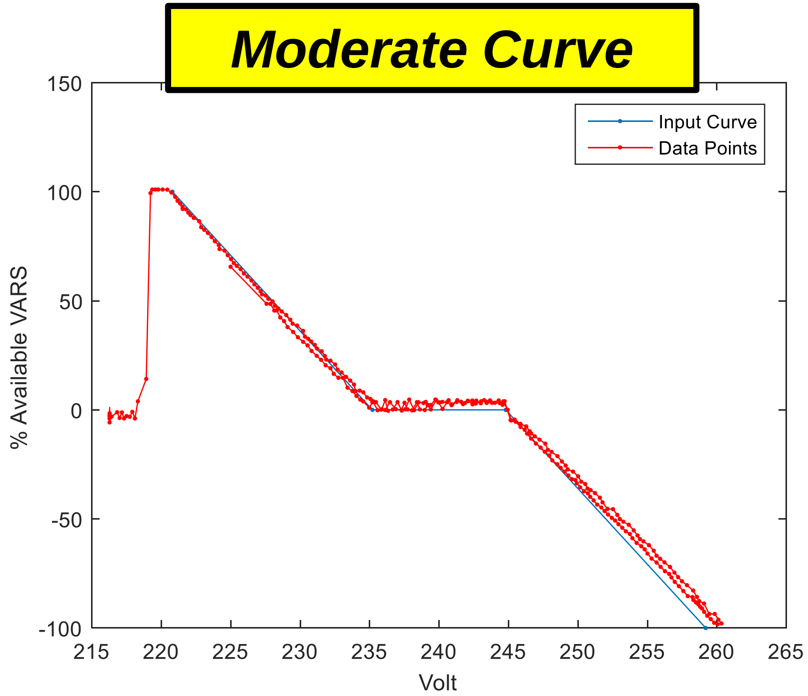
Fundamental Reactive Power

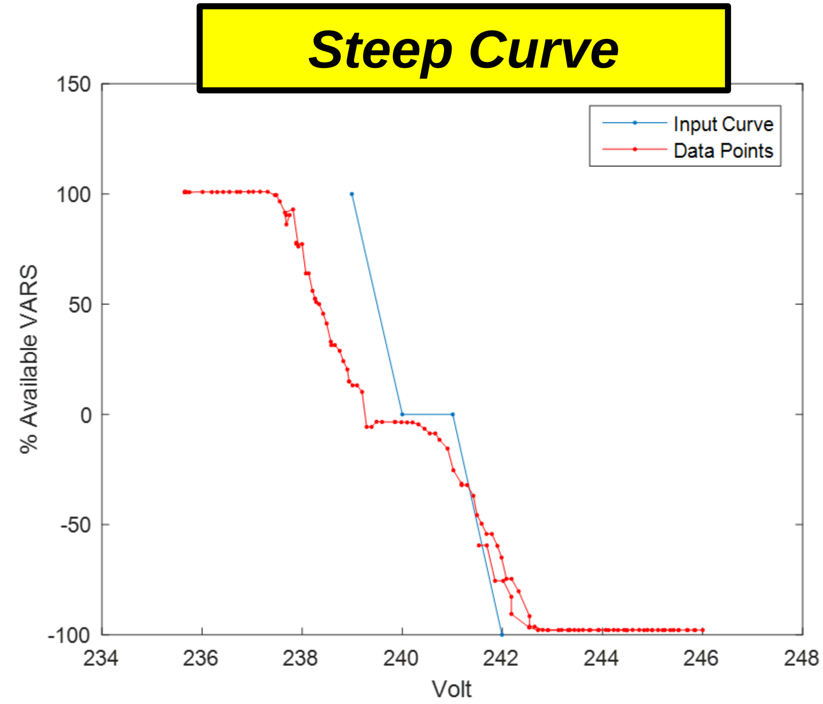
Non Active Power



Advanced Inverter Standardization

- Control curve
  - Number of points
  - Steepness of curves
- Inverter response time
- Interaction between multiple inverters





HECO Advanced Inverter Function Settings

- Advanced Inverter Functions
  - Frequency-watt
  - Volt-var
  - Volt-watt
  - Fixed power factor

Figure 4A-3: Volt-var settings per Table 4A-8.

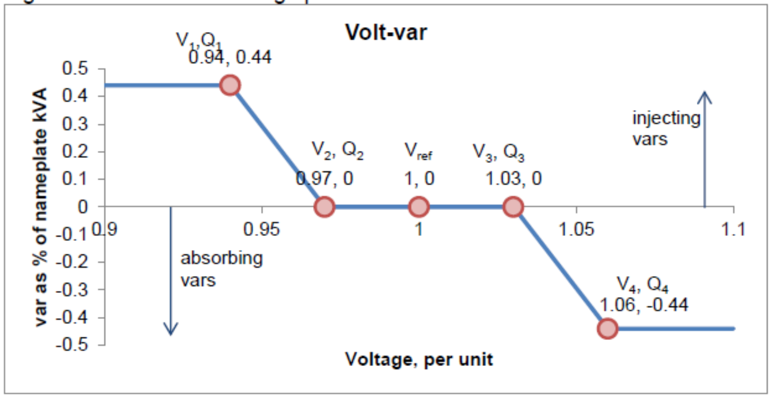


Figure 4A-2:Frequency-Watt settings per Table 4A-7.

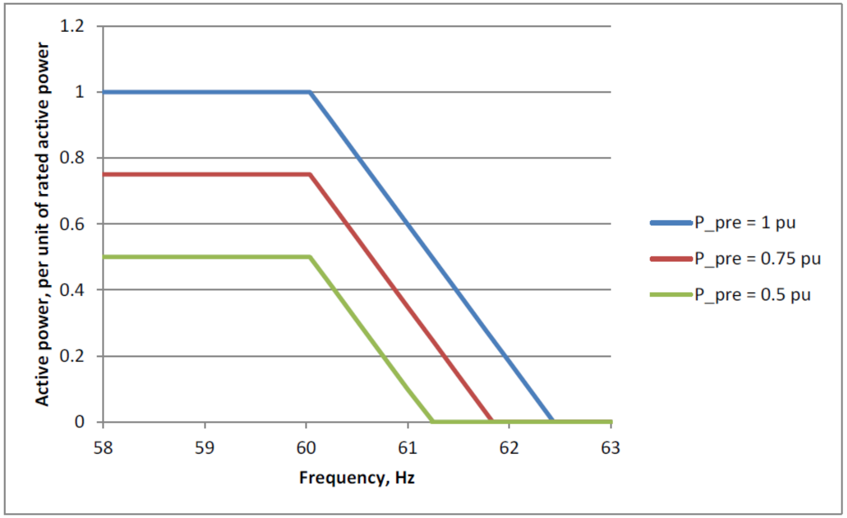
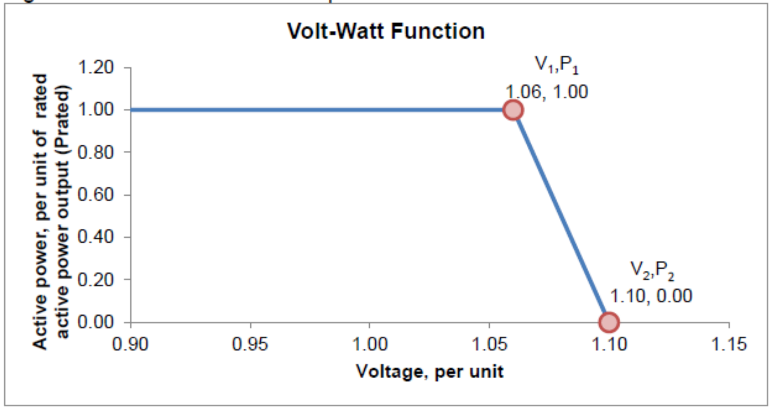


Figure 4A-1: Volt-Watt Function per Table 4A-3.



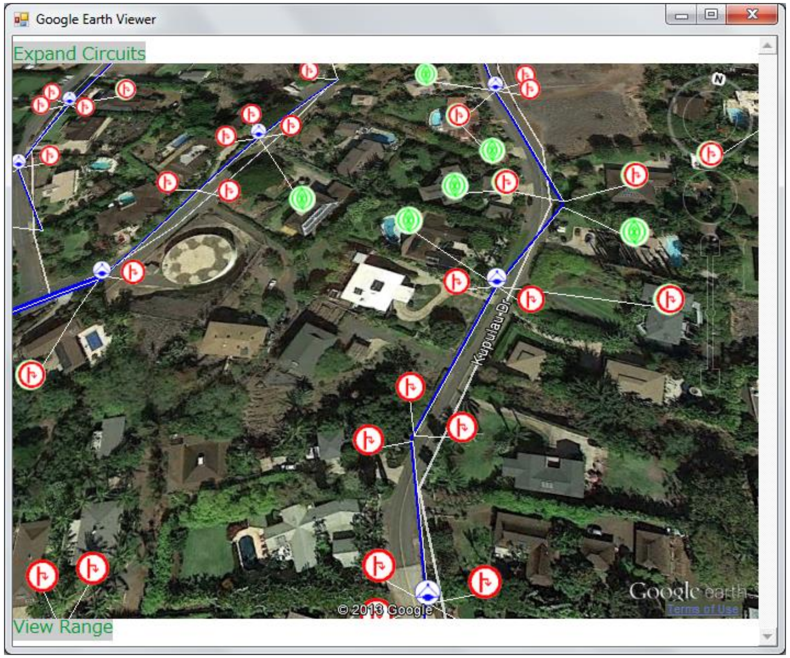
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

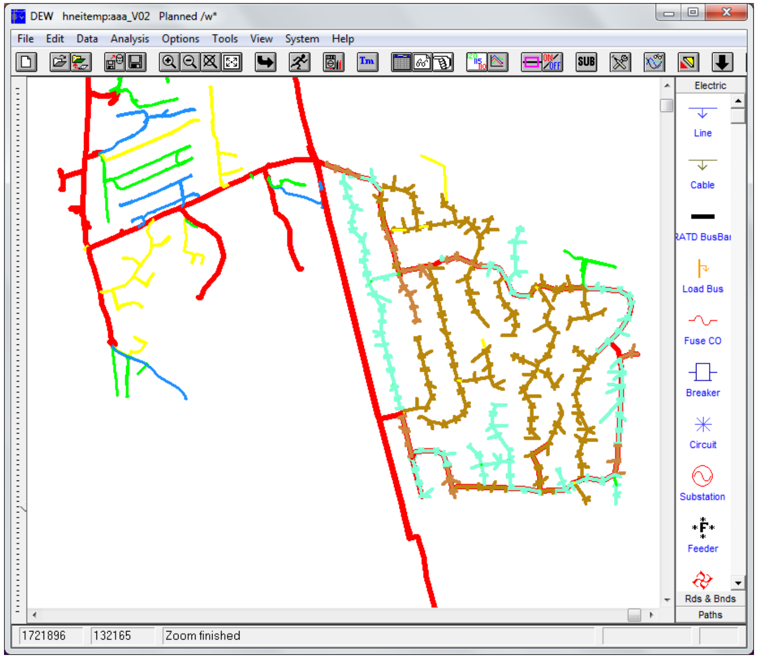
Ongoing DER Research

- HNEI Power Meter
- PV & Load Data Synthesis
- Distribution Modeling
- Predictive Distribution Operator
  - PV & Load Data Forecasting

Using COTS equipment: $2500

Custom, using board-level components: $200





Summary

- System Integration Studies
  - Analysis of various renewable energy and system scenarios, considering economics, reliability, and system-level characteristics
- Interconnection Requirements and Circuit Hosting Capacity
  - Applying industry best practices for interconnection requirements enables high penetrations of DER today
- Distributed Energy Resources (DER)
  - Rapidly growing and viable resource
  - More research and development is required to effectively utilize advanced capabilities of power electronic devices (e.g., PV inverters)

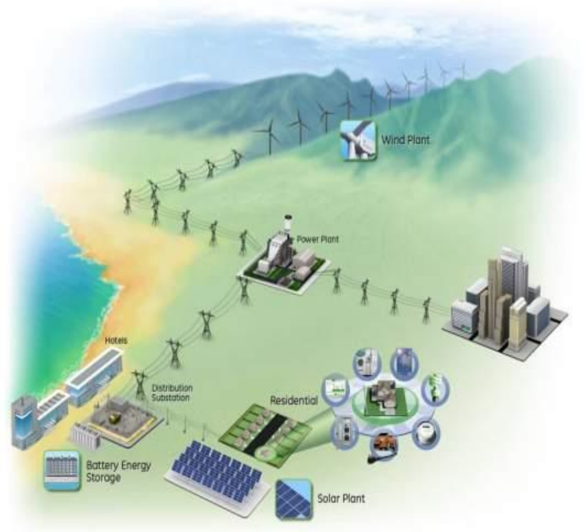
GridSTART

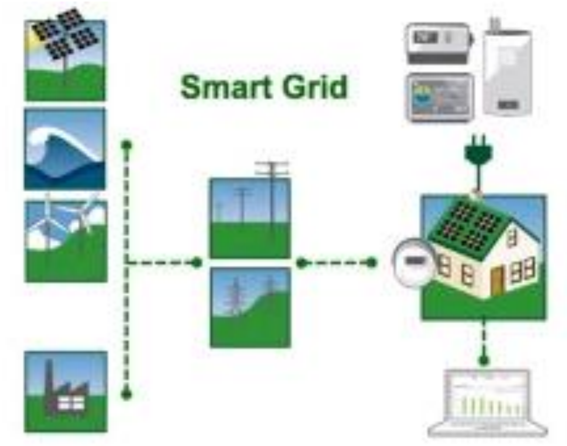
Hawai'i Natural Energy Institute | University of Hawai'i

Grid System Technologies Advanced Research Team

Expertise & Focus:

- *Renewable Energy Grid Integration*
- *Smart Grid Planning & Technologies*
- *Power Systems Planning*
- *Power Systems Operation*
- *Power Systems Engineering and Standards*
- *Communications Design and Testing*
- *Data Center and Cloud infrastructure*
- *Energy Policy*
- *Project Management and Execution*





HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Mahalo!

(Thank you)

For more information, contact:

Leon Roose

Hawaii Natural Energy Institute
School of Ocean & Earth Science & Technology
University of Hawaii at Manoa
1680 East-West Road, POST 109
Honolulu, Hawaii 96822

Office: (808) 956-2331
Mobile: (808) 554-9891
E-mail: lroose@hawaii.edu
Website: www.hnei.hawaii.edu

HNEI
Hawai'i Natural Energy Institute
School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa

UNIVERSITY of HAWAI'I
MĀNOA