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Integrating More Solar with Smart Inverters

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Grand Renewable Energy 2018 Conference

Yokohama, Japan

June 2018

A preprint of this paper can be found at:
https://www.nrel.gov/docs/fy18osti/71766.pdf

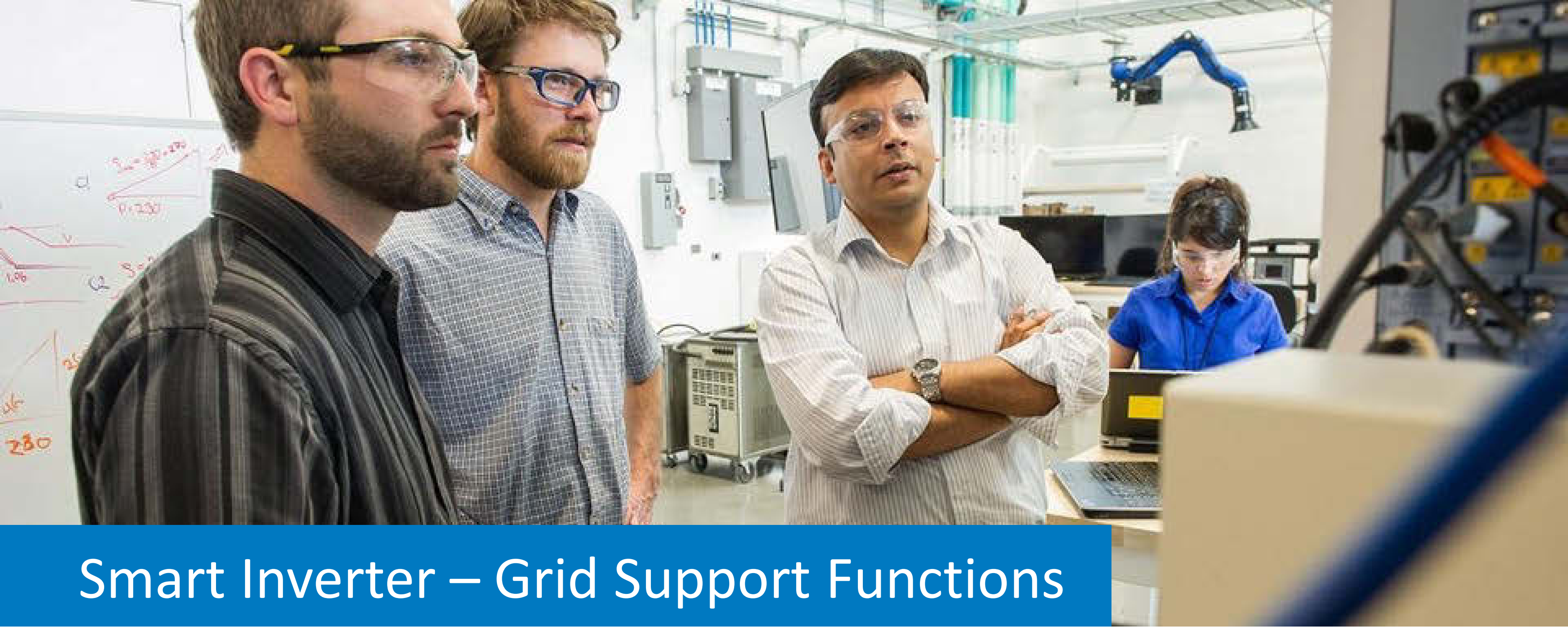
Photo by Ken Kelly, NREL

Integrating PV in Hawai‘i

- In Hawai‘i, PV is cost-effective on residential homes and larger central-station PV plants
- On some of the islands, PV has reached over 50% of the installed generation capacity base
- New smart inverter functionality is being evaluated at significant scale across the islands to maintain stable and safe operations
- This presentation highlights research conducted to validate high PV penetration scenarios with smart inverters

Integrating PV in Hawai‘i

- On the most populous Hawaiian island of O‘ahu, the PV generating capacity is 502 MW.
- This is nearly half of the annual peak load for the entire island of 1.1 GW.
- Of the total PV installed, 54% is on private rooftops—nearly 50,000 residences, or about one out of every three single-family homes.
- Hawaiian Electric, the local utility, does not own or control the residential PV systems.
- Hawai‘i has a goal of 100% renewable energy by 2045.
- Smart inverters are required to have active voltage regulation and frequency response to maintain proper grid operations.



Smart Inverter – Grid Support Functions

- NREL worked with HECO to conduct Power Hardware-in-the-Loop evaluations of smart inverter grid functionality at the Energy Systems Integration Facility (ESIF)

The seven grid support functions that were evaluated included:

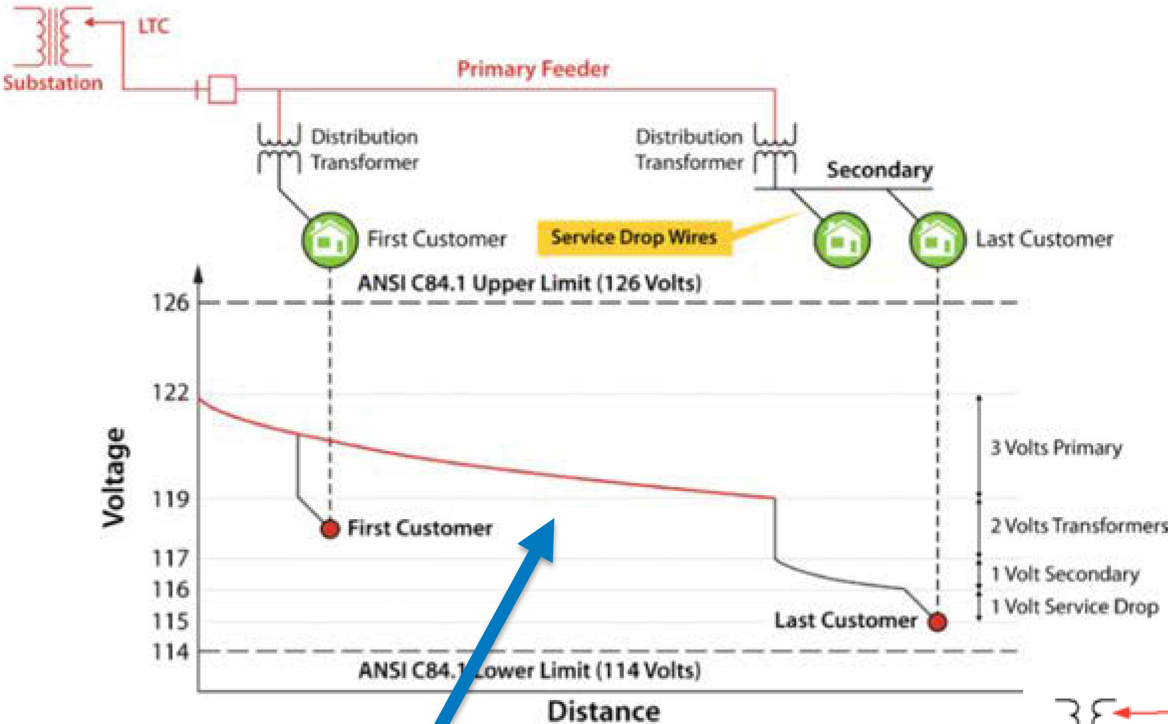
- Fixed power factor operation
- Volt-watt control
- Volt-var control (baseline only)
- Voltage ride-through
- Frequency ride-through
- Ramp rate control
- Soft start reconnection

Photo courtesy of Ben Kroposki

Grid Support Function - Voltage Regulation

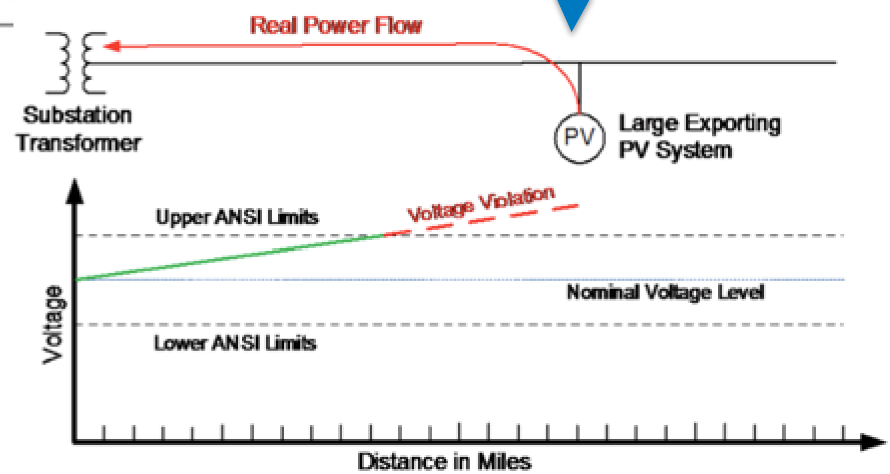
- Active power production from PV inverters tends to increase steady-state grid voltage.
- Absorbing reactive power can bring down voltage with minimal (sometimes zero) impact on real power production, and hence it is generally preferred.
- Inverters have two output parameters available to mitigate this: reactive power and active power.
- Reducing active power can also mitigate overvoltage, but this directly reduces PV energy production and is therefore typically considered an option only when voltage is very high and reactive power is not solving the problem.

Understanding Voltage Regulation

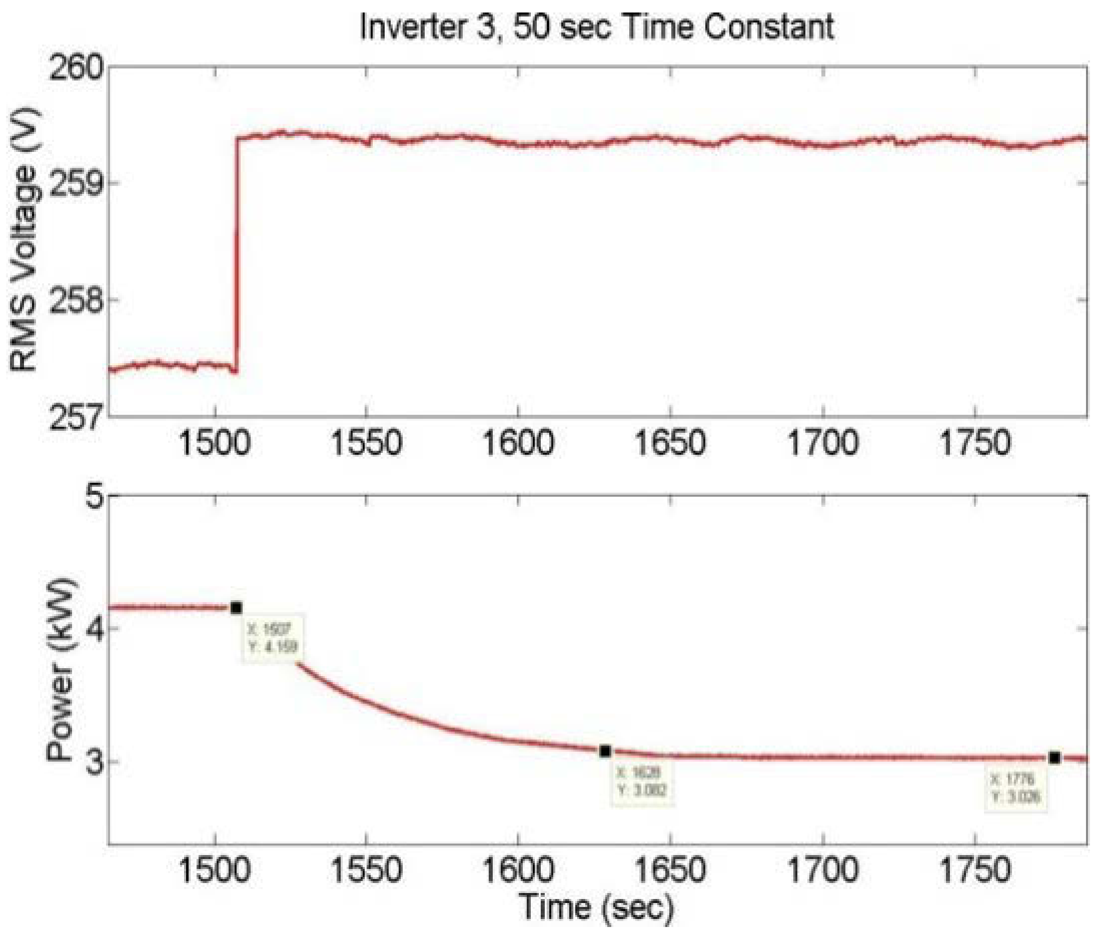


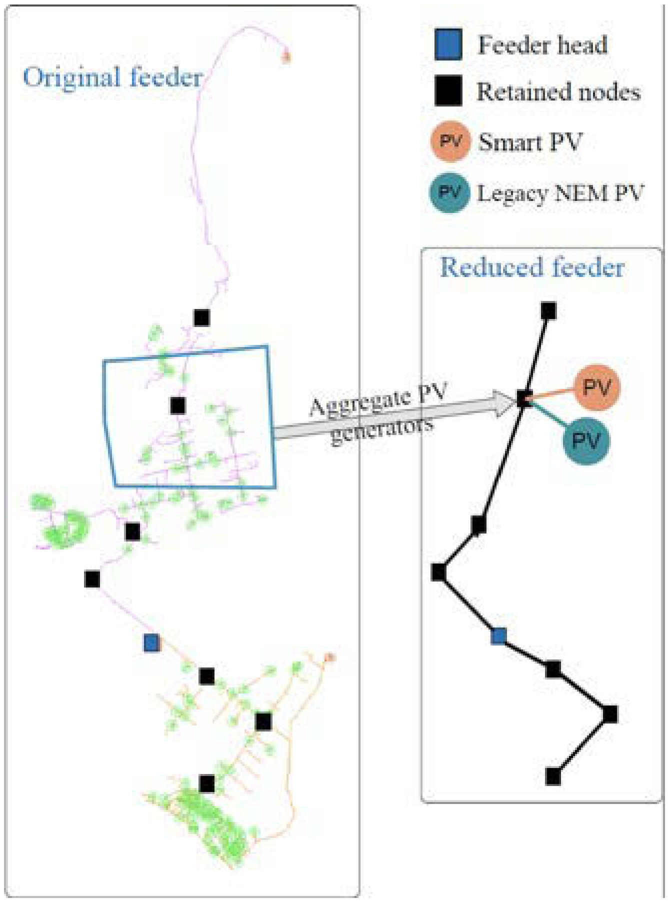
DG PV raises voltage when injecting active power

Voltage normally decreases away from the substation



Grid Support Function – Voltage Regulation

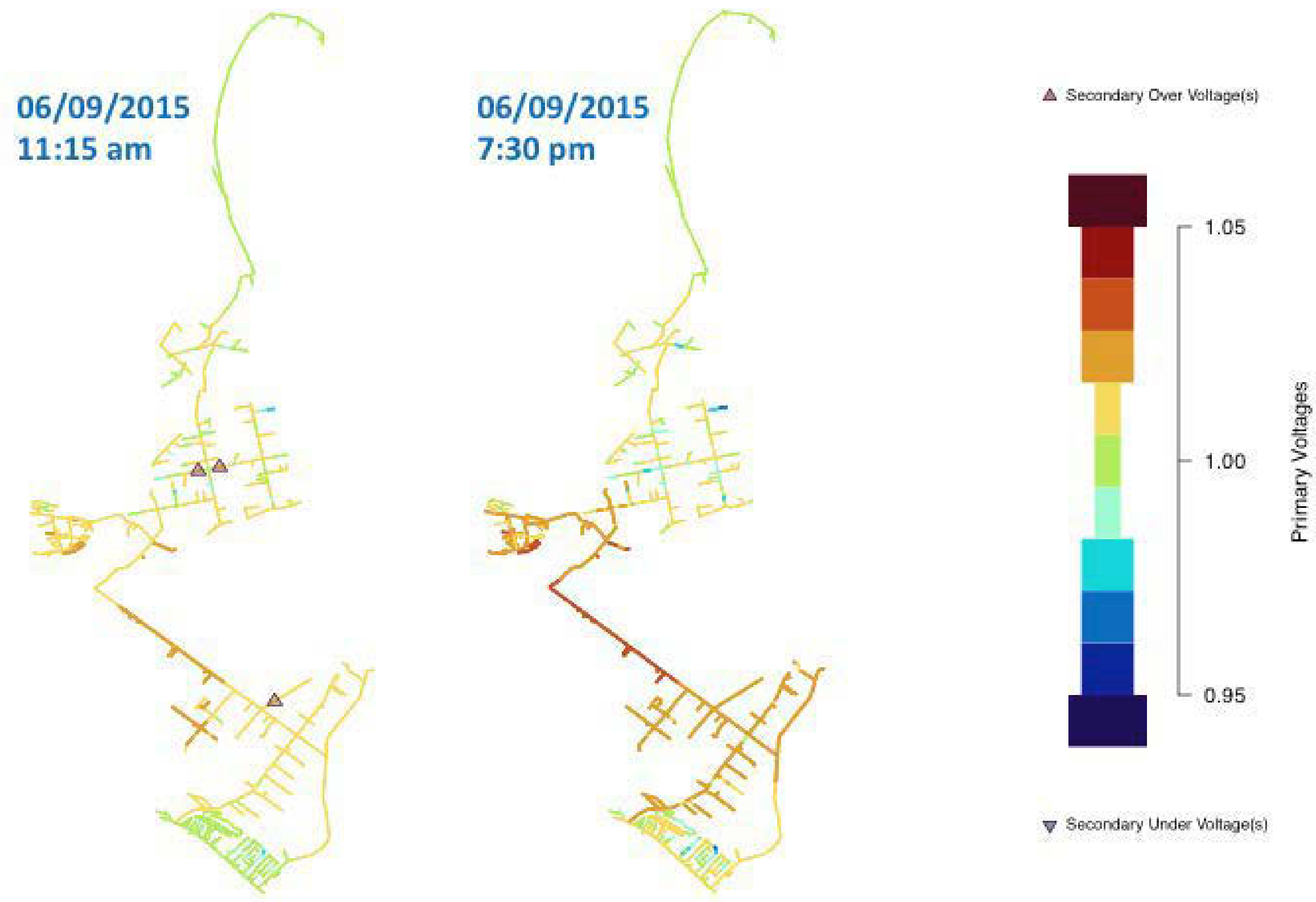




Example of Smart Inverter Volt-Watt Response

Representation of PV on Circuit

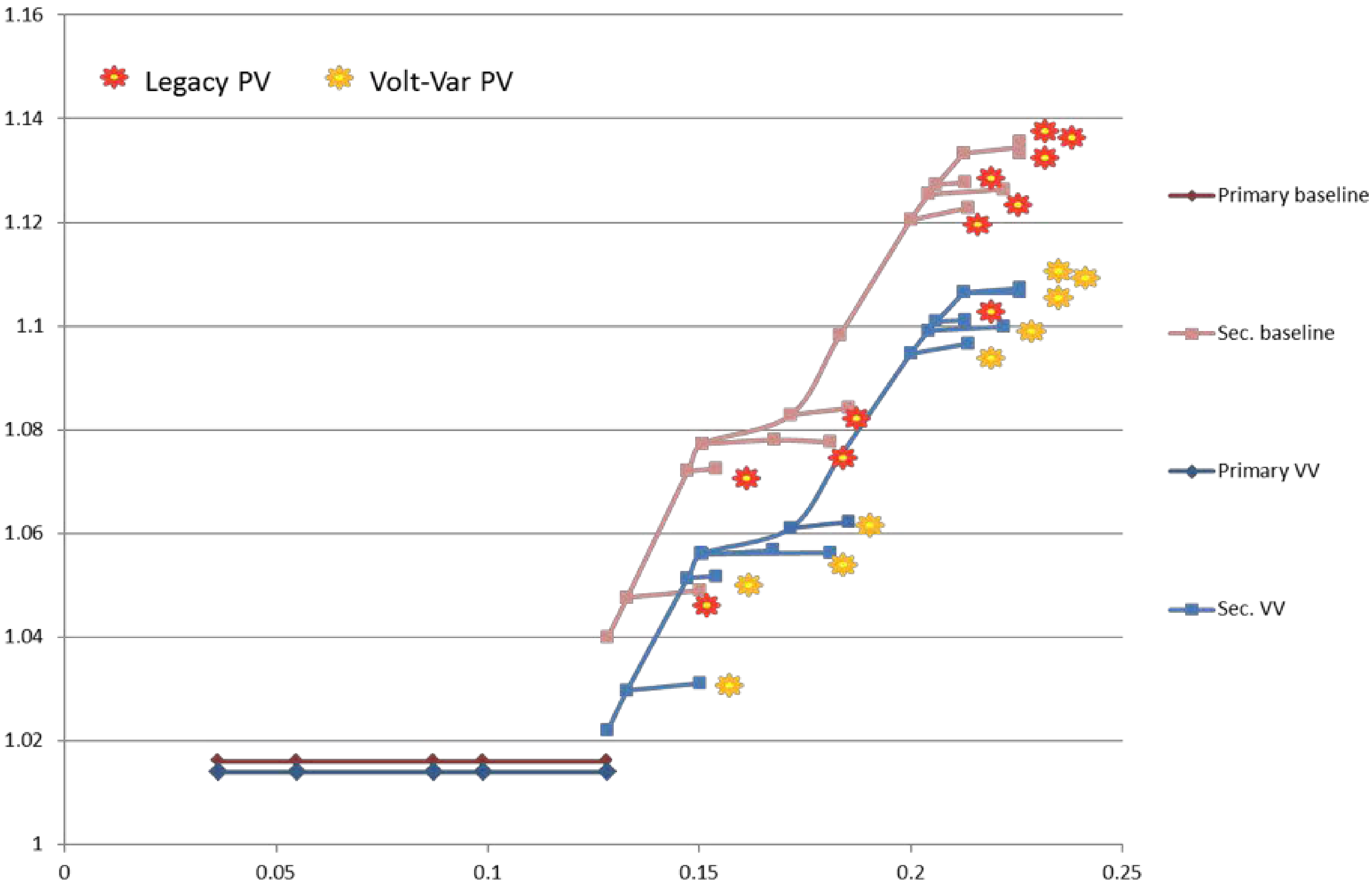
Voltage Regulation Operational Strategies (VROS)



Distribution Primary Voltage Maps for Distribution Circuit with High Level of PV

Primary voltages are lower during day due to LTC settings, as seen in heat maps above, but secondary (customer) voltages are higher during day due to PV (triangles above)

Voltage Regulation Operational Strategies (VROS)



Voltage Profile for Distribution Circuit with Extremely High PV (Legacy and Smart Inverters)

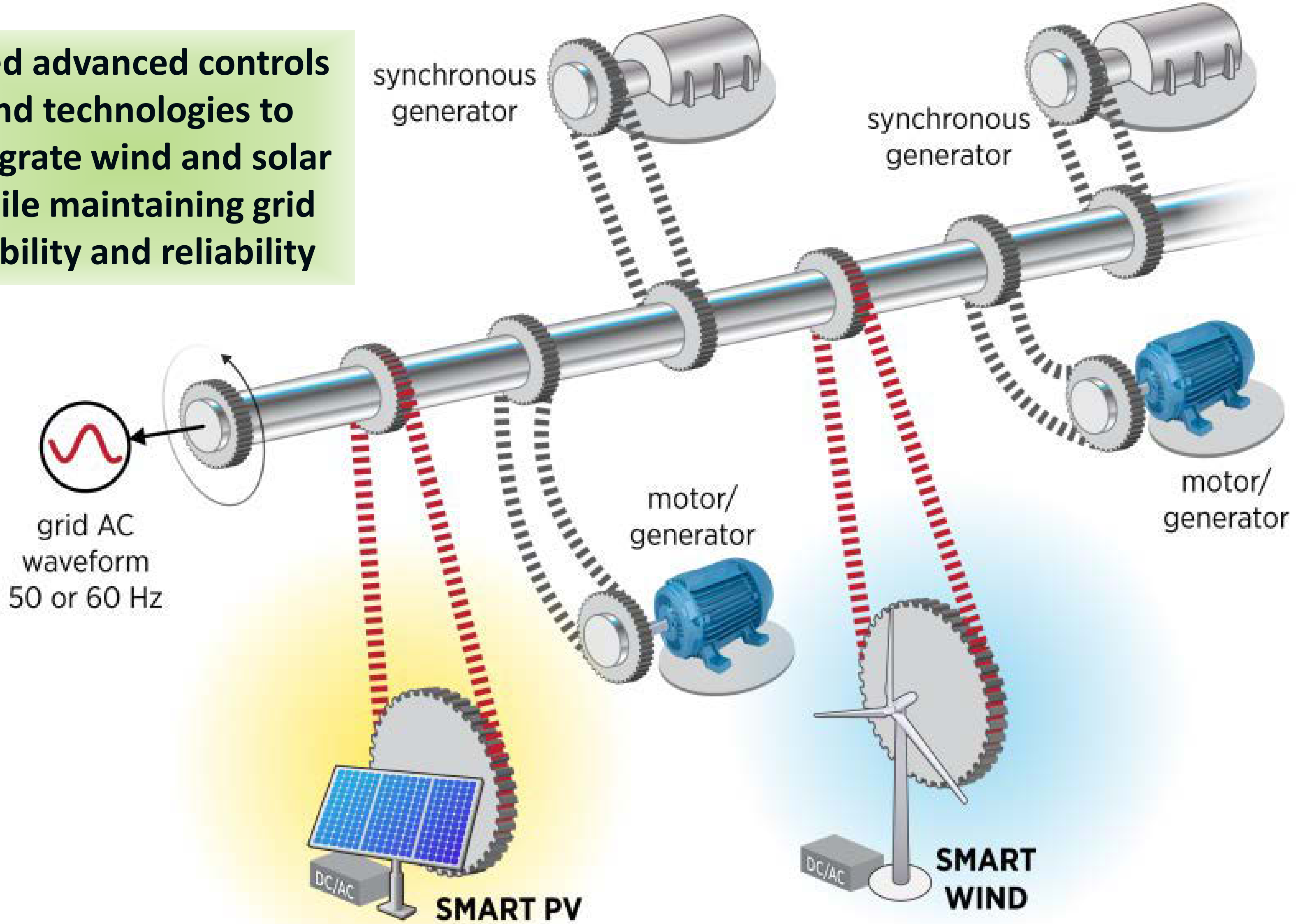
Photo courtesy of Ben Kroposki

Grid Support Function – Frequency Response

- Grid frequency is an indicator of the balance between load and generation.
- When frequency is low, more generation (or less load) is needed; and when frequency is high, less generation (or more load) is needed.
- Advanced inverters can reduce power in response to overfrequency events.
- This function is called frequency-watt control. It follows a frequency-watt curve to reduce/curtail real power so that the system frequency would be reduced.
- Responding to underfrequency events requires the ability to increase power output and this may not be possible unless the inverter is already running in a curtailed mode.

Understanding Grid Inertia and Frequency

Need advanced controls and technologies to integrate wind and solar while maintaining grid stability and reliability



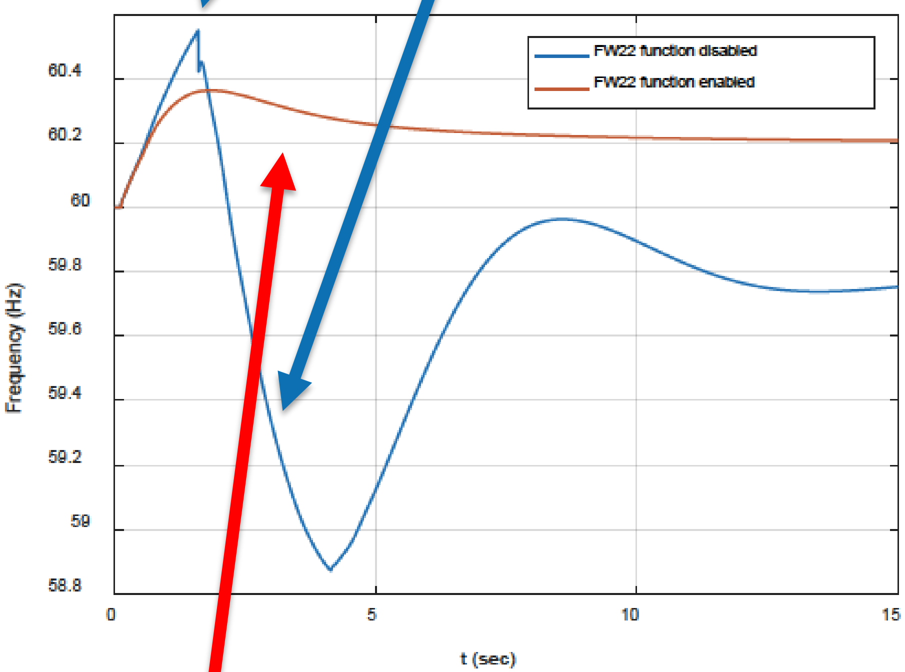
Achieving a 100% Renewable Grid
http://ieeexplore.ieee.org/document/7866938/

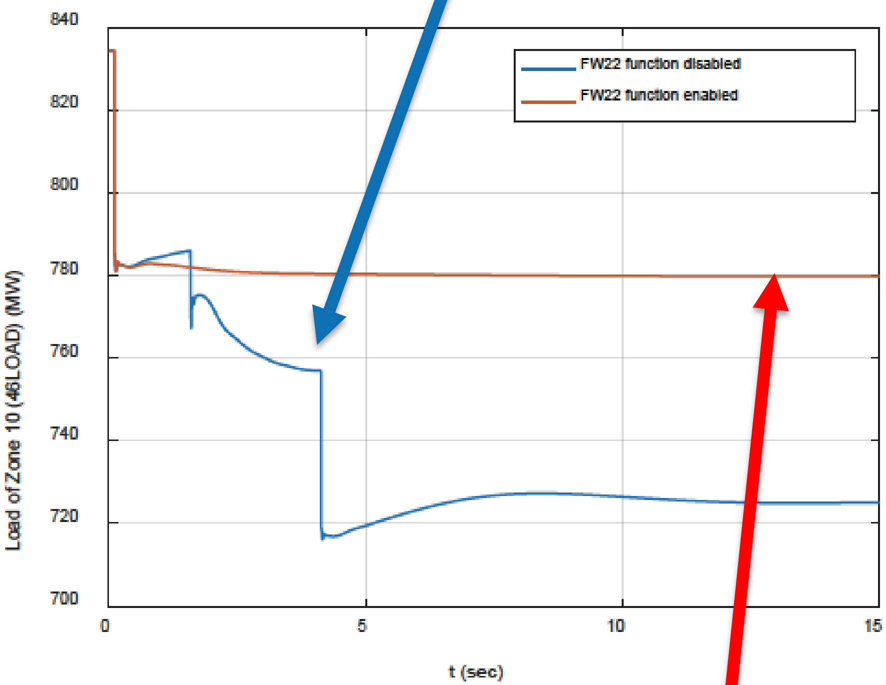
Grid Support Function - Frequency Response

Overfrequency event causes legacy inverters to trip

System frequency declines

Underfrequency Load Sheading occurs to save system





Smart Inverters use frequency-watt control to maintain grid stability

System remains stable and does not drop any load

Summary

- The results demonstrated that smart inverter functions, if properly used, can help maintaining grid reliability with significant amounts of PV without major impacts on customer production.
- Impacts on energy production were negligible for the vast majority of customers, even in future PV penetrations cases beyond the already-high present-day scenario.
- This was true even though all PV systems were modeled as exporting power without restriction, which will not be the case in Hawai‘i due to new DER programs that are designed to avoid export during high irradiance periods and provide operator controls over DER systems.

Photo courtesy of Ben Kroposki

References

A. Nelson et al., “Hawaiian Electric Advanced Inverter Grid Support Function Laboratory Validation and Analysis,” National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-5D00-67485, Dec. 2016.
https://www.nrel.gov/docs/fy17osti/67485.pdf

J. Giraldez et al., “Simulation of Hawaiian Electric Companies Feeder Operations with Advanced Inverters and Analysis of Annual Photovoltaic Energy Curtailment,” National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-5D00-68681, Jul. 2017.
https://www.nrel.gov/docs/fy17osti/68681.pdf

A. Hoke et al., “The Frequency-Watt Function: Simulation and Testing for the Hawaiian Electric Companies,” National Renewable Energy Laboratory, NREL/TP-5D00-68884, Jul. 2017.
https://www.nrel.gov/docs/fy17osti/68884.pdf

Power Supply Improvement Plan, Books 1-4, Hawaiian Electric Companies. Dec. 2016.
https://www.hawaiianelectric.com/about-us/our-vision

Thank You

Mahalo

www.nrel.gov/grid

NREL/PR-5D00-71903

This work was authored in part by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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