GMLC Hawaii Regional Partnership: Distributed Inverter-Based Grid Frequency Support

Austin Nelson, P.E.
Andy Hoke, Ph.D., P.E.
Power Systems Engineering Center, NREL

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Project Overview

- **Team:** NREL, Hawaiian Electric, SNL, Enphase, Fronius, Forum on Inverter Grid Integration Issues, Energy Excelerator
- **Goal:** Investigate and develop methods for DERs to support grid frequency on the fastest time scale (milliseconds to seconds)
- **Approaches:** Conventional (PSSE) simulations, hybrid T&D simulations, lab testing including power hardware-in-the-loop (PHIL), controls development, and field demonstration
- **PI:** Andy Hoke, NREL; **Sandia lead:** Mohamed Elkhatib, SNL
- **Duration:** April 2016 – September 2017

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Hawaiian Electric
Maui Electric
Hawai‘i Electric Light

Sandia National Laboratories

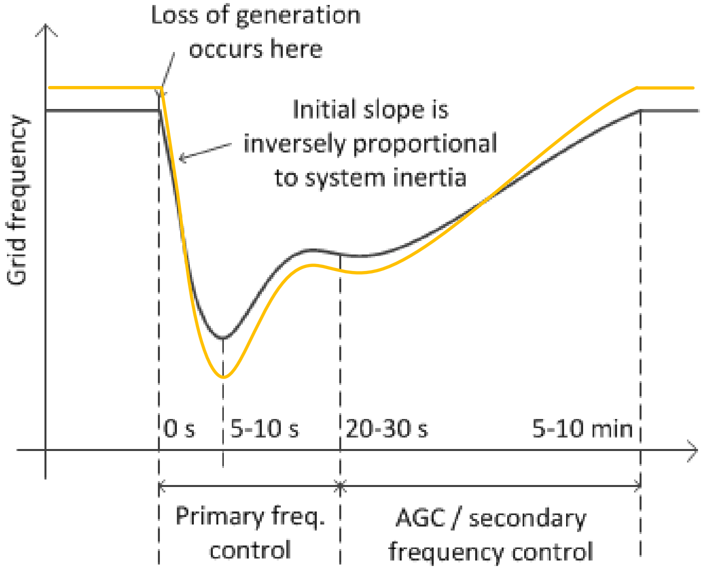
Motivation

- Rotational *inertia* and *governor control* of synchronous generators stabilize grid frequency on the fastest time scales
- Hawaii leads U.S. in portion of electricity produced by distributed PV
- PV, wind, ESS displace synchronous generation
  - Inverter-coupled: no inertia, typically no frequency response
  - Reliability impacts at higher penetrations
  - Can lead to load shedding (outages), grid instability

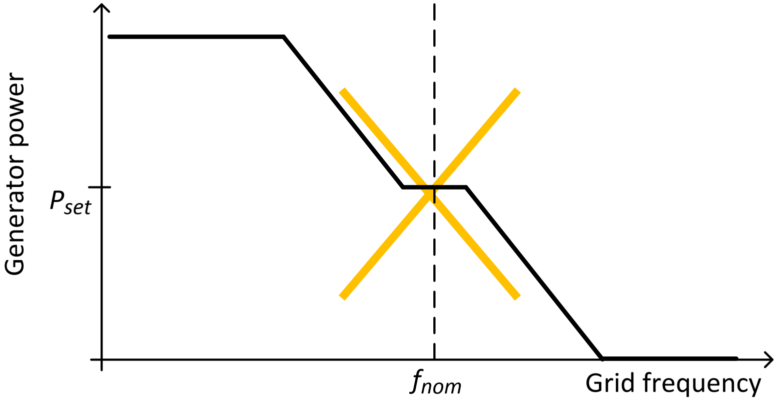
Gas turbine

Image credit: web.ornl.gov

Underfrequency event:



Simple P-f droop characteristic:



Objectives

- Investigate whether DERs (PV and storage inverters) can support grid frequency by autonomously modulating output power
  - Large wind plants often provide similar services today
- Identify settings for “conventional” PV frequency-watt function (downward response only)
- Identify future opportunities (and challenges) to improve system performance and reliability at very high renewable penetrations through improved frequency support from DERs
- Quantify how PV and energy storage could help
- Identify challenges and risks associated with DER frequency support

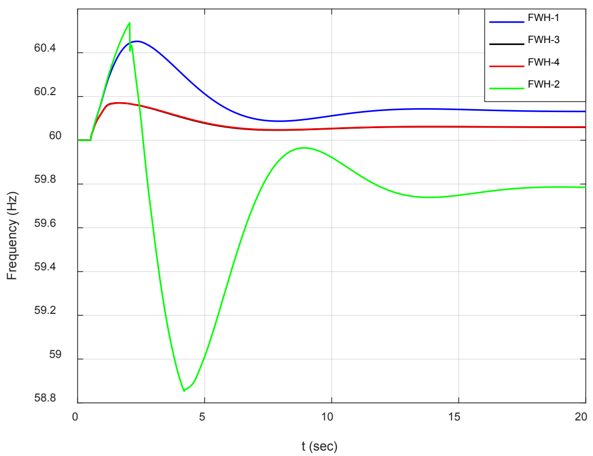
Approach

- Bulk grid simulations (PSSE) of Oahu power system (Sandia)
- Development of new modeling and simulation techniques, including hybrid bulk power system and distribution system simulations
- PV inverter controls development
- Lab testing of presently available PV and storage inverters
- PHIL testing of PV and storage inverters in an environment that mimics Oahu bulk system and distribution system dynamics
- Field demonstration of presently available PV frequency-watt droop
- Oversight by external technical review committee

Notable outcome

- **Generator inertia must be replaced with other *very fast* frequency support services**
- Exact response time needed varies by system; Oahu needs sub-second response
- Experiments and simulations confirm PV and storage inverters can provide sufficiently fast support
- Speed of response is faster than currently envisioned for mainland U.S. – concerns about unintended interactions with sync gen (e.g. SSTI, inter-area oscillations)
- Based on input from this project, **Draft IEEE Standard P1547 modified** to allow sub-second frequency droop *if coordinated with bulk system reliability authority*.

2019 Oahu overfreq event with varying f-W response times. (Green = 1 s response)



Excerpt from IEEE P1547 (to ballot May 2017)

P1547/D6.7, March 2017
IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Table 25—Parameters of frequency-droop (frequency/power) operation for DER of Category I, Category II, and Category III

Parameter	Ranges of adjustability [c]			Default settings [a]		
	Category I	Category II	Category III	Category I	Category II	Category III
db_{OF}, db_{UF} (Hz)	0.017 [b] – 1.0	0.017[b] – 1.0	0.017[b] – 1.0	0.036	0.036	0.036
k_{OF}, k_{UF}	0.03 – 0.05	0.03 – 0.05	0.02 – 0.05	0.05	0.05	0.05
$T_{response}$ (small-signal) (s)	1 – 10	1 – 10	0.2 – 10	5	5	5

Allows responses as fast as 0.2 seconds

IEEE PES Power & Energy Society®

IEEE

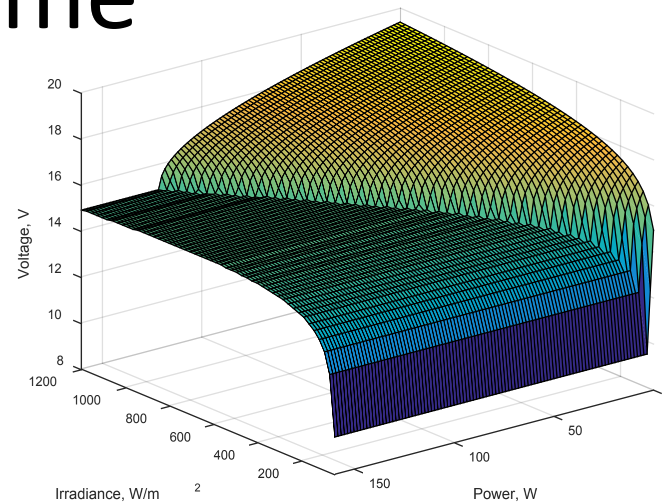
Notable outcome

Publication:

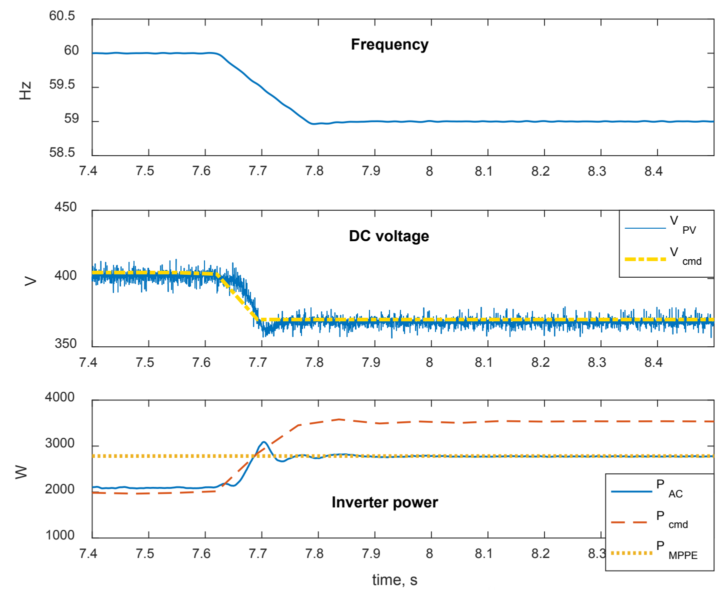
A. Hoke, M. Shirazi, S. Chakraborty, E. Muljadi, D. Maksimovic, "Rapid Active Power Control of Photovoltaic Systems for Grid Frequency Support," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* Feb 2017

- Method for **estimating the presently available power** from a PV array in real time
- Method for **controlling the active power of a PV system accurately and rapidly** (within 2-4 cycles)

3-D lookup table for rapid APC of PV



Prototype PV inverter performing rapid APC in response to grid frequency transient

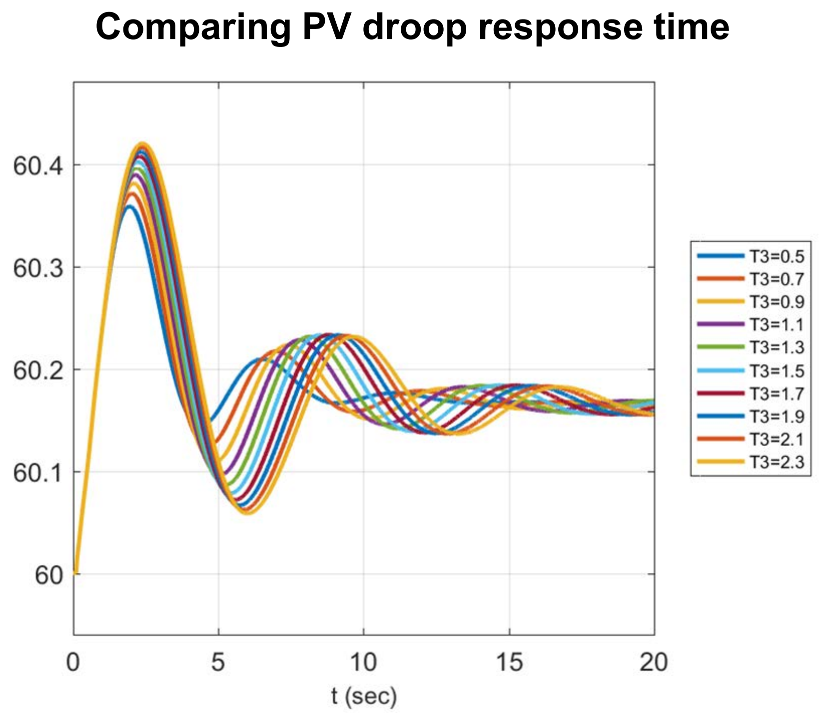


Notable outcome

Publication:

M. Elkhatib, J. Neely, J. Johnson, "Evaluation of Fast-Frequency Support Functions in High Penetration Isolated Power Systems," *IEEE Photovoltaics Specialists Conference*, 2017

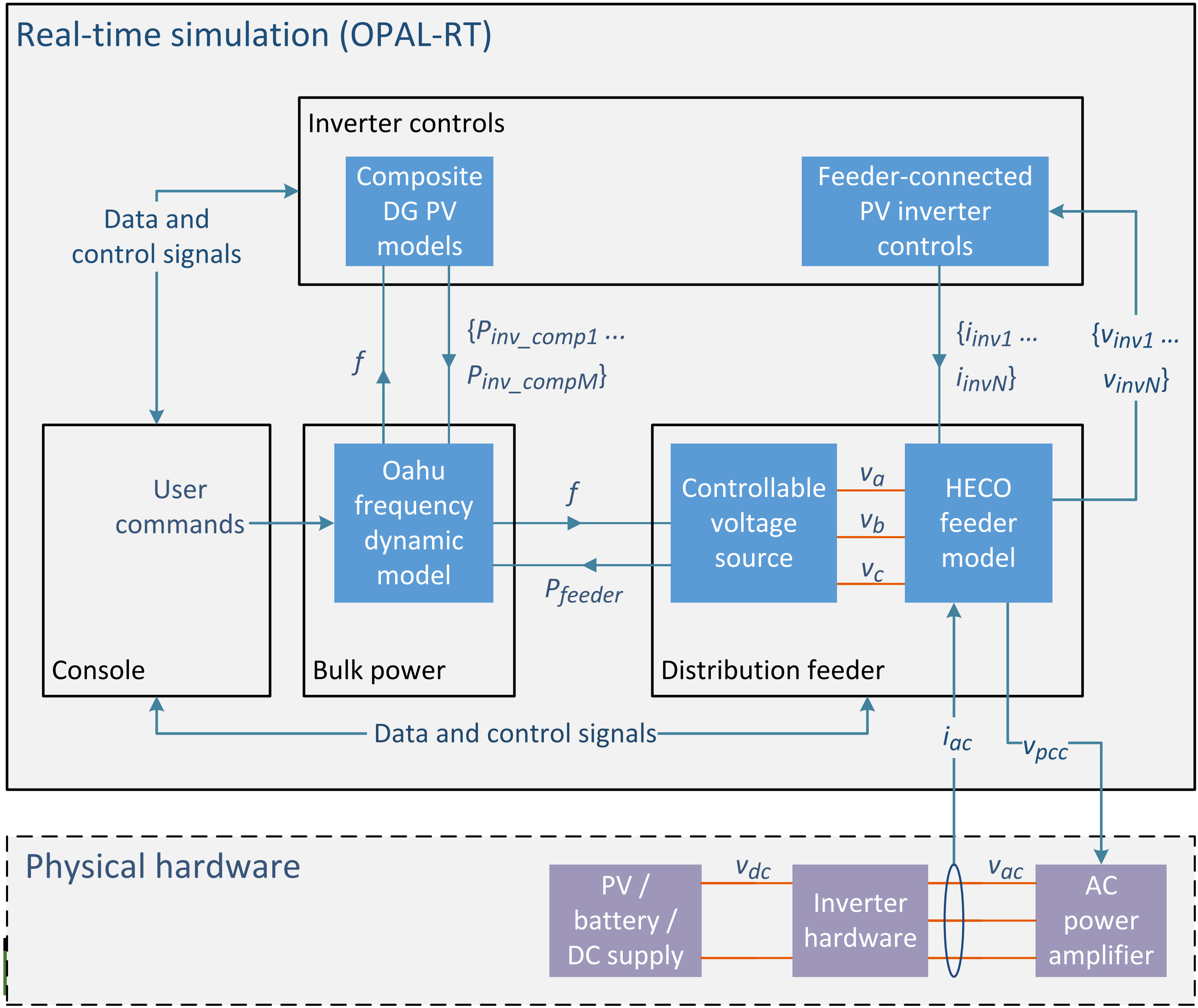
- Comparison of PV droop parameters using PSS/E model of future Oahu power system
- User-defined PSSE model of frequency-responsive PV
- Key finding: faster responses may be more stable in Oahu scenarios studied
- To appear in June 2017



Coming soon: PHIL validation

Custom PHIL platform captures bulk grid and distribution dynamics:

- Real-time Oahu frequency dynamic model simulates contingency events
- Frequency dynamic model drives frequency of voltage waveforms in distribution system simulation
- Hardware inverters connected to AC supply driven by simulated PCC voltage
- Many more inverters simulated with various controls, both on distribution feeder and in bulk system model



Next Steps

- Oahu PSSE simulations
  - Grid forming inverter controls
- Small-scale field demonstration of PV f-W response
- Recommendations to HECO for near-term implementation of PV frequency-watt control (downward response only) – Summer 2017
- Final report detailing project findings (Fall 2017), including:
  - Recommendations for possible implementation of DER frequency support to include upward response
  - Summary of challenges and limitations of DER-based frequency support
- Results will inform Hawaii grid operations today and will become relevant to the mainland U.S. in the years to come