GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.3.29 – Grid Frequency Support from Distributed Inverter-based Resources in Hawaii

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Grid Frequency Support from Distributed Inverter-based Resources in Hawaii (1.3.29)
High Level Summary

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Project Description

Work with the Hawaiian Electric Companies (HECO) to investigate, develop, and validate ways that distributed PV and storage can support grid frequency stability on the fastest time scale (starting within a few line cycles of a frequency event).

Value Proposition

- ✓ Can DERs reliably and autonomously support grid frequency in very high renewable penetration scenarios, and what are the challenges involved?
- ✓ In a SunShot future with low levels of synchronous generation, conventional methods of stabilizing grid frequency may no longer be adequate

Project Objectives

- ✓ Enable distributed PV and storage inverters to support grid frequency starting a few AC line cycles after the appearance of a frequency event.
- ✓ Characterize frequency support capabilities of existing inverters.
- ✓ Validate DER frequency support via conventional simulation (PSSE), hybrid T&D simulation, and power hardware-in-the-loop testing.
- ✓ Recommend DER frequency control strategies to HECO.
- ✓ Develop new models and modeling methods for DER frequency support functions.

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Project Team

Project Participants and Roles

NREL – Overall lead; hardware testing including PHIL; controls; hybrid T&D simulation; field deployment

SNL – Bulk power system simulation

HECO – Support modeling and simulation; field deployment

Enphase Energy and **Fronius USA** – Supply test and field hardware and technical support

FIGII and **Energy Excelerator** – Advisory

PROJECT FUNDING			
Lab	FY16 $	FY17$	Lab Total
NREL	$510k	$180k	$690k
SNL	$300k	-	$300k
Total	$810k	$180k	$990k

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Relationship to Grid Modernization MYPP

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Directly aligns with 3 of 4 activities in the DIST area:

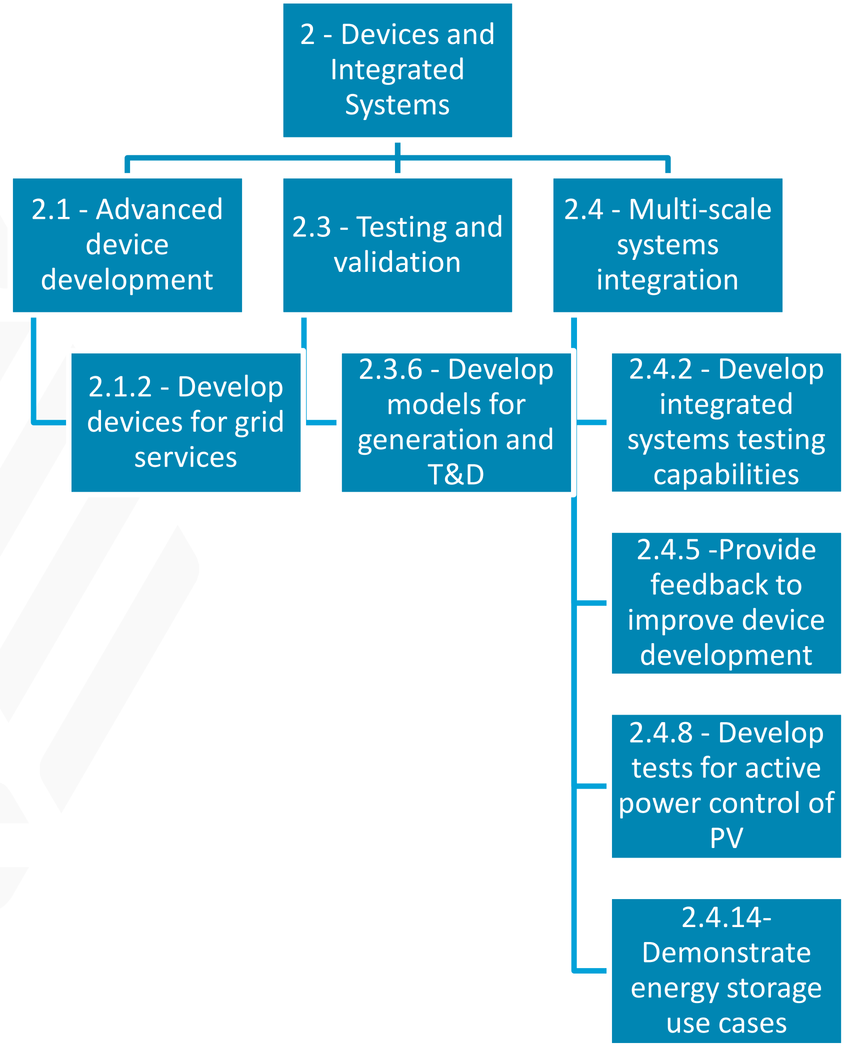
- 2.1 - Develop advanced power electronics, ESSs
- 2.3 - Build capabilities, test and validate devices
- 2.4 - Conduct multi-scale systems integration

Indirectly impacts the 4th DIST activity:

- 2.2 - Develop standards and test procedures

Also aligns with several activities in other areas:

- 4.2 - Develop coordinated system controls
- 5.2 - Develop tools for improving reliability
- 7.1 - Provide technical assistance to states



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Approach

Task	Subtask
1 - Bulk system modeling and simulation	a) PSSE model development b) Parametric study of bulk system c) Power balancing and reserve requirement modeling
2 - Time domain modeling, simulation, and controls development	a) Hybrid time-domain system model development b) Inverter model development/validation c) Inverter controls development d) Simulate and compare control methods e) Implement/upgrade controls in vendor firmware f) Real-time PHIL model development
3 - Hardware testing including PHIL	a) Open loop inverter hardware testing b) PHIL validation of frequency supportive hardware c) PHIL validation of side-effect mitigation
4 - Field testing and demonstration	a) Field test bed planning and installation b) Field hardware demonstration c) Compare field results to lab tests and simulations
5 - TRC and reporting	a) Establish TRC and obtain TRC feedback b) Final summary report

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Key Project Milestones

Milestone (FY16-FY17)*	Status	Due Date
1.4 - Simulations contrasting Oahu grid response to various control methods (homogeneous control implementation scenarios) complete	Complete	March 31, 2017
2.4 - Prototype inverter controls for improved DER frequency support developed	Complete	March 31, 2017
3.4 - Initial results from PHIL testing of second inverter agree with pure simulation	Complete	March 31, 2017
4.4 - Field installation of all inverters at HECO site complete	In progress. Delayed due to subcontract issues.	March 31, 2017
5.4 - Progress report delivered to TRC for review	Complete	March 31, 2017

*Project includes 30 milestones (5 per quarter). Only FY17 Q2 milestones are shown here due to space/time constraints.

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Accomplishments to Date

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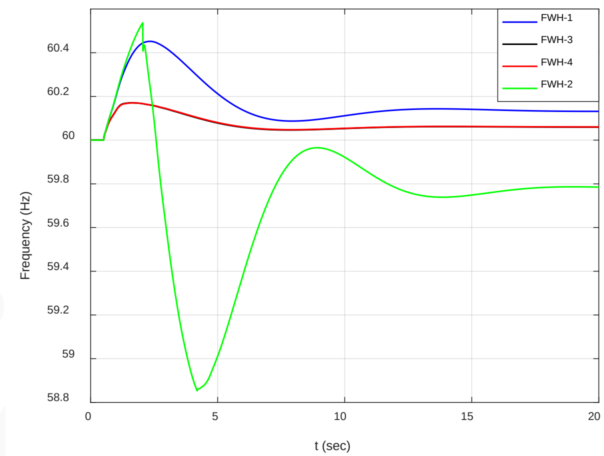
Technical finding:

- As inverter-coupled generation displaces synchronous generation, **generator inertia must be replaced with other *very fast* frequency support services**
- Exact response time 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.

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

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Accomplishments to Date

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Publications:

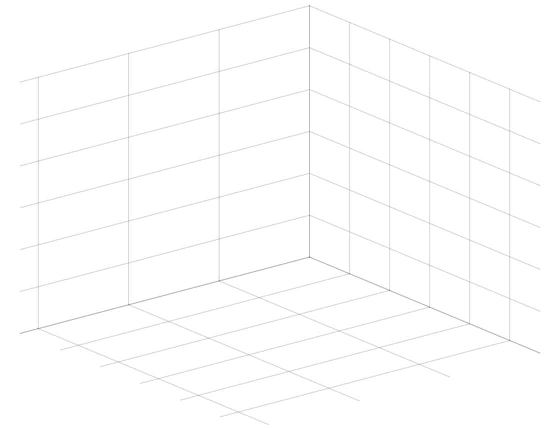
[1] A. Hoke, M. Shirazi, S. Chakraborty, E. Muljadi, D. Maksimovic, "Rapid Active Power Control of Photovoltaic Systems for Grid Frequency Support," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 2017

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

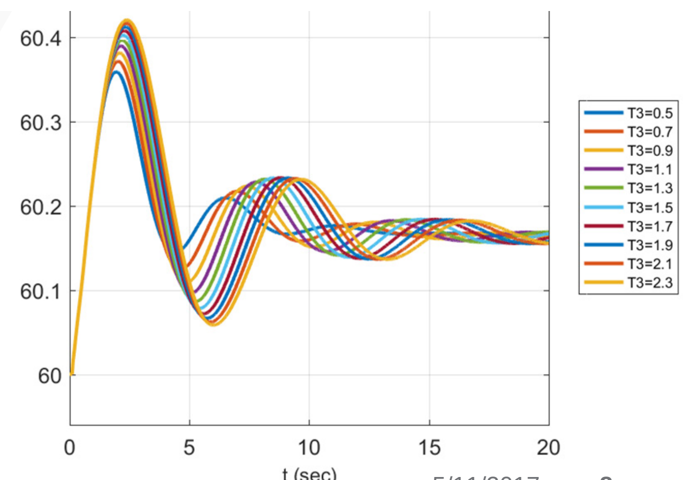
[2] M. Elkhatib, J. Neely, J. Johnson, "Evaluation of Fast-Frequency Support Functions in High Penetration Isolated Power Systems," *IEEE Photovoltaics Specialists Conference*, 2017

- Comparison of PV droop parameters using PSS/E model of future Oahu power system
- User-defined model of frequency-responsive PV

3-D lookup table for rapid APC of PV [1]



Comparing PV APC response time [2]



Recommendation	Response
The ability of PV systems to "ramp up" in response to a contingency needs to be investigated as part of this project and should not be a "long-term goal."	Agreed – that has always been the plan. To clarify, *full-scale implementation* of upward response from PV is a possible long-term goal, but *experiments and simulations* of that are core tasks of this project. See publication [1] on previous page, as well as technical detail slides.
This should also include understanding the implications between the distribution and transmission systems.	Agreed. The PHIL simulation platform is specifically designed to validate the ability of real hardware inverters to respond to frequency events in an environment that emulates distribution and transmission system dynamics

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Project Integration and Collaboration

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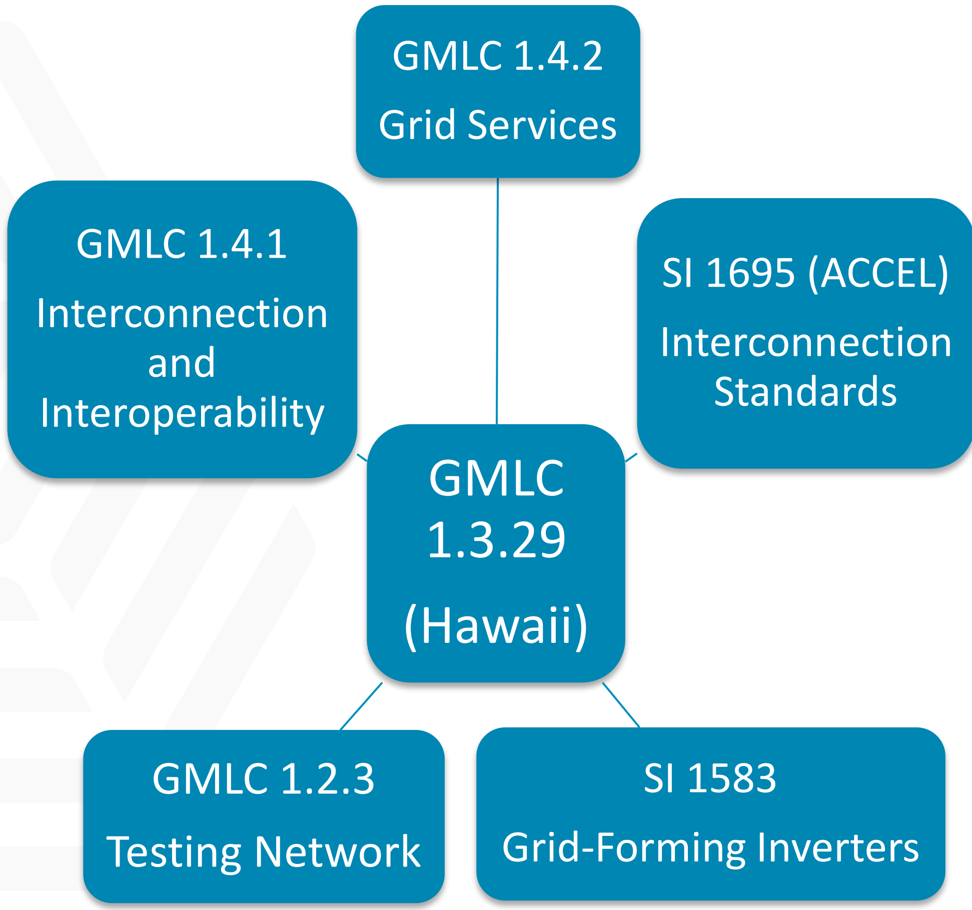
- Members of the project team are coordinating with IEEE 1547's work through ACCEL to standardize DER-based grid support functions.
- Because this project aims to develop a new grid service, it requires coordination with GMLC 1.4.2 (Definitions, Standards, and Test Procedures for Grid Services), GMLC 1.4.1 (Interconnection and Interoperability), and GMLC 1.2.3 (Testing Network). Standards gaps identified will be conveyed to 1.4.1.
- Like this project, SuNLaMP project 1583 on Grid-Forming Distributed Inverter Controllers seeks to address the stability of low inertia grids. We are meeting periodically with Brian Johnson to coordinate and seek synergies.



Communications

- Presented at HECO Technical Conference. Attendees included Hawaii PUC, parties to the PUC's DER Docket, Hawaii Smart Inverter Technical Working Group, California IOUs, etc. – October 2016
- ISGT Panel Session – April 2017

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Next Steps and Future Plans

Future activities and impacts:

- PSS/E investigations:
  - Effect of DER inverter response to transmission faults on frequency stability
  - Grid-forming inverter controls simulation
- Completion of PHIL tests of fast PV and storage-based frequency support (both up and down)
- Parametric comparison of DER-based frequency support using governor-only Oahu model
- *Course correction:* One manufacturer dropped most project support to focus on near-term financial goals. Incorporating new PV and storage inverters as replacements.
- Final report – September 2017
  - Summary of project findings, including limitations
  - Recommendations to HECO

Possible additions and expansions:

- Holistic study of fast frequency support including: loads (DR), EVs, bulk storage and renewables, and conventional generation in addition to DERs.
- Monitoring/visibility of DER reserve capacities for planning and operations
- Expanded investigation and development of DER controls for high-pen grids (e.g. low-SCR stability, DER fault responses)

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Conclusion

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Project summary

This project is developing and validating a new fast-responding DER service for stabilization of high-renewable grids through simulation, hardware testing, and field demonstration.

Impact highlights

- Draft IEEE 1547 revision incorporated recommendations from this project
- Developing custom PHIL platform for combined T&D simulation
- HECO intends to modify grid operations based on the findings of this work
- Relevant in Hawaii now, and on mainland U.S. in years to come

Thank you!

Questions welcome

Technical backup slides follow

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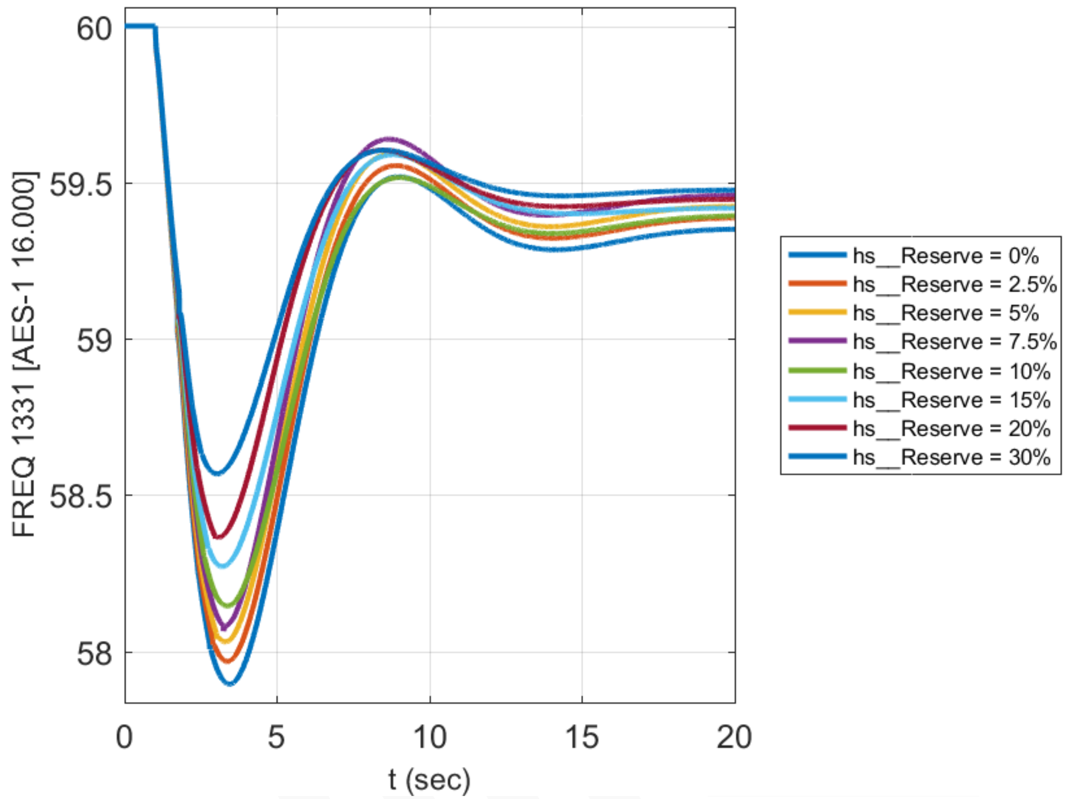
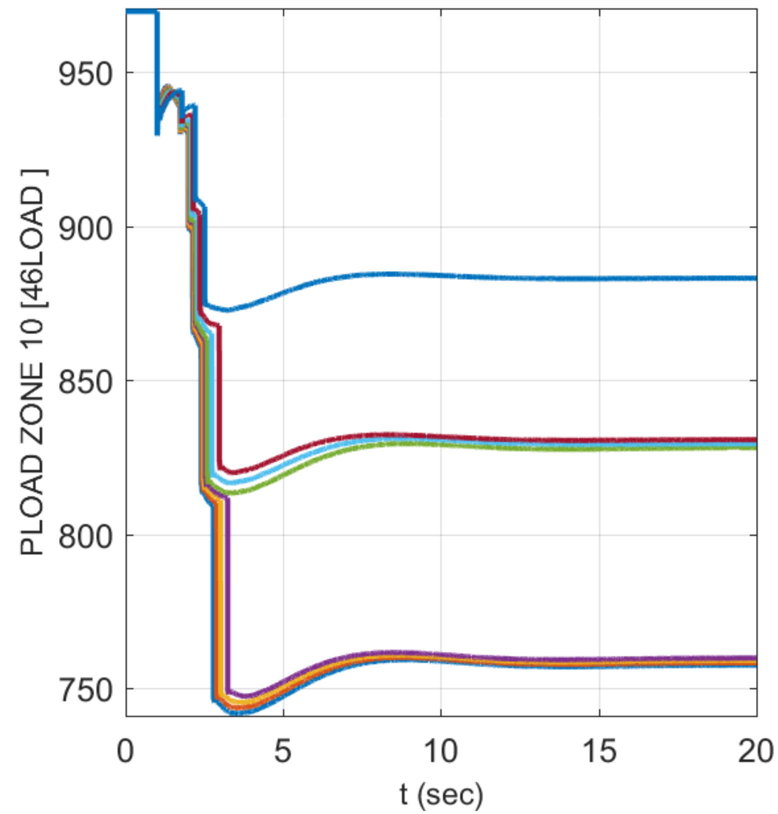
Underfrequency Event with Varying PV Reserve

PV-based up-regulation during loss-of-generation contingency: Comparison of amount of Type 3 PV held in reserve. At least 10% reserve is needed to impact load shedding





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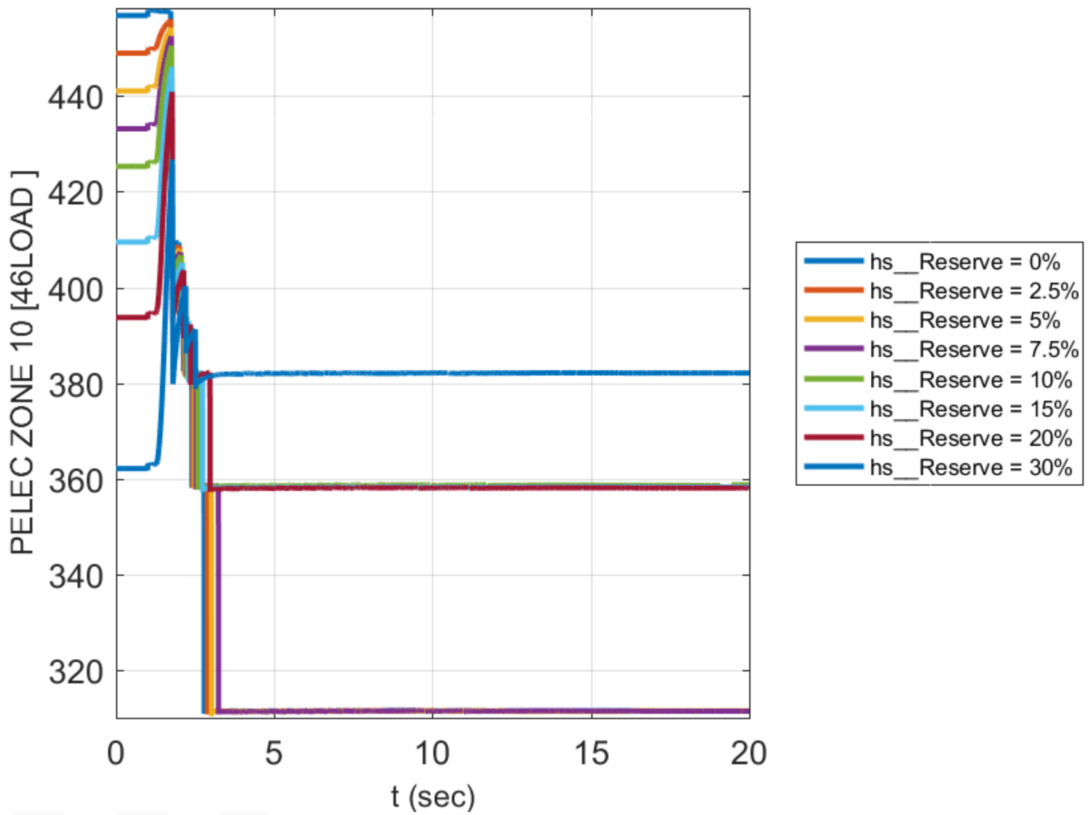
Underfrequency Event with Varying PV Reserve

PV power during event on previous slide.

Note that current load shedding scheme largely counteracts PV response by shedding PV!



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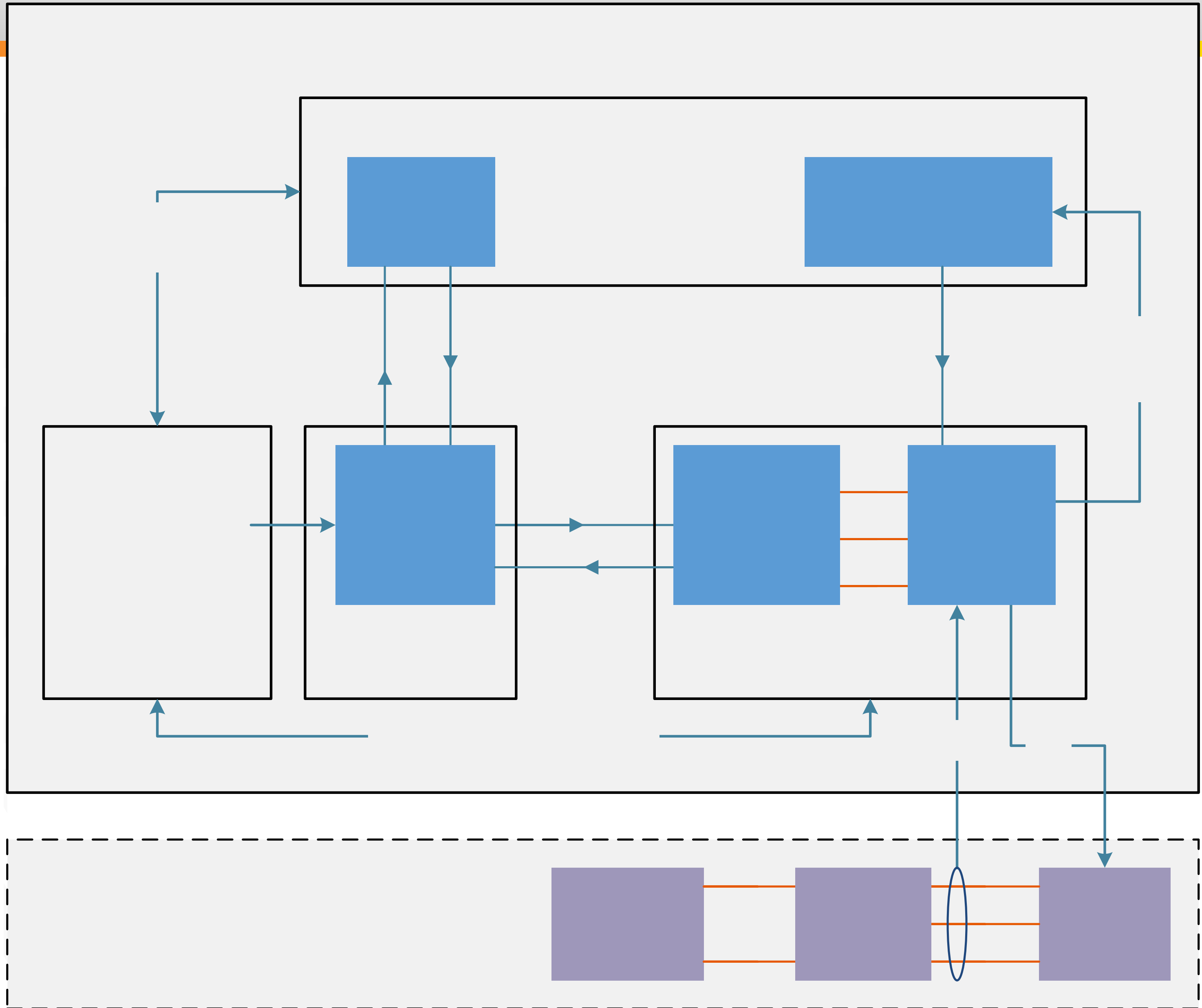
PHIL Model Overview

- Real-time Oahu frequency dynamic model simulates contingency events
- Frequency dynamic model drives frequency of voltage waveforms in distribution system simulation
- Hardware inverter is 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



PHIL validation of PV-based frequency support.