Power HIL evaluation of inverter controls for 100% inverter-based bulk power systems

A power electronics grid integration case study

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Power Electronic Grid Interface (PEGI) Platform Workshop

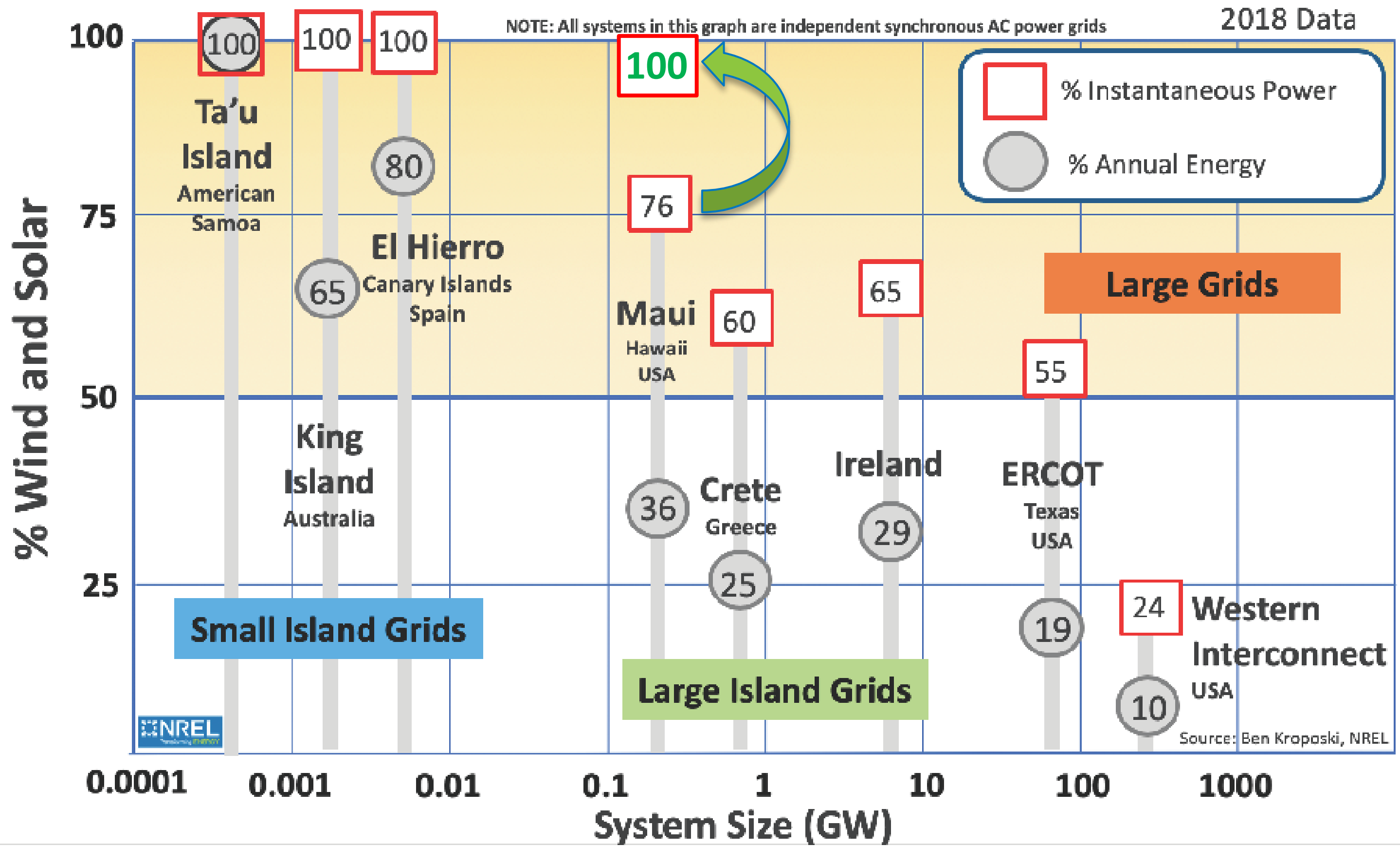
October 13, 2020

Motivation

- As PV and wind generation reaches roughly 1/3 to 2/3 of annual energy production, peak instantaneous IBR generation can reach 80-100% of load
    - Inverter-based resource (IBR) = PV, wind, BESS, etc
- At these very high instantaneous levels of inverter-based generation, the dominant physics of grid operations change
    - “Very high” ≈ instantaneous IBR generation is 80-100% of load
- At very high IBR levels, **synchronous inertia and generator magnetic flux** that stabilize grid frequency and voltage **need to be supplemented/replaced with well-designed power electronic inverter controls**
- Similar inverter controls are widely used for small islands and off-grid microgrids*, but RD&D is needed to adapt them for larger systems
    - “Larger systems” = systems large enough to have a transmission system
- The PEGI platform is designed to test such controls in scenarios that mimic real grid dynamics

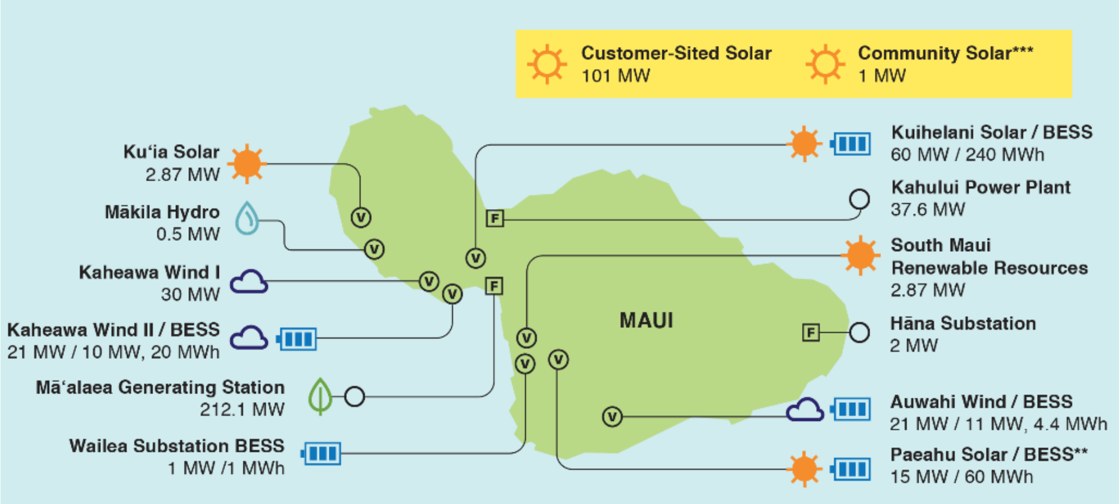
*Plenty of room for improvement in microgrid island transitions and co-operation with larger power system.

Wind and Solar in Synchronous AC Power Systems as a Percentage of Instantaneous Power and Annual Energy



Background

- Hawaiian Electric expects Maui to be the first large island to operate with 100% inverter-based resources
  - 2018 peak: ~80% IBR
- 100% IBR expected to occur for certain hours by 2023
- Maui would be the first interconnected power system of its size (200 MW peak) with highly distributed utility-scale generation and 69 kV voltage levels to reach this milestone
- Grid-forming controls required for Stage 2 PV-BESS plants (~2023 interconnection)
- Technical hurdles need to be overcome to ensure grid stability on the shortest time scales
- Currently performing EMT study (PSCAD)
- Next step: Power HIL at Flatirons

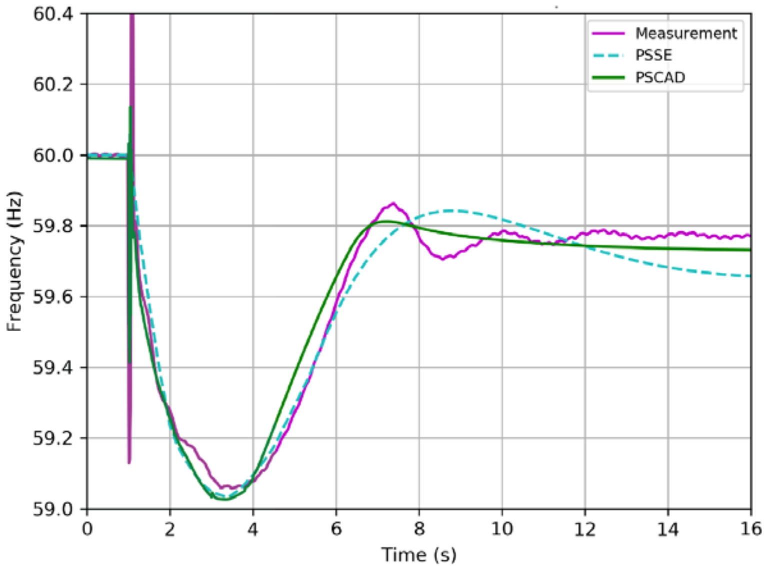


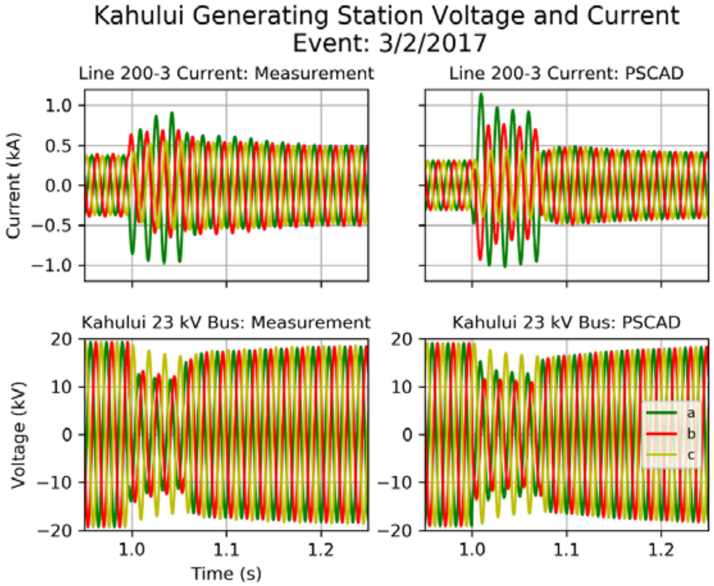
Maui PSCAD study

- Developed EMT (PSCAD) model of Maui, parallelized on 28 cores*
- Validated against HECO field event data and PSSE model [1]
- Simulating faults, contingencies under various grid and IBR configurations

3/2/2017 Event:

Line-ground fault induces generation trip





*Thank you to Electranix for providing E-TRAN Plus

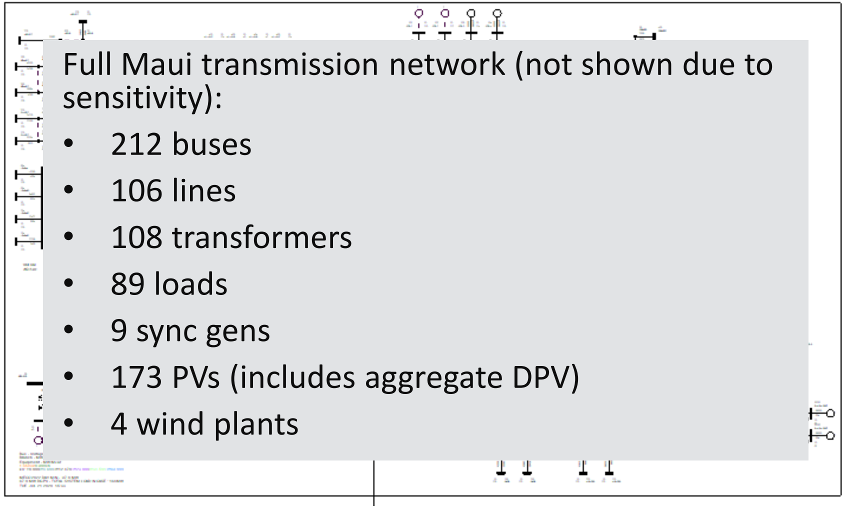
[1] R. W. Kenyon, B. Wang, A. Hoke, J. Tan, B. Hodge, “Validation of Maui PSCAD Model: Motivation, Methodology, and Lessons Learned,” IEEE NAPS, April 2021.

Why power HIL?

- When models of hardware devices (e.g. inverters, controllers) are not available or not validated, HIL testing can be used to link the physical device to a real-time simulation of the rest of the system
- Advantages
    - Provides additional confidence in hardware performance
    - Can be used to validate models
    - Particularly valuable to *de-risk field deployments of new technologies*
- Disadvantages
    - May require model reduction for real-time simulation
    - Can introduce additional dynamics, especially on very short time-scales
    - Requires specialized hardware and software

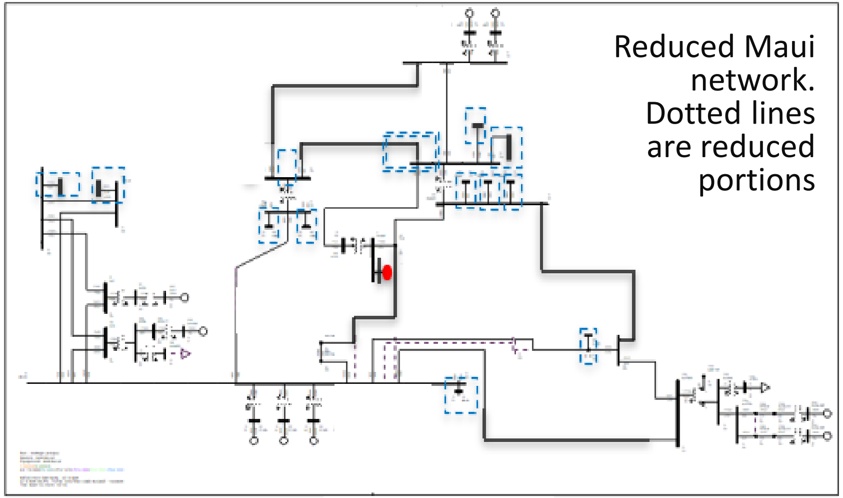
Maui PHIL study

- Maui project will use MW-scale power HIL to confirm findings of EMT study
- Connect MW-scale PV/BESS inverters at Flatirons campus to real-time simulation of Maui network
    - Include scaled replica of one of the actual hybrid power plants to be constructed on Maui
    - Test contingency events, faults
- Maui dynamic model converted to RSCAD
    - Reduced transmission network model using single-port and two-port equivalent networks:



Full Maui transmission network (not shown due to sensitivity):

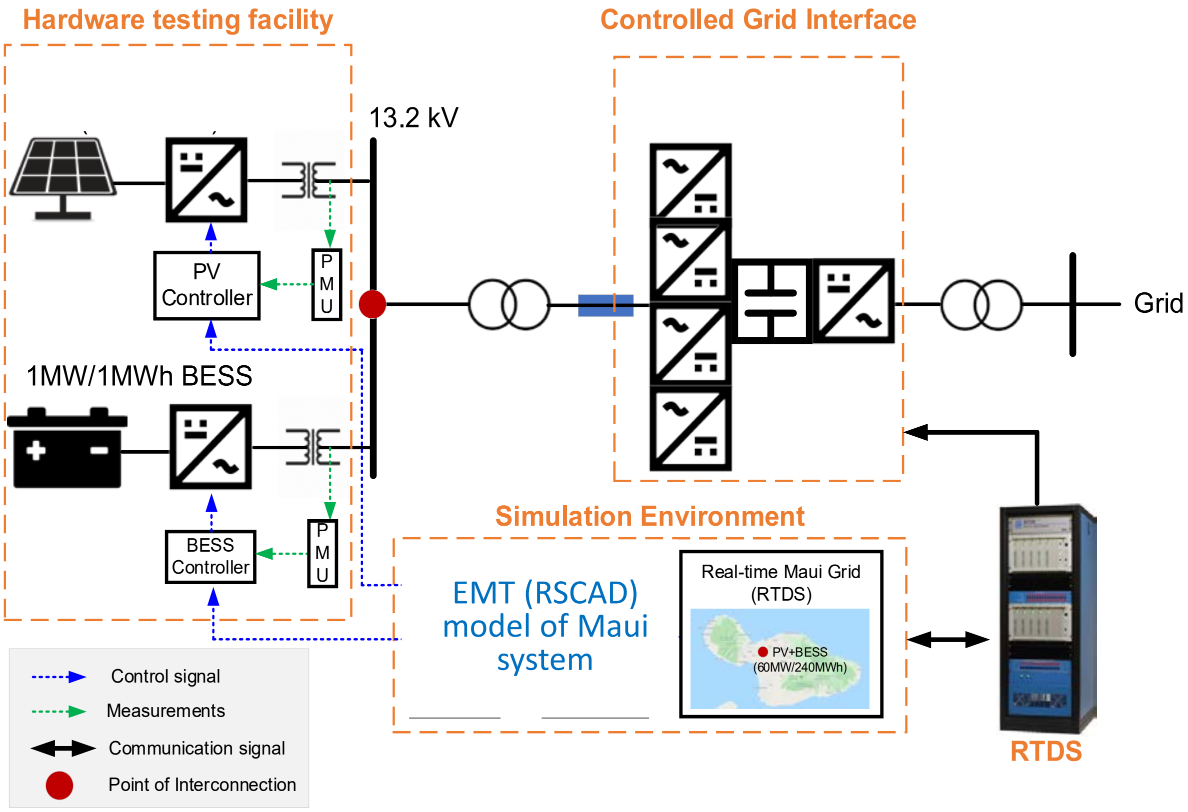
- 212 buses
- 106 lines
- 108 transformers
- 89 loads
- 9 sync gens
- 173 PVs (includes aggregate DPV)
- 4 wind plants



Reduced Maui network. Dotted lines are reduced portions

Maui PHIL study

Scaled down hardware PV and storage plants, including grid-forming and grid-following inverters



Questions we hope to answer

- Can an inertialess or very low inertia system offer the same system stability as the present system (or better)?
- How should inverters be controlled?
    - Fast droop controls? Other forms of fast frequency response?
    - Voltage and reactive power control?
    - Grid-forming mode (i.e. fast voltage control without PLL?)
    - Do these answers depend on system inertia or other factors?
- How will behind-the-meter generation interact with IBR controls?
    - Rooftop PV can be >70% of instantaneous generation on Maui
    - Behind-the-meter hydro may be online or off at any time
- Are additional technologies needed? Synchronous condensers?
- What constraints should be placed on IBR controls to ensure they are stable, both with and without other generation present in the system?
- Are current models sufficient to answer these questions?

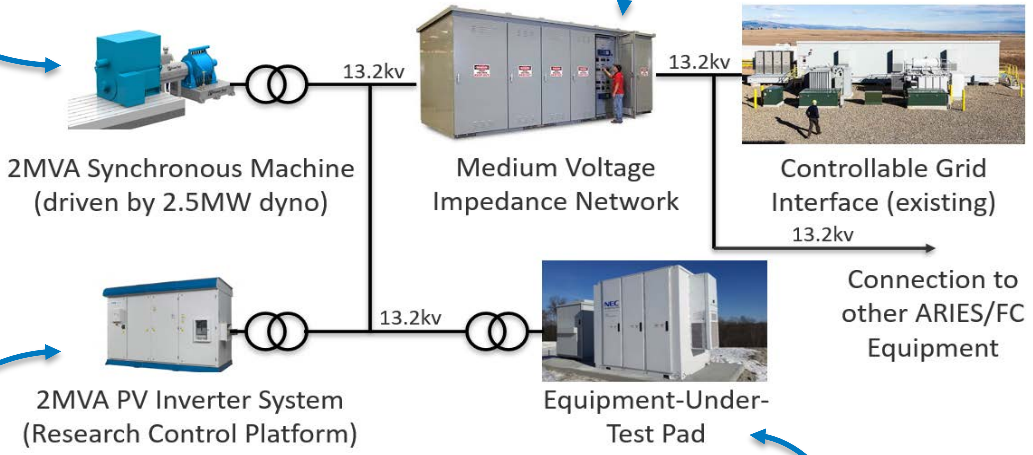
Beyond Maui PHIL study: What could PEGI do?

Test fault responses with physical impedance (no computational delay). How do inverters behave? How do protection devices behave?

Test inverter interactions with hardware synchronous generator / condenser.

E.g. can a 100% IBR system be stable with only *grid-following* inverters (performing FFR and voltage regulation) and *synchronous condensers*? [2]

PEGI Platform Schematic



Test interactions between multiple IBRs connected at different points in the same real-time model (multi-PCC PHIL)

Test prototype inverter controls

(FFR, GFM, etc)

Test interactions between various inverters (both prototypes and off-the-shelf inverters

[2] R. Kenyon, A. Hoke, J. Tan, B. Hodge, "Grid-Following Inverters and Synchronous Condensers: A Grid-Forming Pair?," *2020 IEEE Clemson University Power System Conference*, March 2020

Challenges/ Opportunities

- Like a computer simulation, a power HIL test is only as good as the real time model
- PEGI/ARIES provide greater flexibility in linking MW-scale power to real-time models
- Real-time models (both of grid and of connected devices) should be validated. For PEGI applications, this will typically mean EMT models
- Path to confidently operating grids with 80-100% IBRs includes four key components (hopefully disseminated as widely as possible)
    - Technology development and maturation
    - EMT simulations of key scenarios
    - Selective use of power HIL to confirm performance and stability
    - Field deployments

Questions?

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NREL/PR-5D00-78605

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided in part 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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