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Advanced Power-Hardware-in-the-Loop Evaluation of Inverter-based Resources (IBRs)

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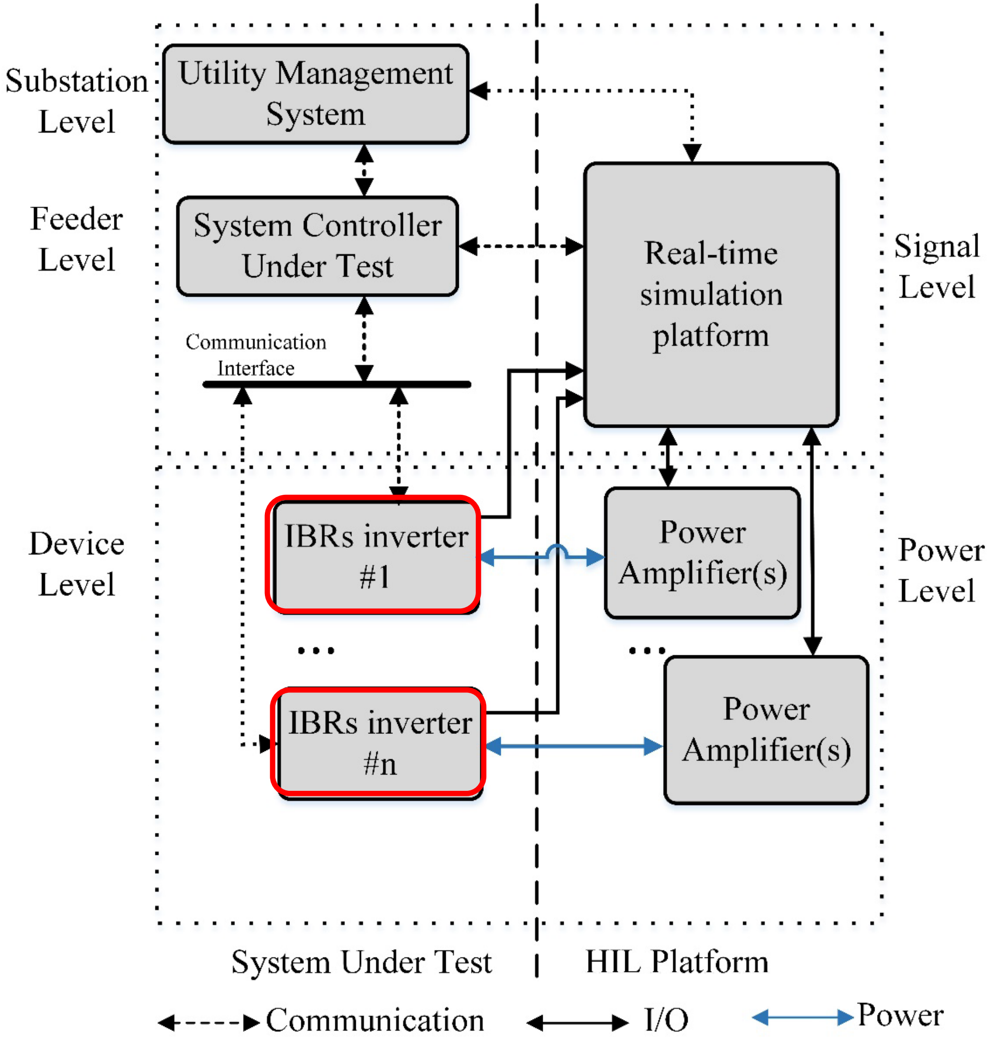
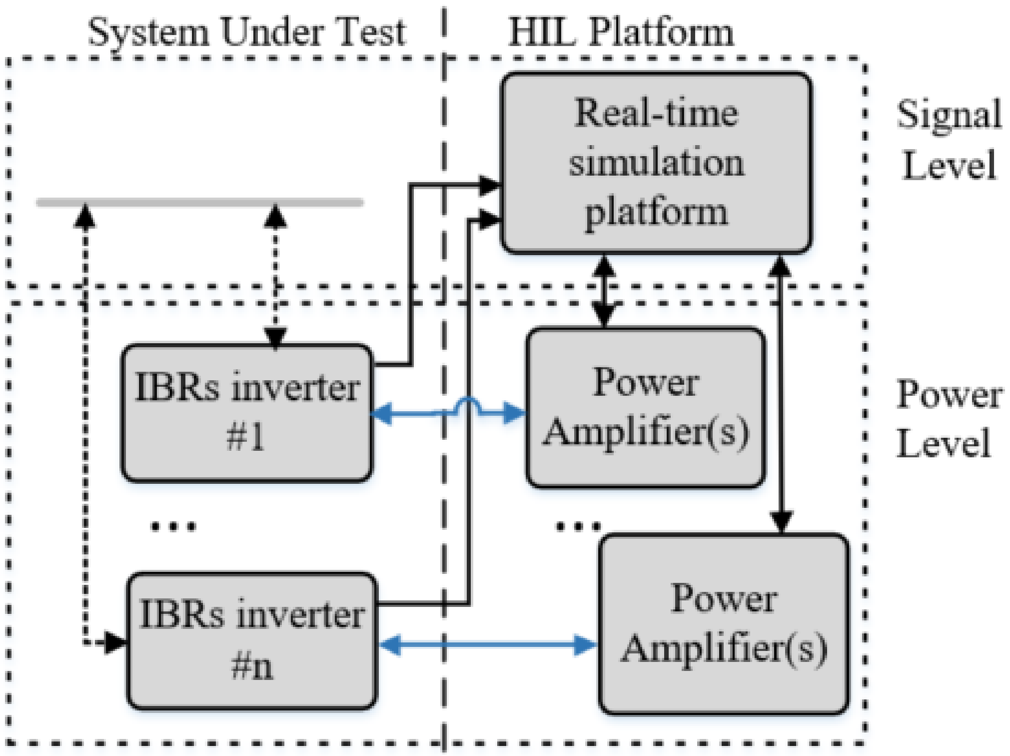
Background

- Power-hardware-in-the-loop (PHIL) evaluation of IBRs has become more and more important as it provides reliable testing results.
- A successful lab PHIL testing gives confidence of hardware system to be deployed and de-risk technology integration prior to field deployment
- A general HIL platform for system evaluation



Requirements and Applications

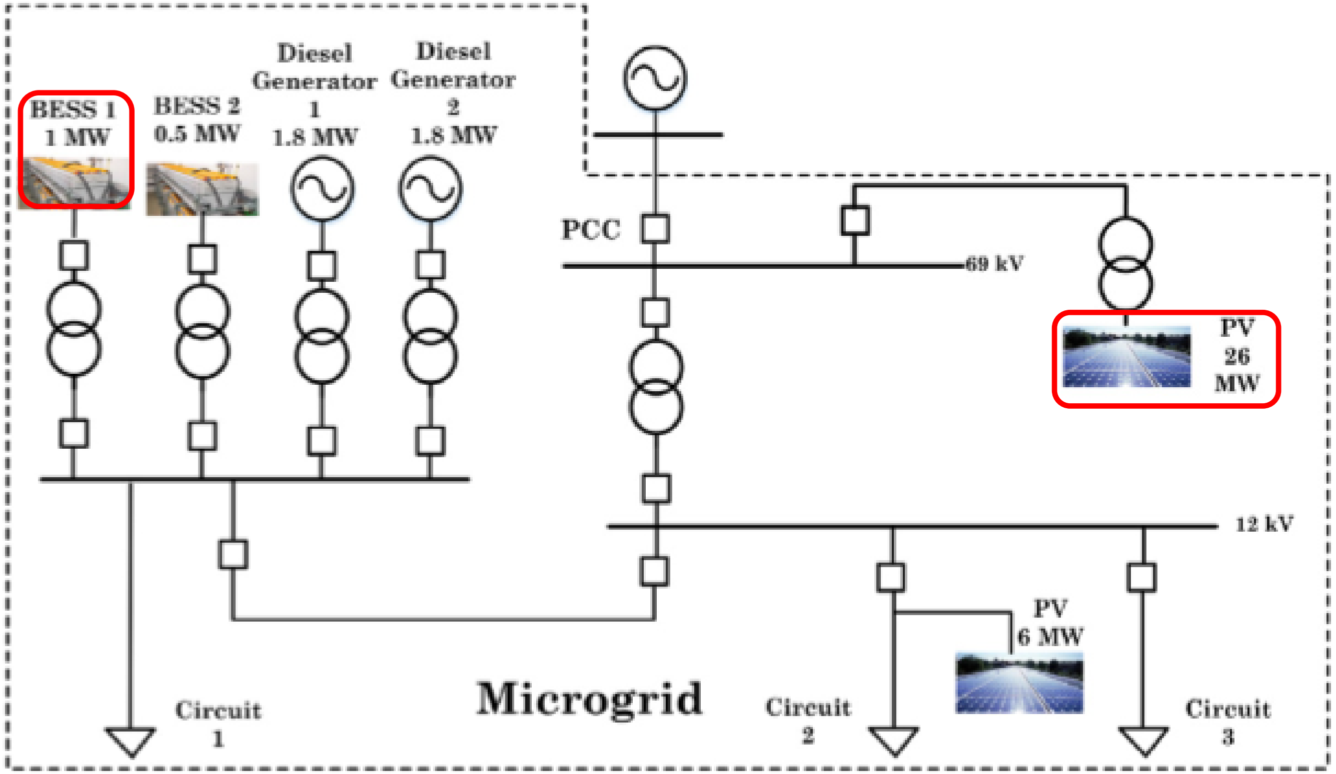
- Dynamic/electro-magnetic transient
  - Study stability of IBRs, transient dynamics, inverter spontaneous responses
  - Replicate the actual current and voltage dynamics in the inverter
  - Large utility IBRs, feedback current



- Phasor domain
  - Study collective grid services provided by IBRs (e.g., voltage regulation)
  - Multiple inverters and PCCs, compromise between stability and accuracy
    - Behind-the-meter IBRs, feedback power

Example I: Evaluate dynamic transients of IBRs

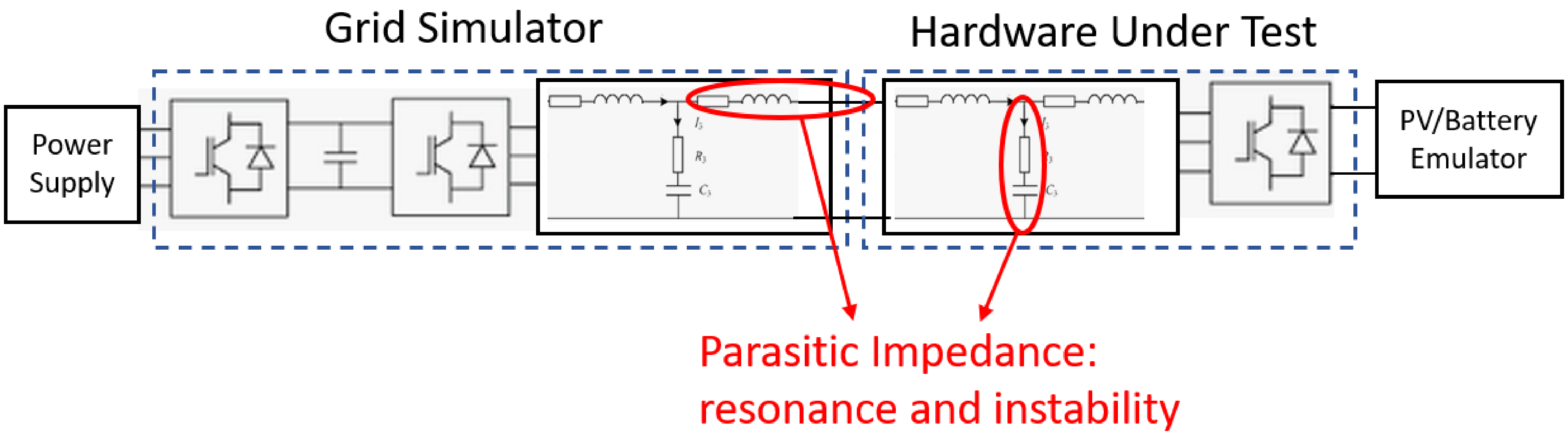
- **Objective**: demonstrate whether a microgrid system, including a specific commercial microgrid controller, is able to meet the functional requirements for Borrego Springs Microgrid.
  - Disconnection
  - Resynchronization
  - Steady-state frequency and voltage in islanded mode
  - Dispatch
  - Enhanced resilience (e.g., fault)



Dynamic transients, need to feedback current

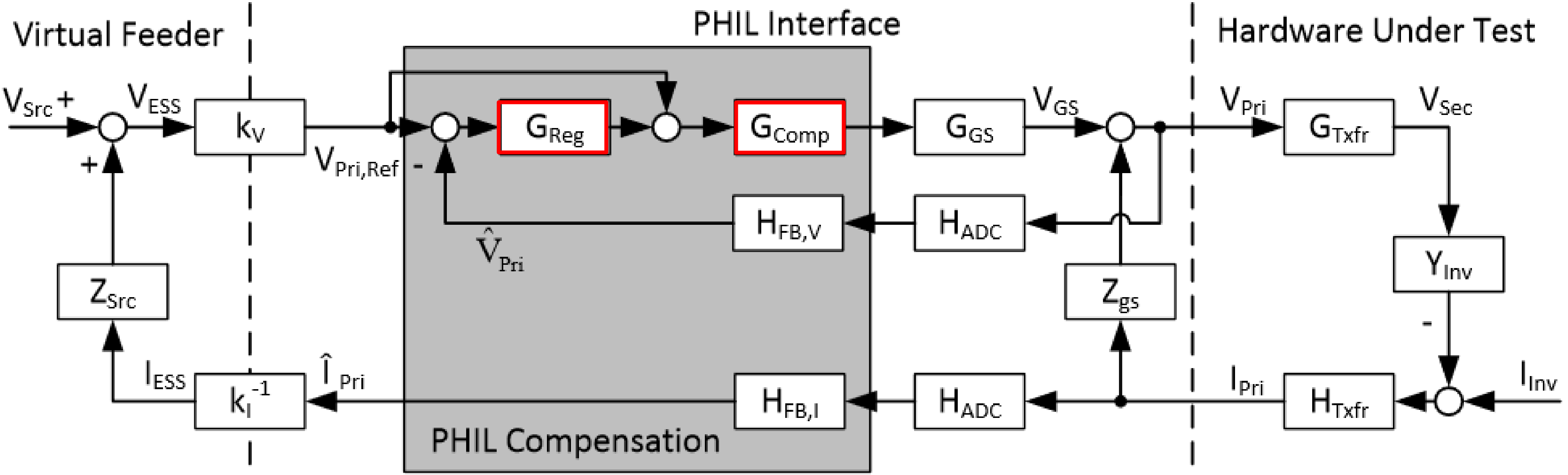
Stability issue of the PHIL interface

- Parasitic resonance that exists due to the interaction between the grid simulator inductance and the inverter filter capacitance.
  - Instability of PHIL current loop due to the resonance and the loop time delays
- Voltage difference between simulated voltage and reconstructed voltage
- Illusionary effect in P and Q due to time delays



Solution for the Stability Issue

- Address the challenges of distribution systems especially associated with high penetrations of distributed PV, such as voltage stability



G_{comp}: Notch filter; G_{Reg}: PR control

Figure from [1]

1. Answorth N, et al. Modeling and compensation design for a power hardware-in-the-loop simulation of an ac distribution system, In: North American Power Symposium (NAPS), Denver, CO, 2016, pp.1-6

Implementation of the PHIL interface

- Develop standard AFBs that can be used as an interface between PHIL simulation and hardware. AFBs can be reused and reconfigured for various applications.

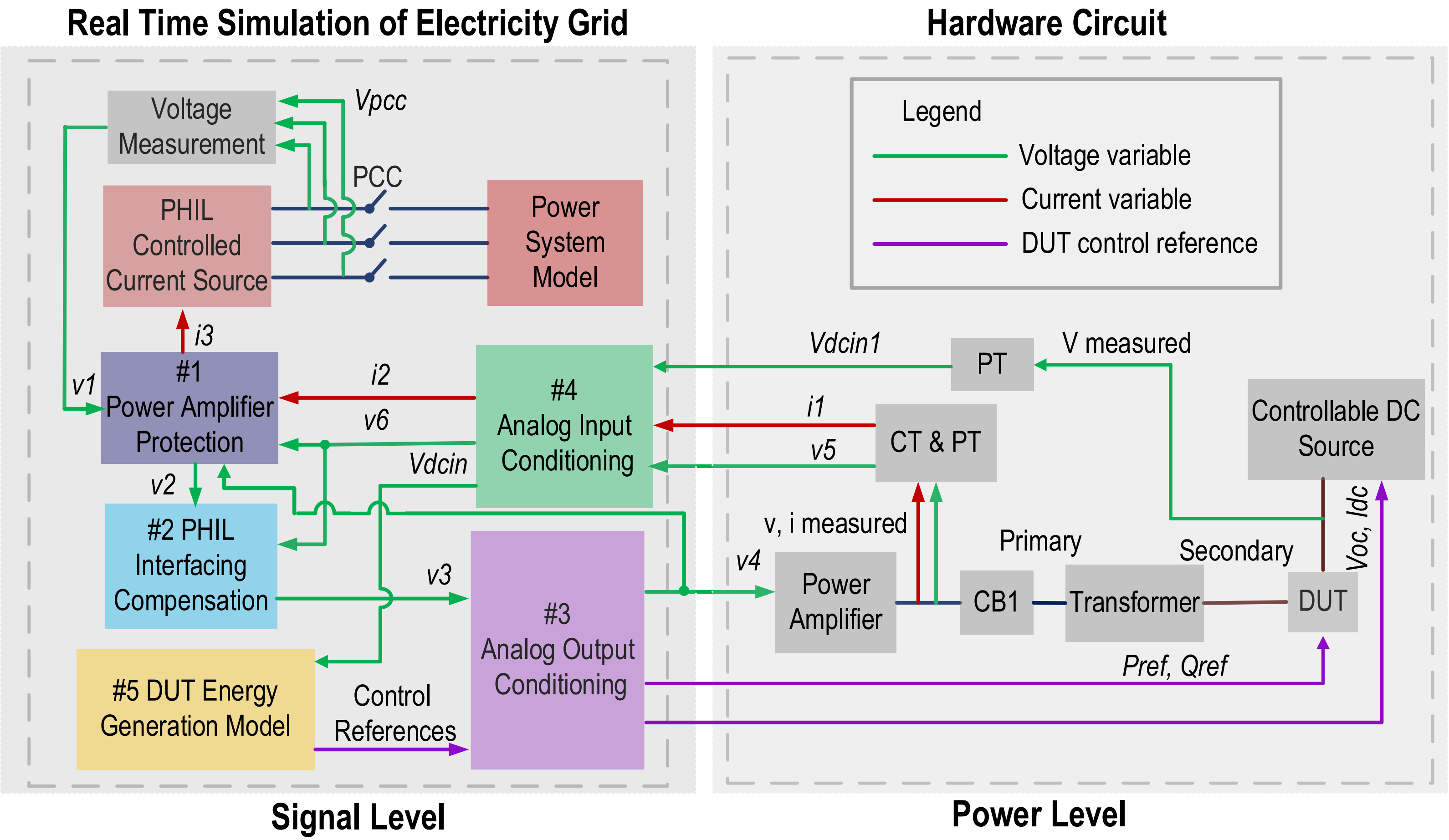
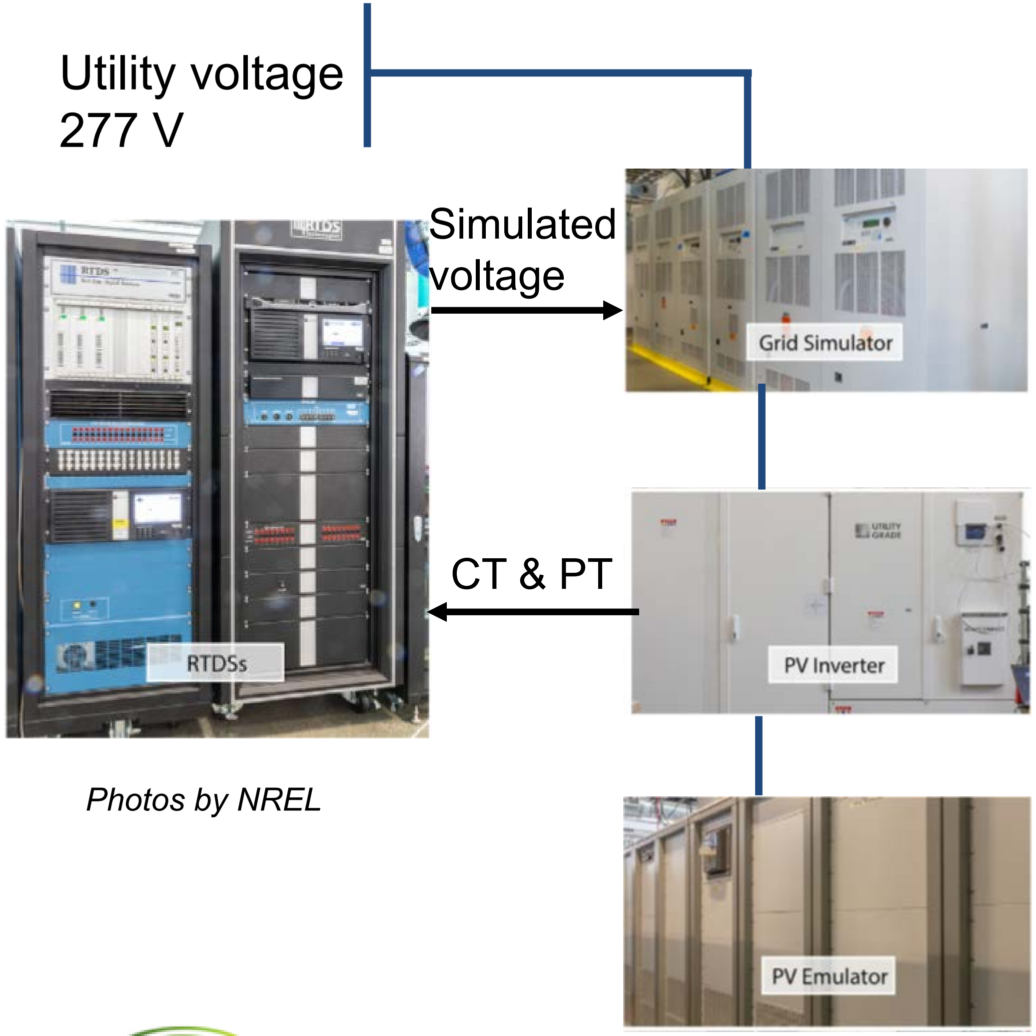


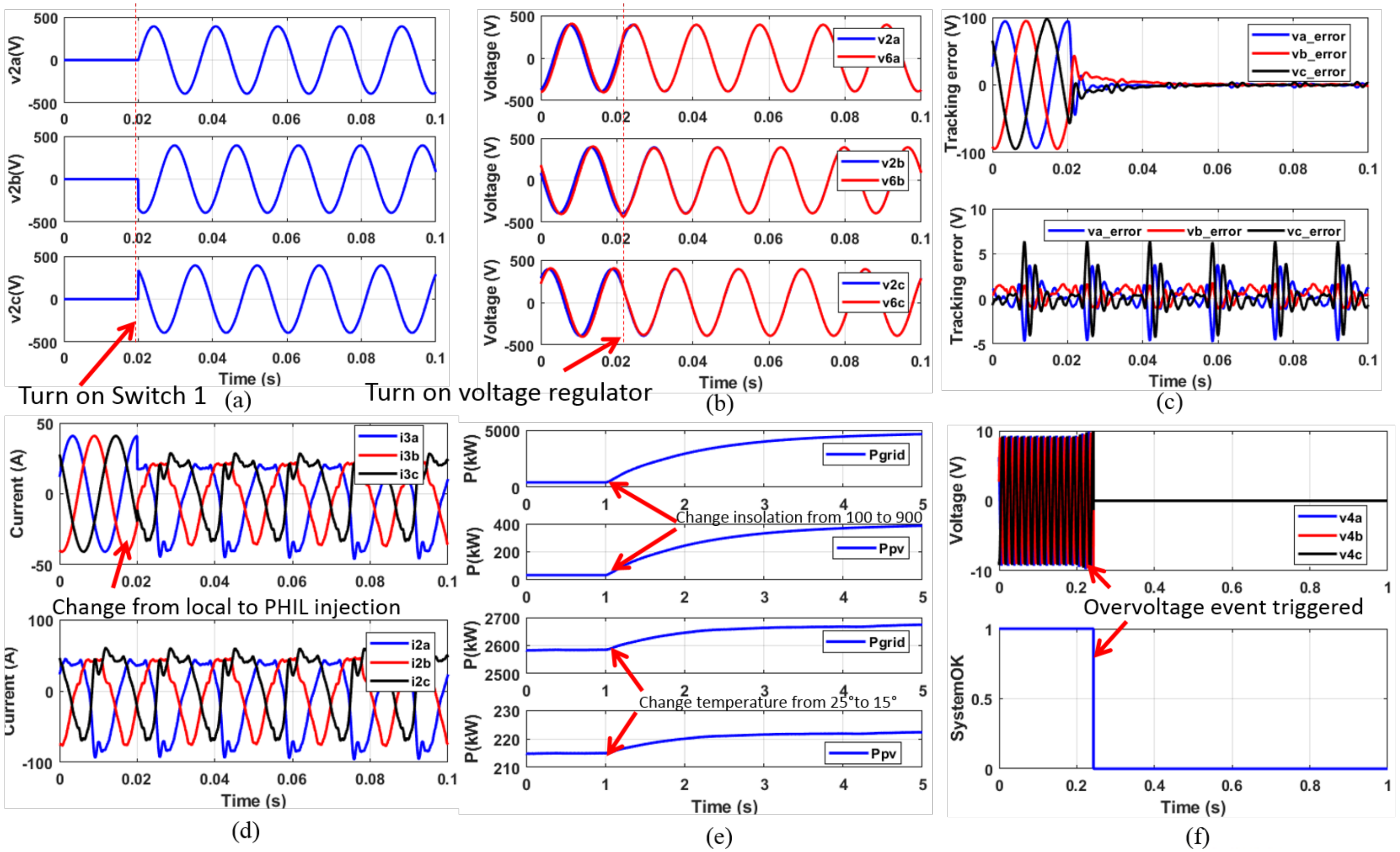
Figure from [2]

2. J. Wang, et al., “Development of Application Function Blocks for Power-Hardware-in-the-Loop Testing of Grid-Connected Inverters,” 2018 9th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Charlotte, NC, USA, 25-28 June 2018.

Experimental Results



Photos by NREL



Example II: Evaluate Grid Services Provided by IBRs

- **Objective**: evaluate the voltage regulation performance of Distributed Energy Resource Management Systems (DERMS) in a realistic lab environment.
- **Requirements**: large scale PHIL with multiple PCCs, and DERMS <u>interacts with hardware inverters with standard communication protocols</u>.

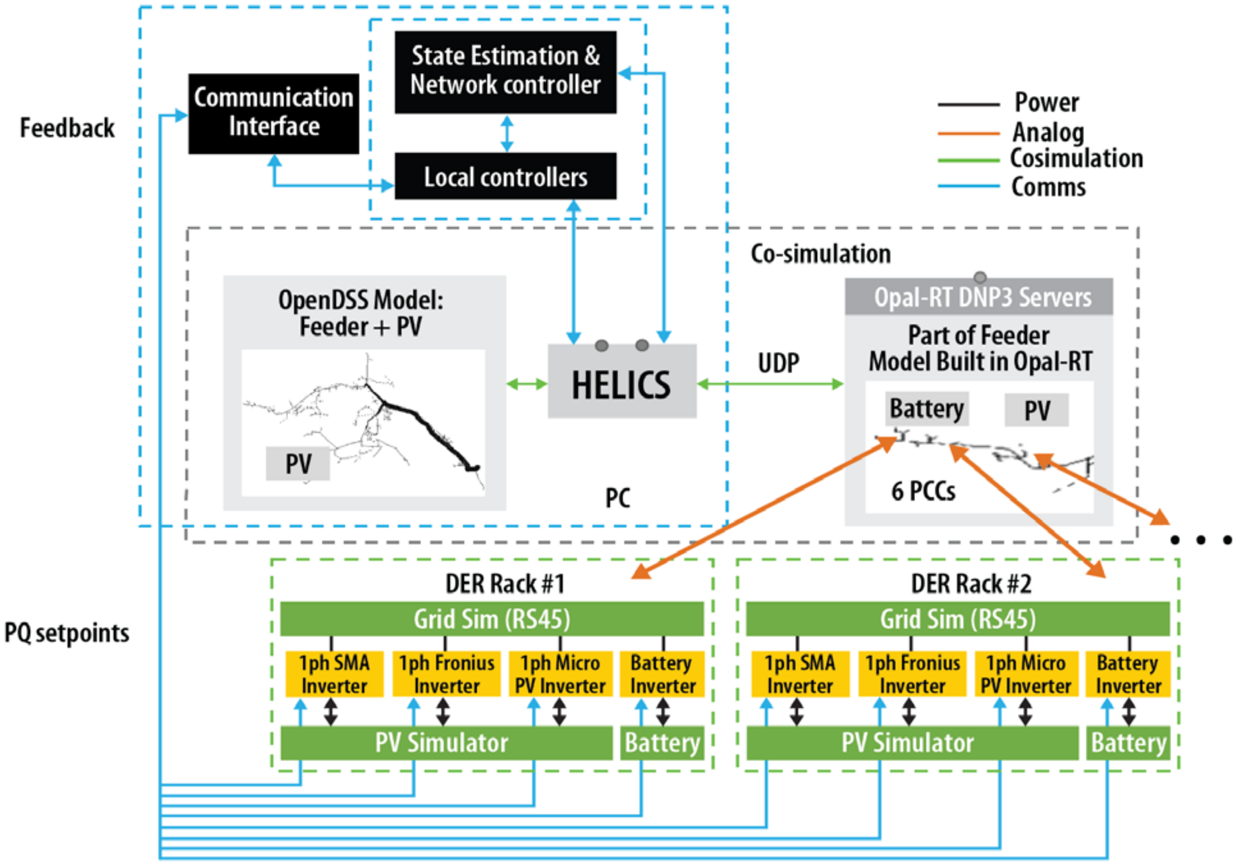
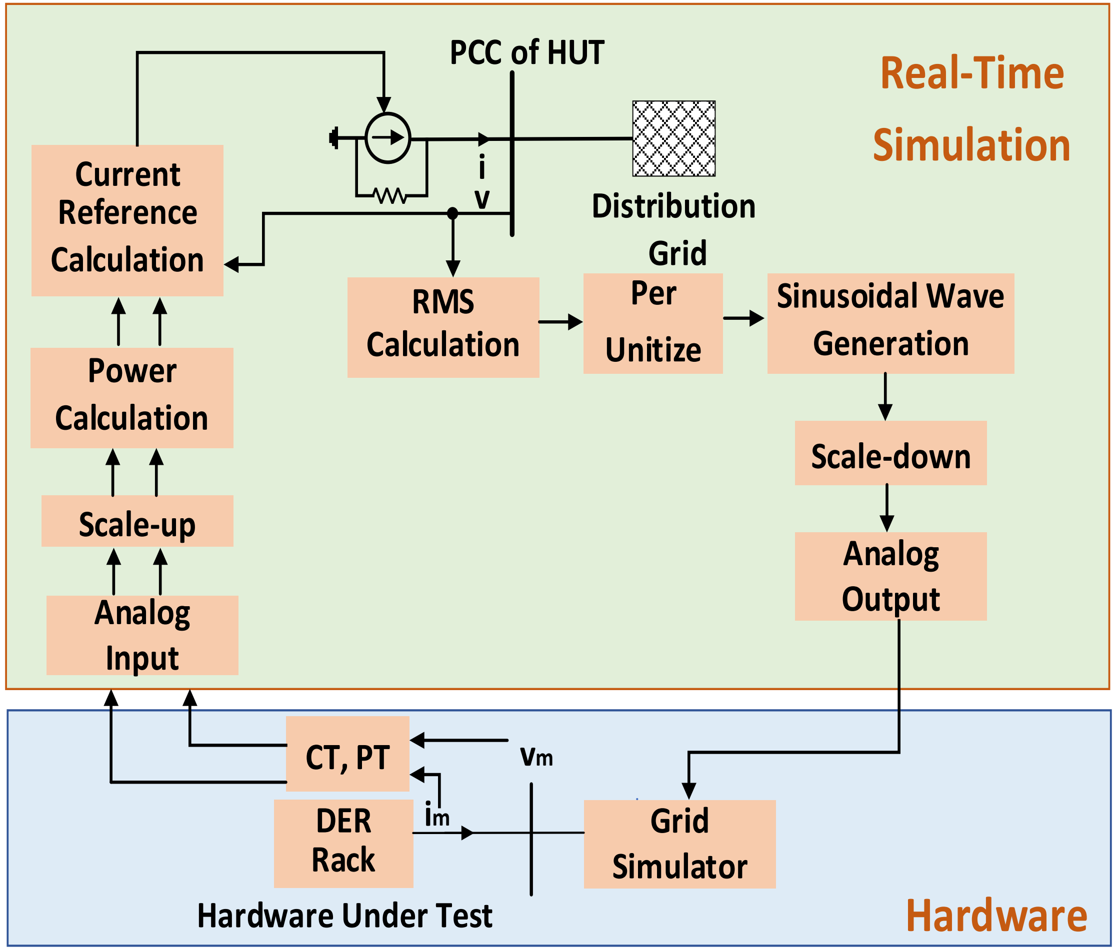


Figure from [3]

3. J. Wang, J. Huang and X. Zhou, “Performance Evaluation of Distributed Energy Resource Management Algorithm in Large Distribution Networks,” IEEE PES GM 2021.

Implementation of Multiple PCCs for PHIL

- **Approach**: decouple the dynamics and interactions between inverters under test.
  - Regenerate the simulated voltage
  - Use feedbacked power instead of current (power is the important variable for grid service rather than EMT transients)
- **Implementation**: standard Application Function Blocks (AFBs)
  - Only change voltage level
  - Reuse for other PCCs and different projects for similar purposes/applications.



Hardware Setup

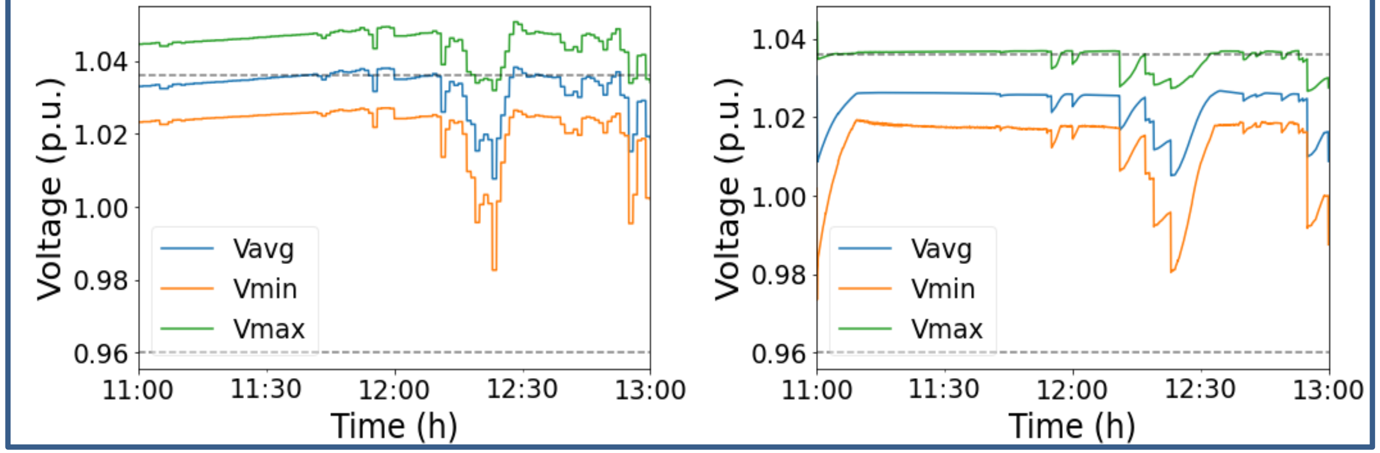
Photos by NREL

Experimental Results

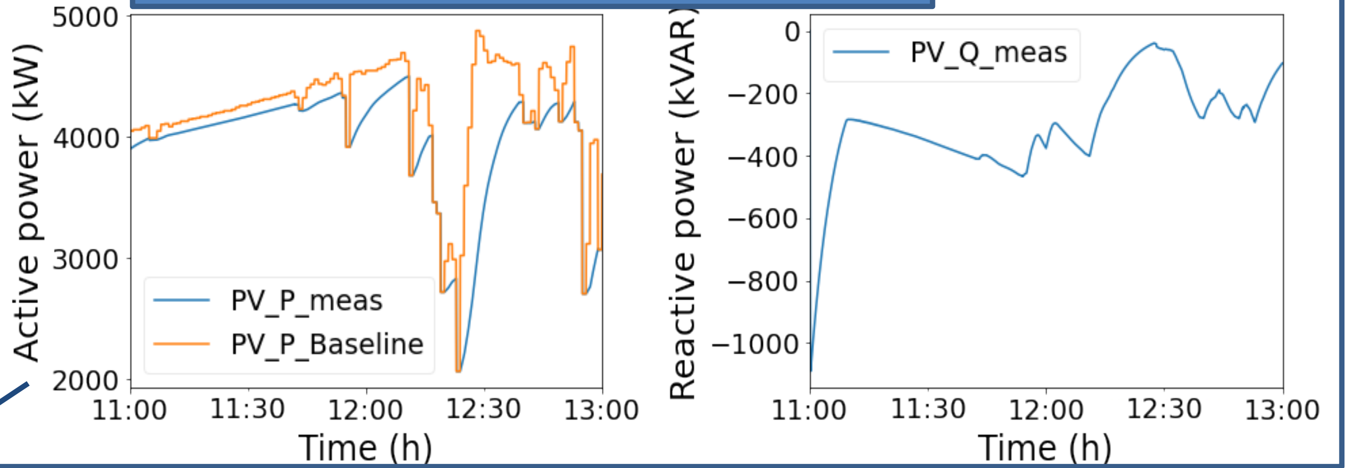
CHIL and PHIL testing

- Setup configuration
  - 11,000 node distribution feeder (IEEE 8,500 node test feeder and a modified EPRI Ctk7 test feeder)
  - 532 simulated PV in OpenDSS
  - 6 PCCs in OPAL-RT with PHIL testing of 6 DER Racks (90 DER hardware inverters)
  - 2-h from 11:00-13:00
  - Voltage regulation performance

Baseline and Controlled voltages



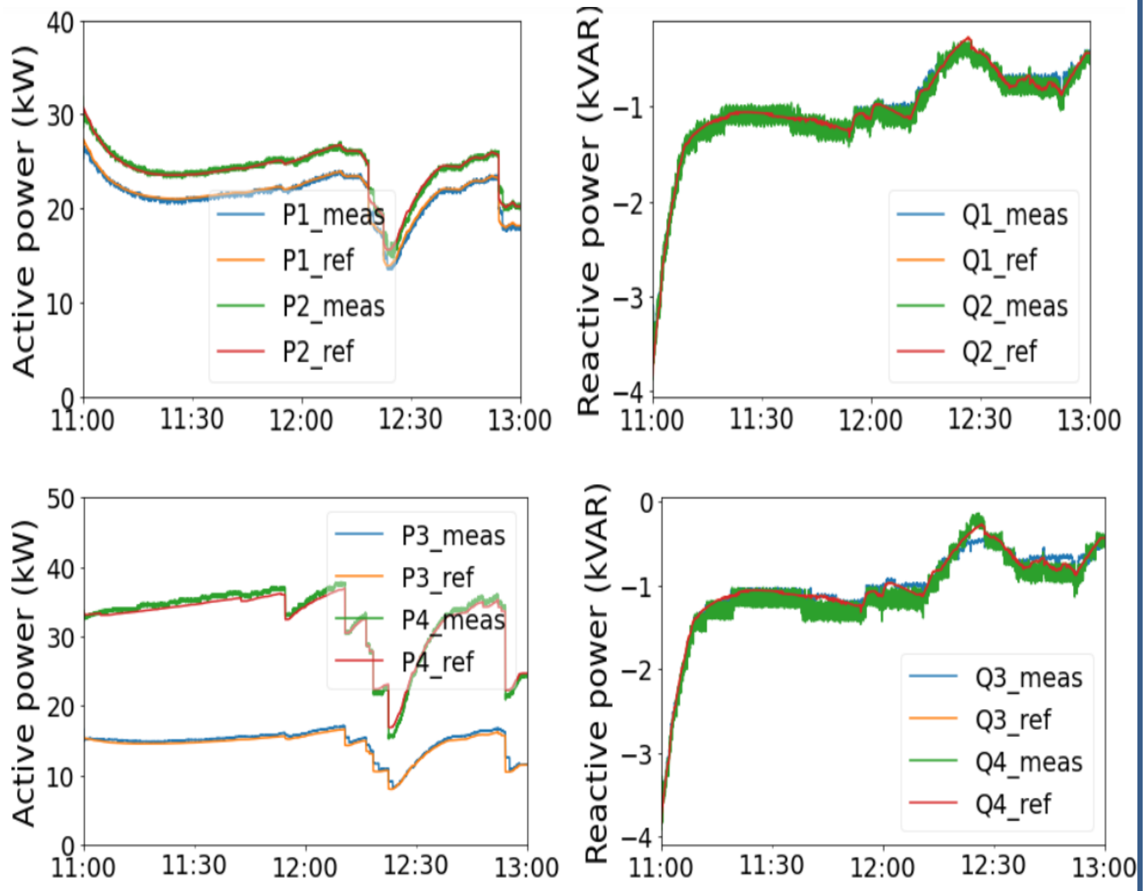
Total PV Active and Reactive Power



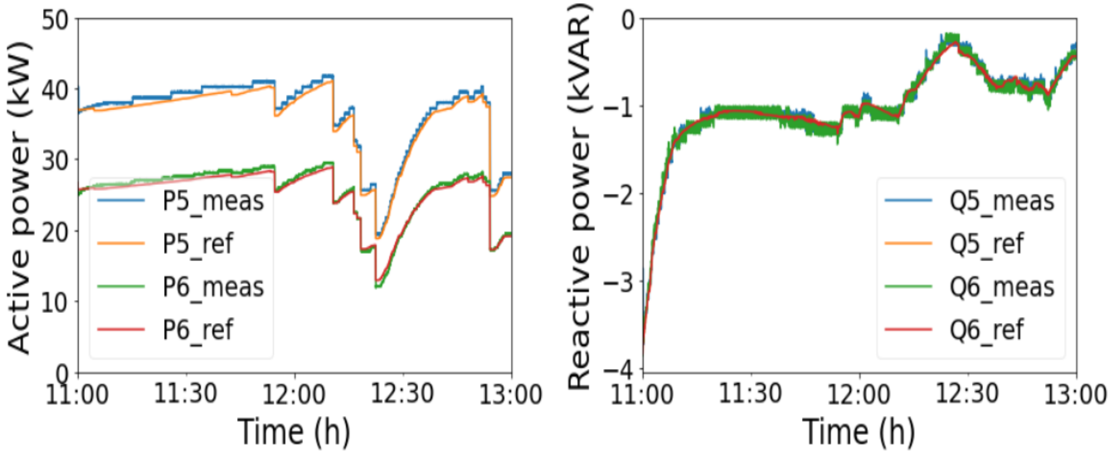
6.55% curtailment

Experimental Results

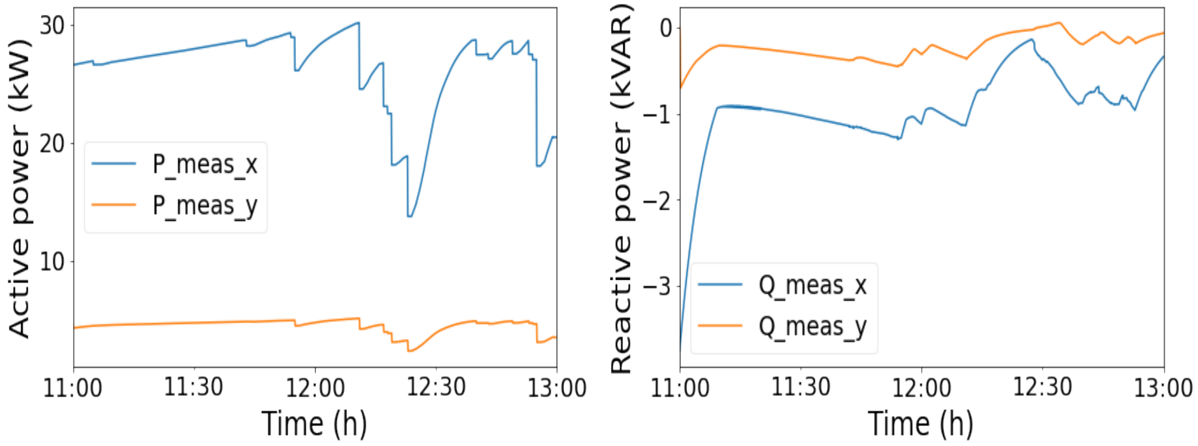
PHIL results: DER Rack #1-4



PHIL results: DER Rack #5-6



Results of two selected simulated PV



Thank You

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