Performance Evaluation of Distributed Energy Resource Management Systems using Software- and Hardware-in-the-Loop

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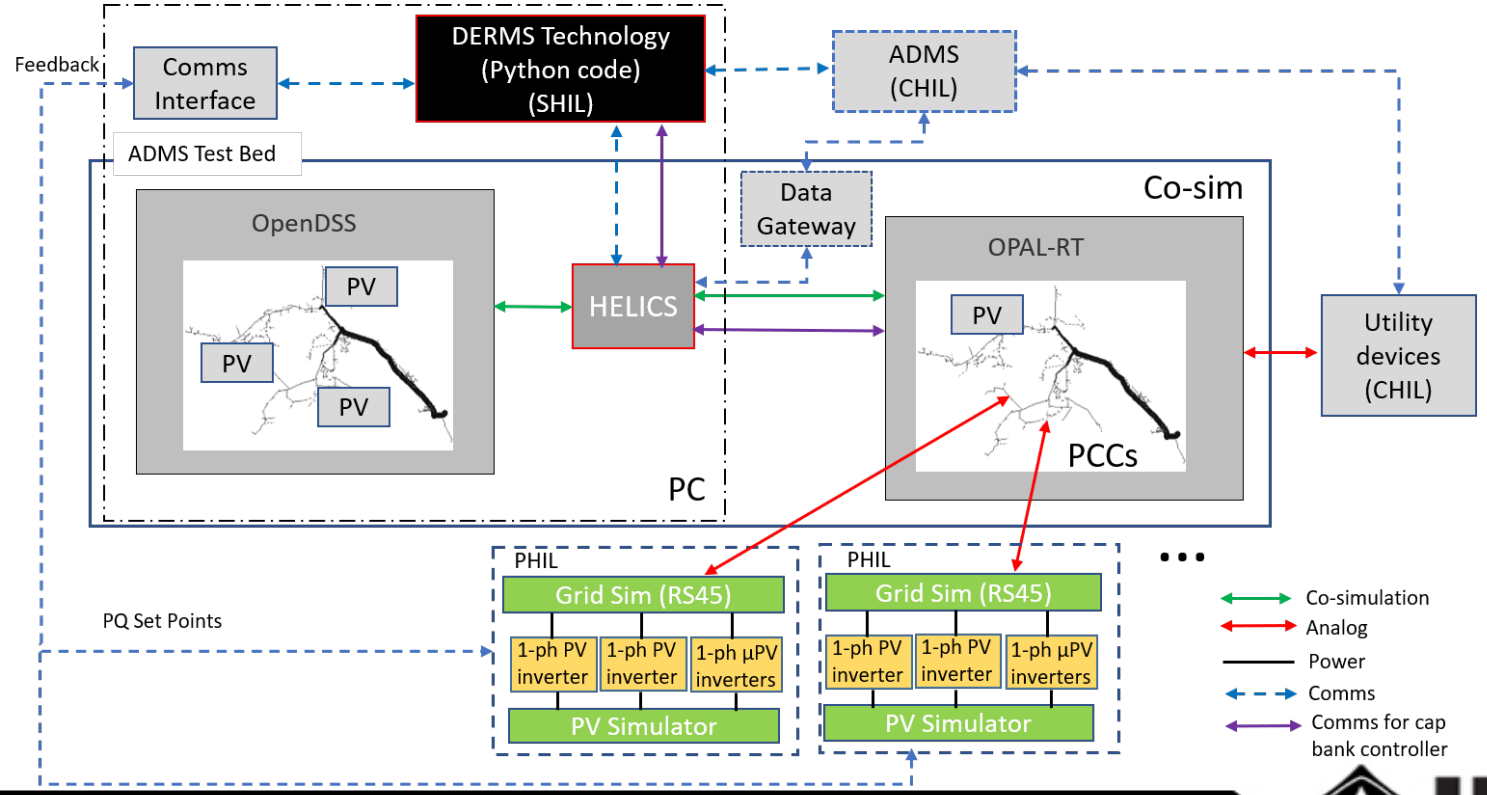
Background

- ***Challenges***: integrate distributed energy resources (DERs) like rooftop PV into the grid while balancing that generation with traditional utility generation.
- ***Needs***: develop software and hardware solutions for utility distribution system control and operations that integrate sensing, communication, and data analytics.
- ***Requirements***: field-tested by utilities to demonstrate their performance and value in real-world operating environments.

Need to test those solutions prior to field commissioning in a realistic lab environment.

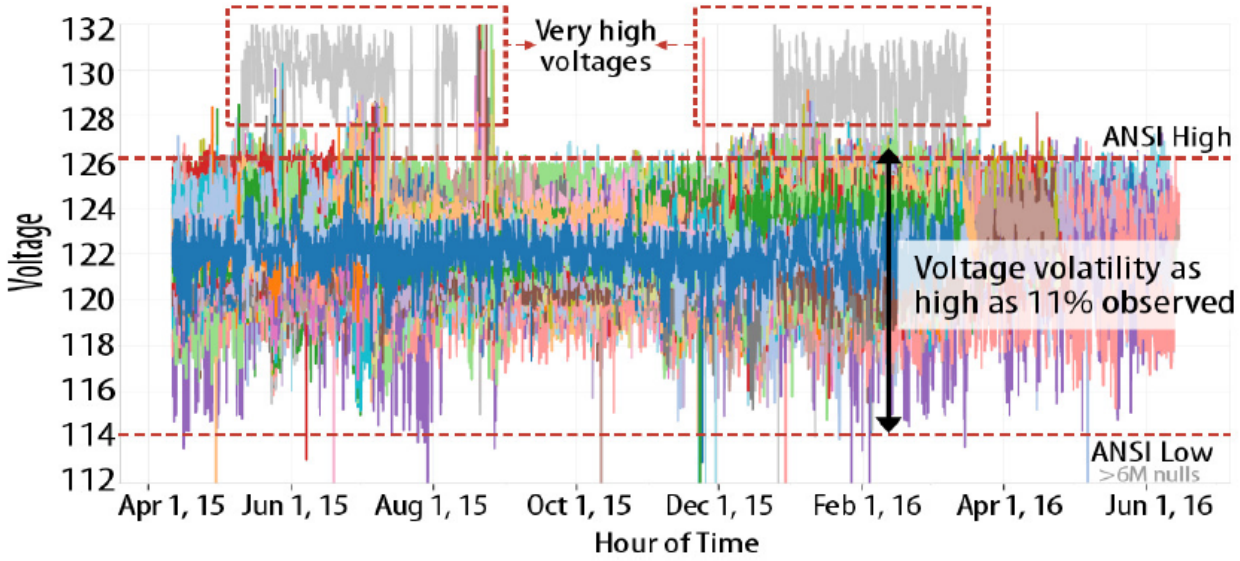
Generic Platform

- Objective: develop an easy configure and plug-in-play platform to provide realistic laboratory testing
- Integrated hardware-in-the-loop (HIL) platform
  - Co-simulation
  - Software HIL
  - Controller HIL
  - Power HIL
  - HELICS



Project I: ECO-IDEA

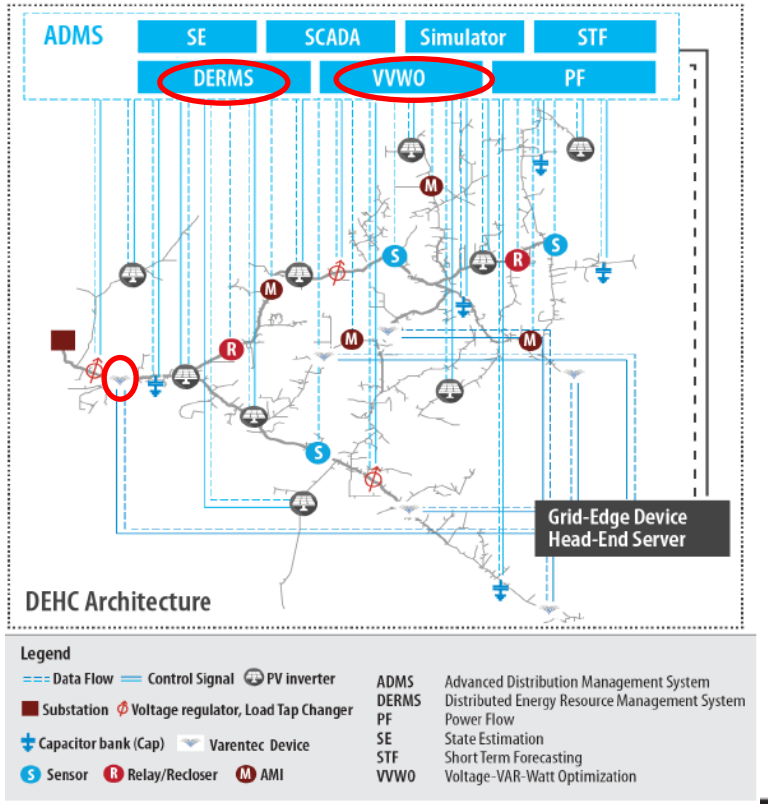
- Address the challenges of distribution systems especially associated with high penetrations of distributed PV, such as voltage stability



Voltage variability at the grid edge measured by 1,005 AMI meters collected over 14 months

Project I: ECO-IDEA

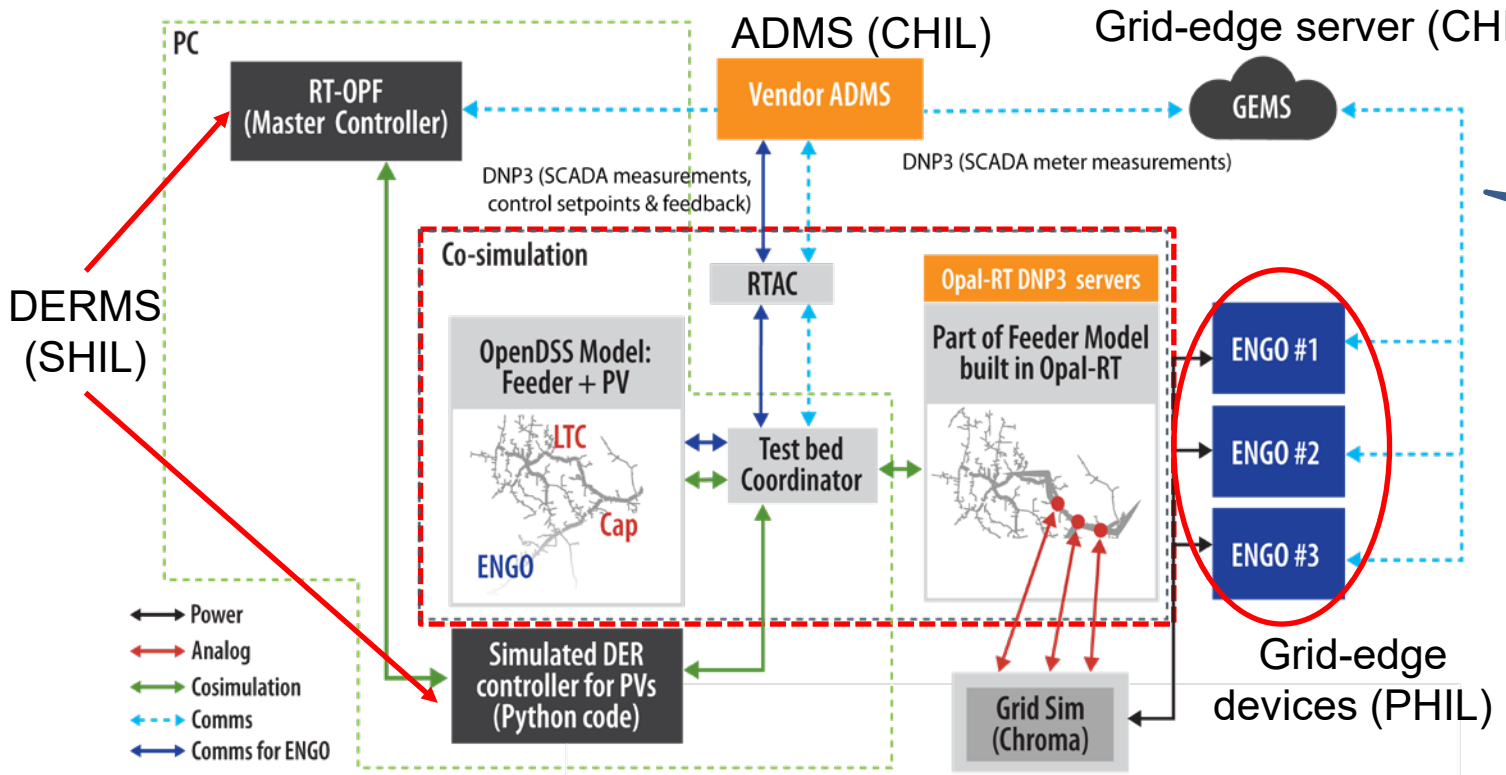
- Address the challenges of distribution systems especially associated with high penetrations of distributed PV, such as voltage stability
  - State-of-the-art grid operation: ADMS controls the legacy devices, limited control and visibility of PVs and grid-edge devices
  - Develop a unique and innovative **Data-Enhanced Hierarchical Control (DEHC) architecture**
  - Real-time operation and control for distribution systems
    - ADMS — legacy devices
    - ADMS — grid-edge synergy
    - Real-time optimal power flow (DERMS)



Proposed a Hardware-in-the-Loop (HIL) platform[1]

– Co-simulation, SHIL, CHIL and PHIL with standard communications protocols

- Accurate real-time modeling of distribution system from a utility partner
- Real controller (ADMS and grid-edge server), software controller DERMS
- Hardware grid-edge devices

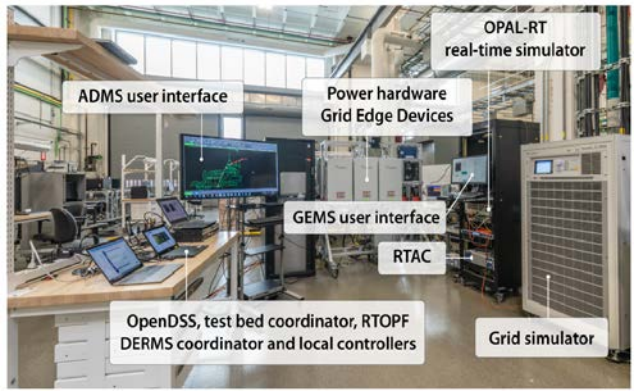


Evaluate coordinated control between ADMS and DERMS

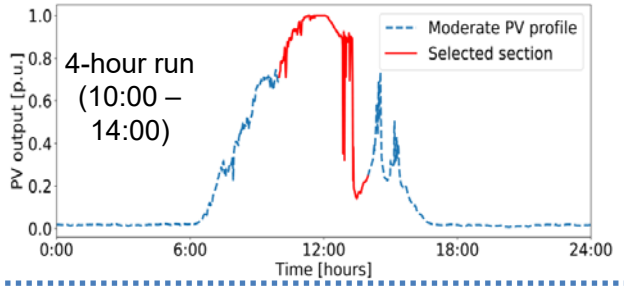
[1] J. Wang, et al., "Performance Evaluation of Hierarchical Controls for Advanced Distribution Management System-Centered Grid Operations," IEEE PESGM, 2020.

Experimental Results

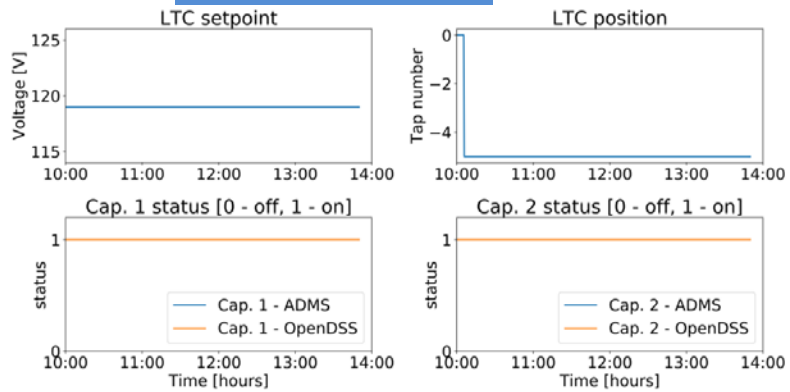
Photo of setup in the lab



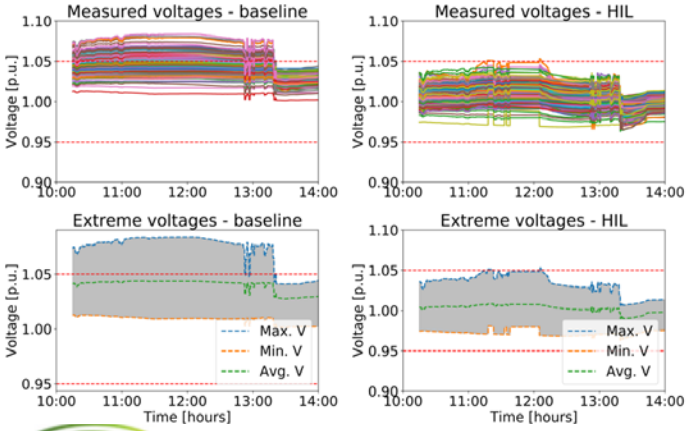
Selected PV profile—high-voltage scenario



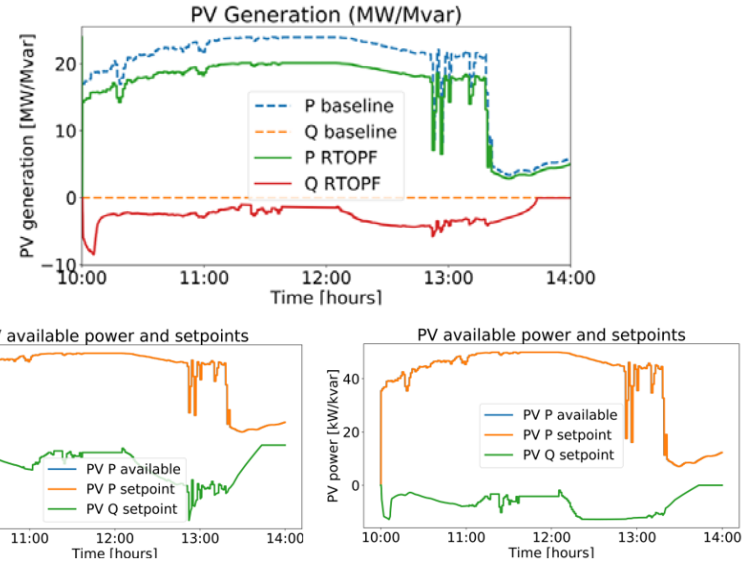
Legacy devices



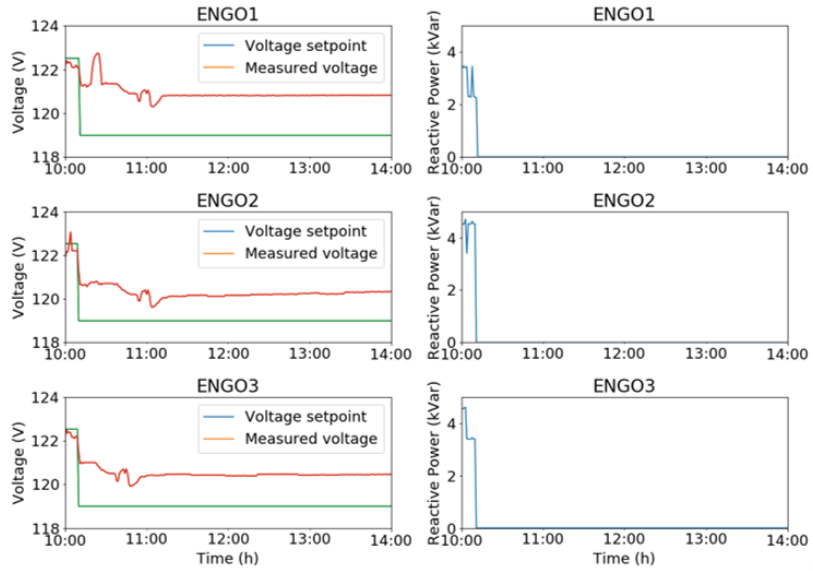
Voltage measurements



DERMS and PV

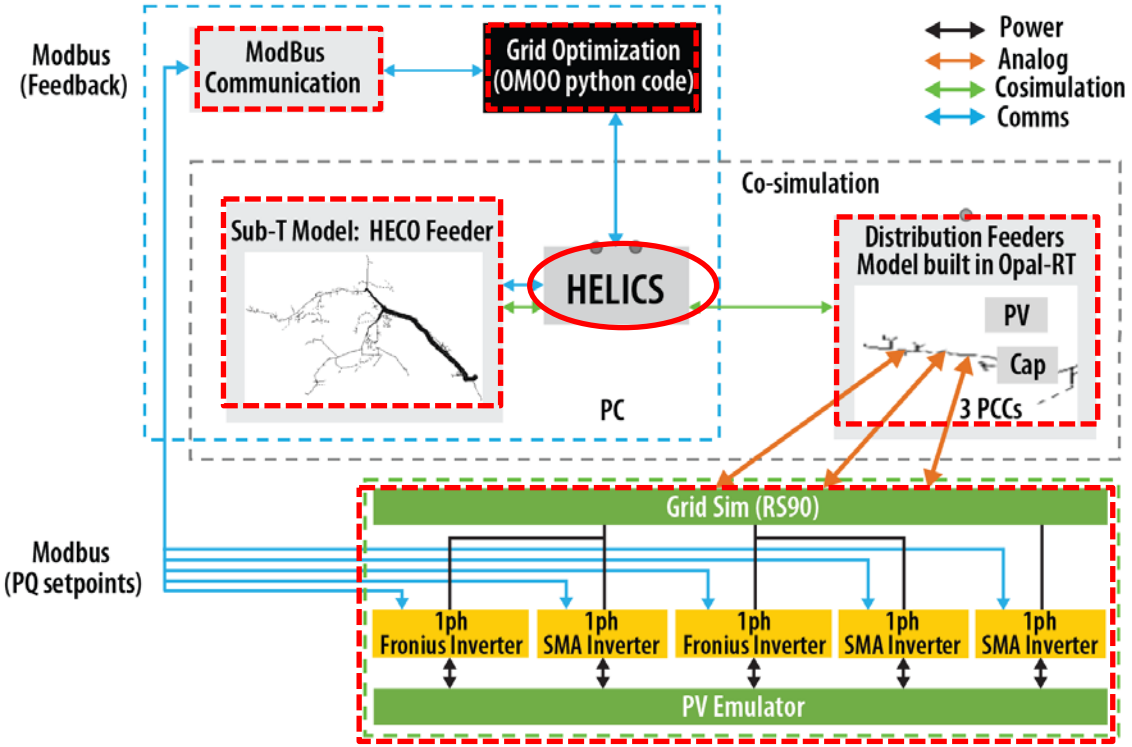


PHIL: Grid-edge devices



Project II: GO-Solar

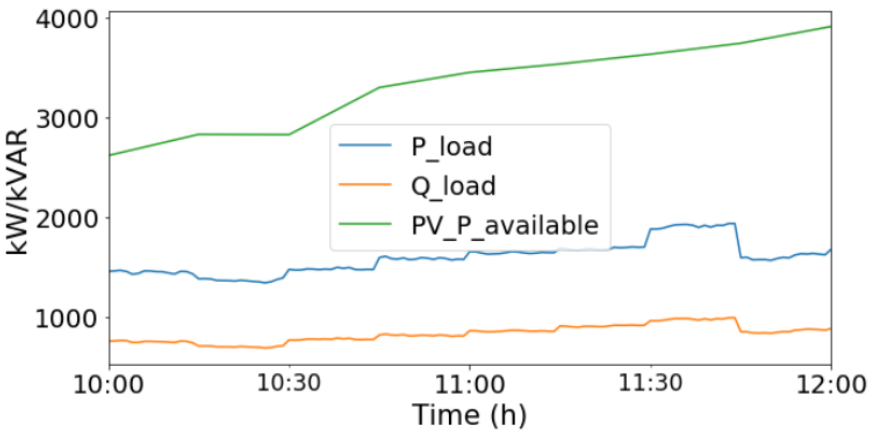
- Objective: Validate the control and optimization solution[2] in a realistic testing environment
  - Four major elements of the HIL platform:
    - Co-simulation
    - Grid Optimization algorithm
    - PHIL with 5 PV inverters (each 3-5 kVA)
    - ModBus communication interface
  - Software controller interacts with the real-time simulation model and hardware inverters as if the controller were interacting with a real-world system

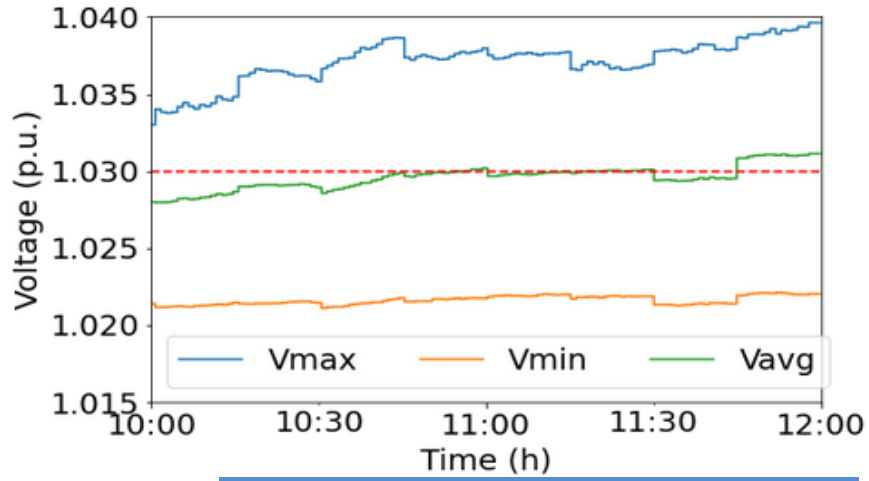


[2] J. Wang, et al., "Hardware-in-the-Loop Evaluation of an Advanced Distributed Energy Resource Management Algorithm," IEEE PES ISGT North American, 2020.

Experimental Results – Voltage Regulation

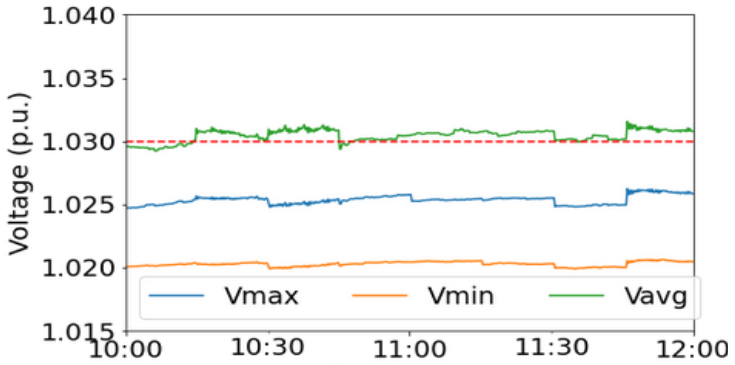
- Distribution feeder from Hawaiian Electric Company
  - Over 2,000 nodes
  - 245 loads and 245 PVs (242 simulated and 3 PCCs with hardware PV inverters)
  - 50% PV penetration
- Testing details
  - Simulation time 10:00-12:00 2-hour run at high solar irradiance
  - Voltage regulation target: 0.95 – 1.03 p.u.



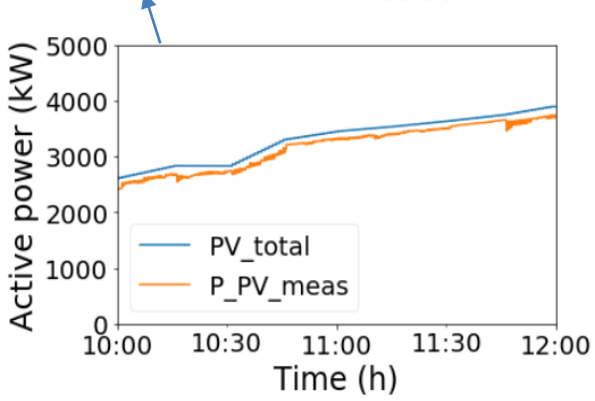


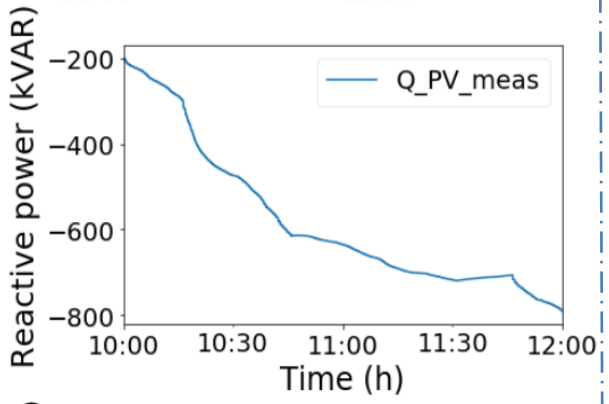
Baseline without DERMS control

Results from real-time simulation

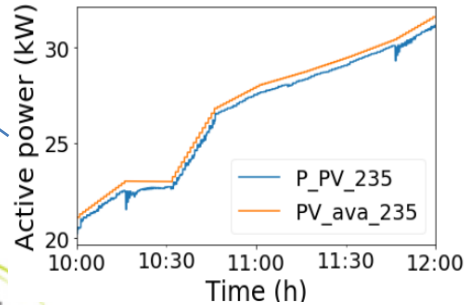


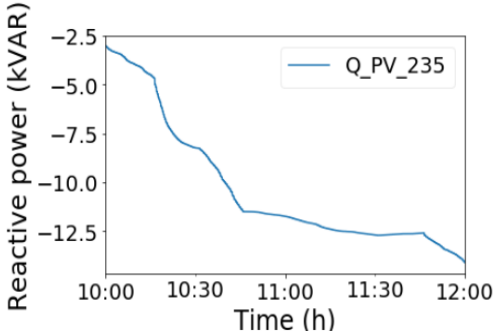
4.2% curtailment



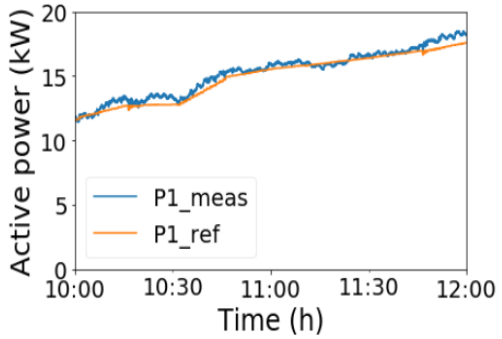


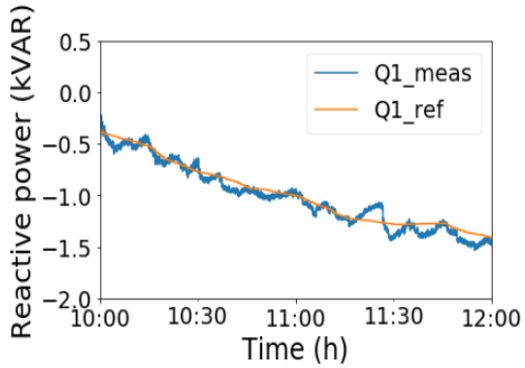
1.6% curtailment

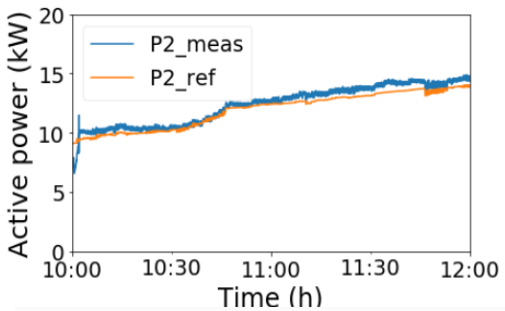


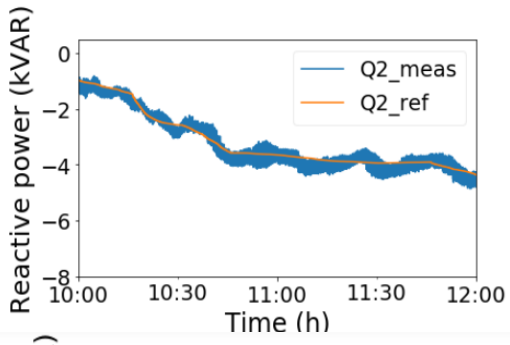


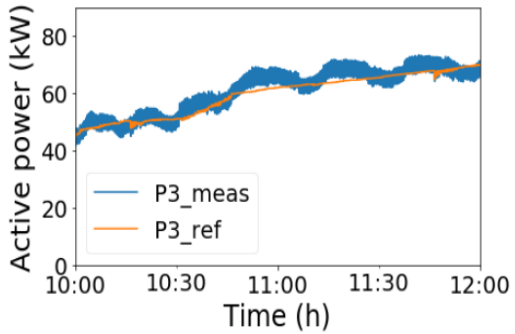
Results from PHIL – 3 DER racks

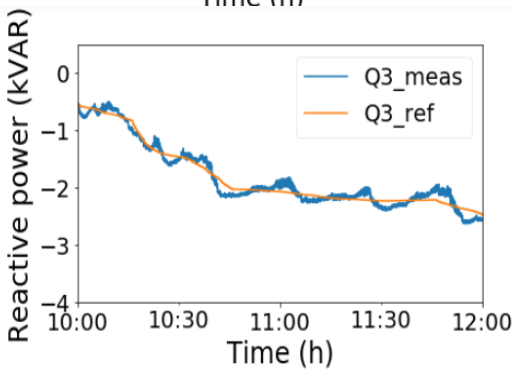






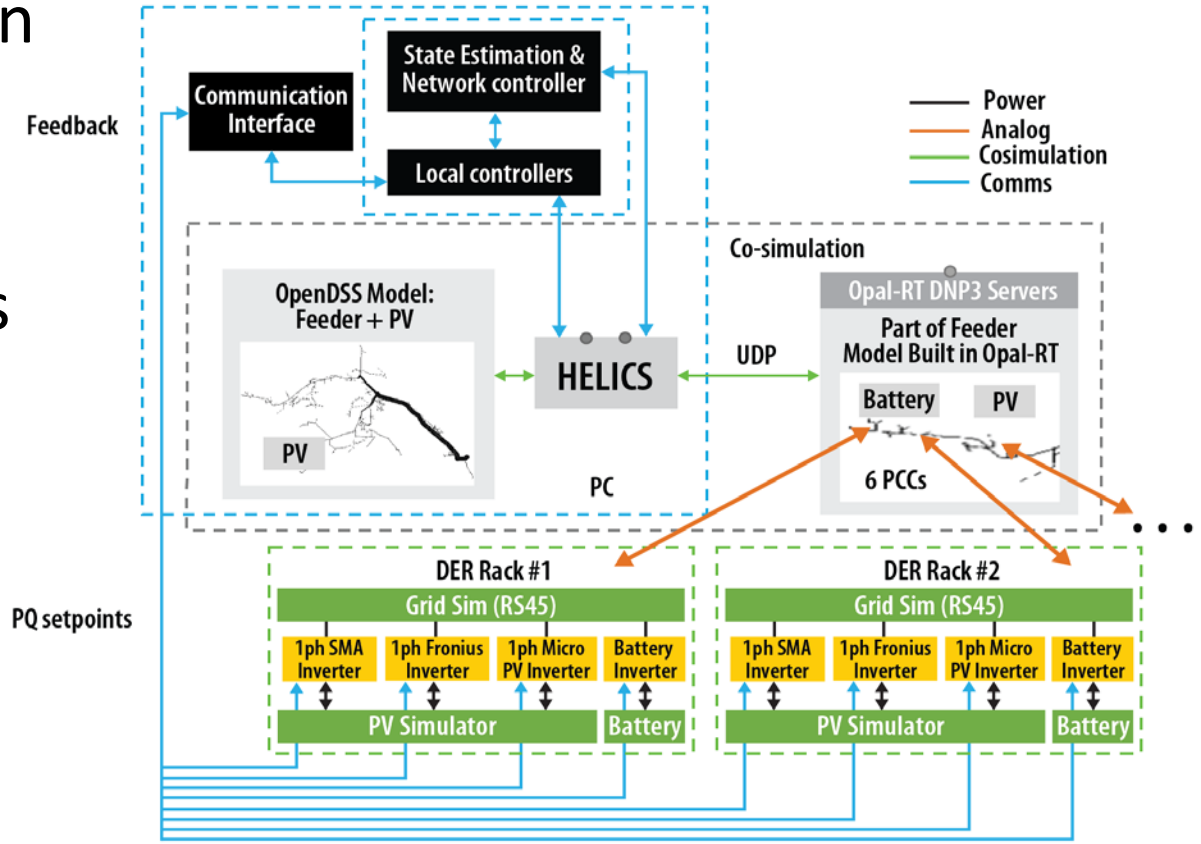






Project III: SolarExpert

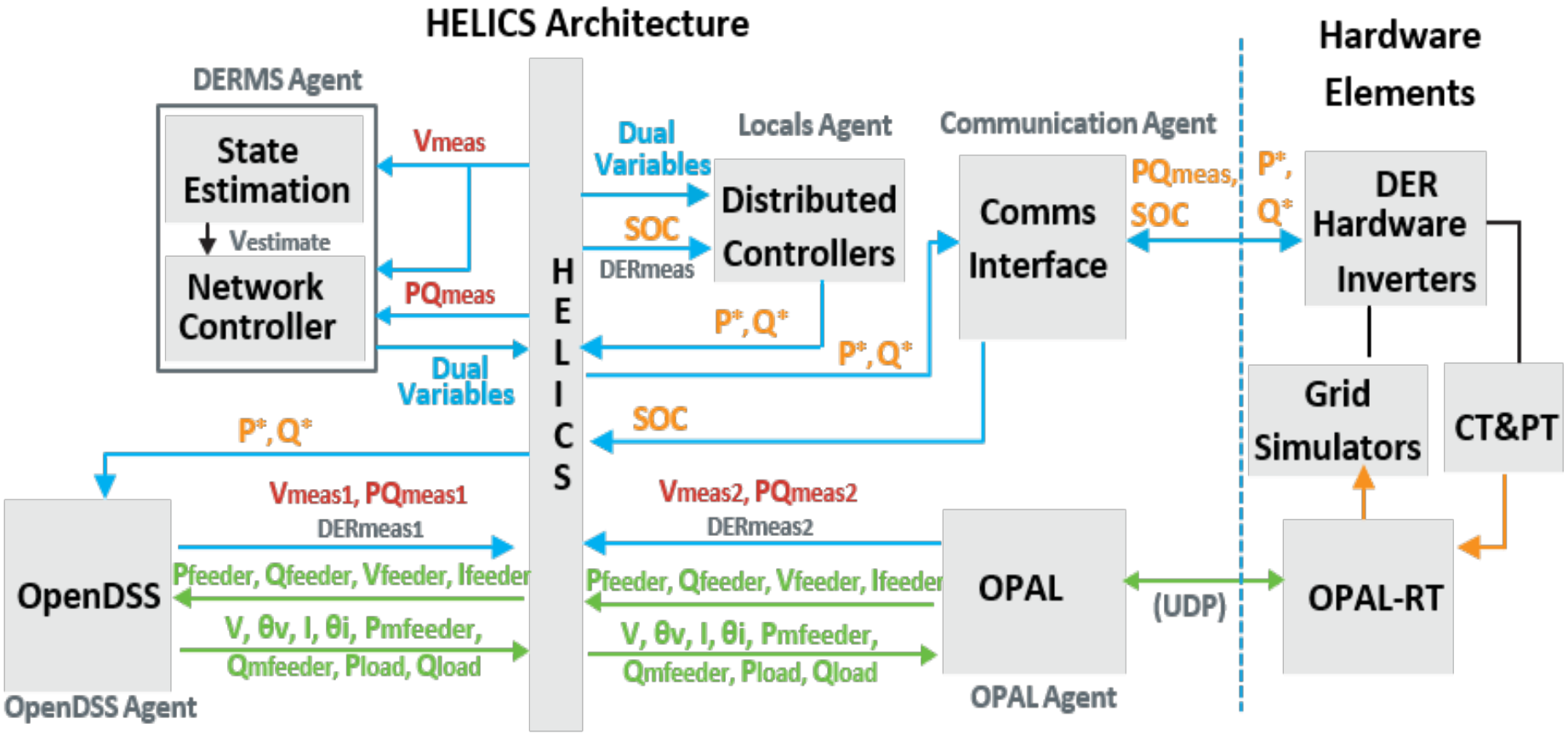
- Need to evaluate DERMS Technology[3] in a more realistic environment
- **Requirements**: real-time simulation of large network, software controller runs in fixed time-step, interact with hardware inverters with standard communication protocols.
- Integrated hardware-in-the-loop platform by using HELICS



[3] Jing Wang, Jianqiao Huang, Xinyang Zhou., "Performance Evaluation of Distributed Energy Resource Management Algorithm in Large Distribution Networks," IEEE PESGM, 2021.

Implementation

- HELICS Architecture and Hardware Setup

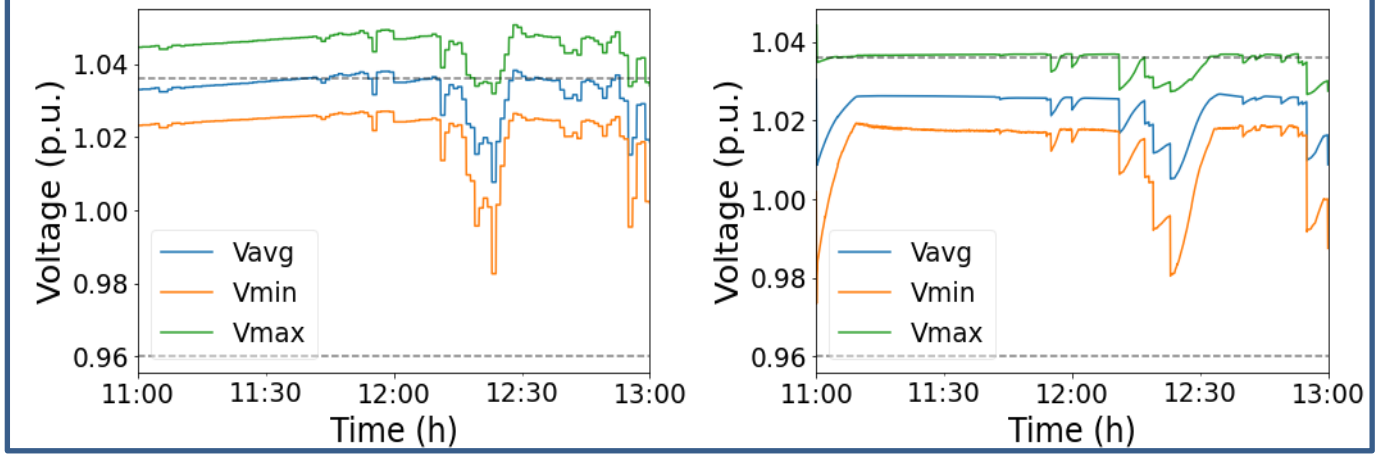


Experimental Results

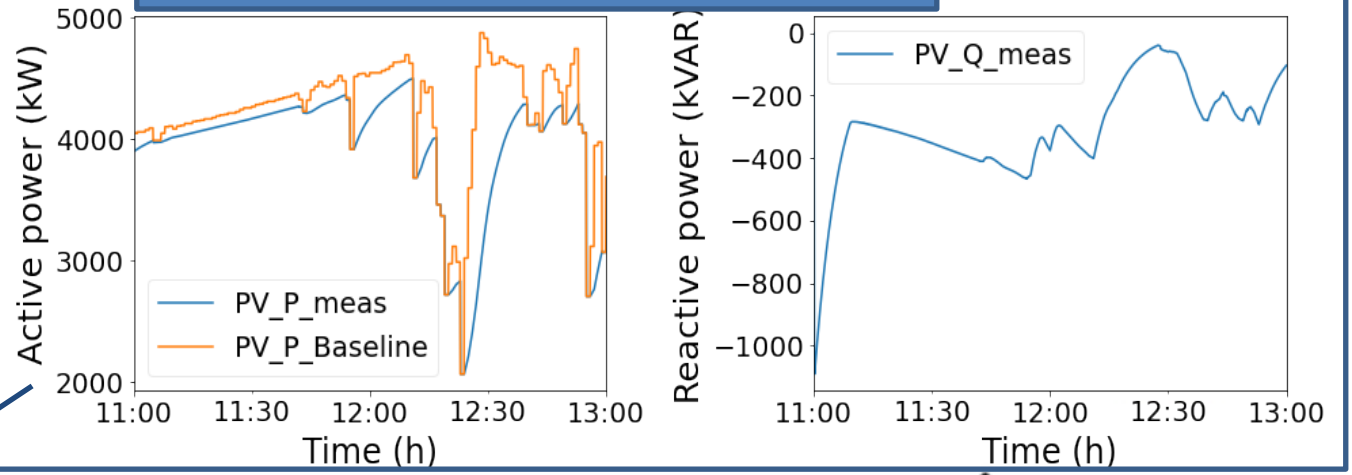
CHIL and PHIL testing

- 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



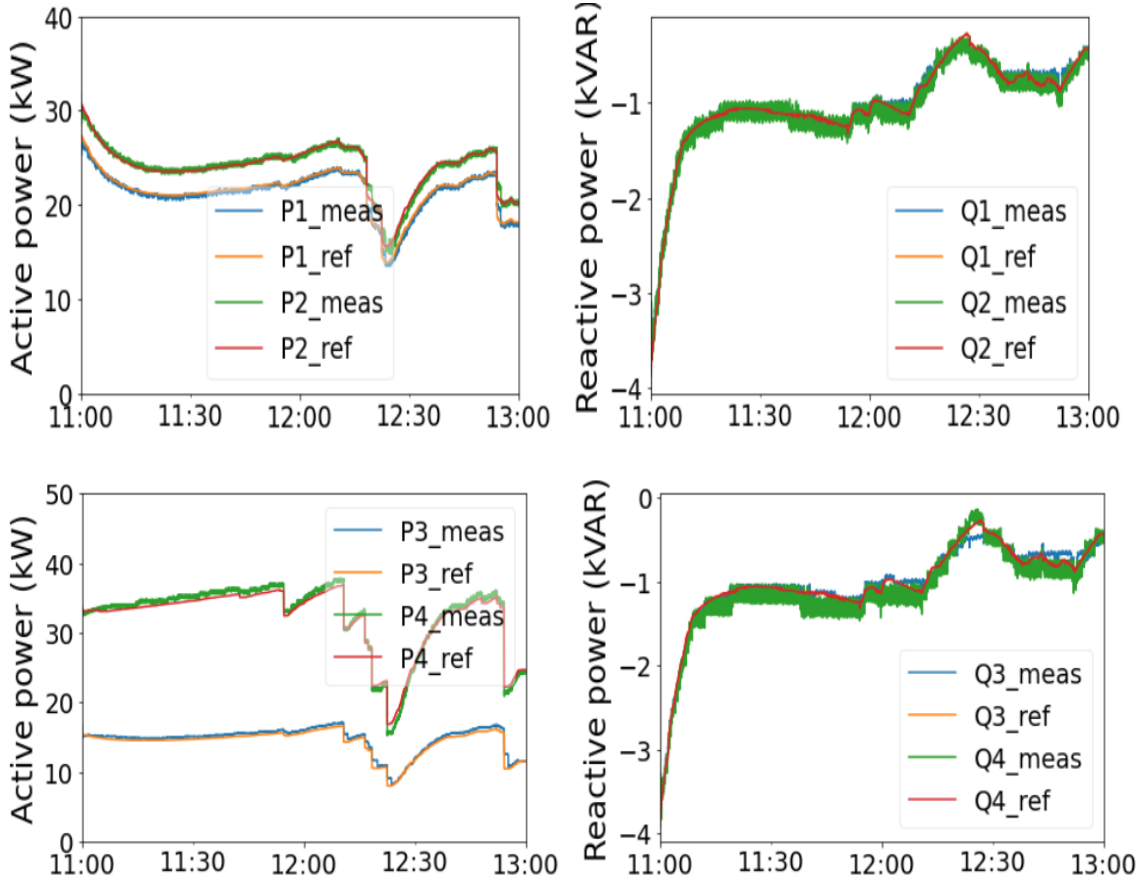
Total PV Active and Reactive Power



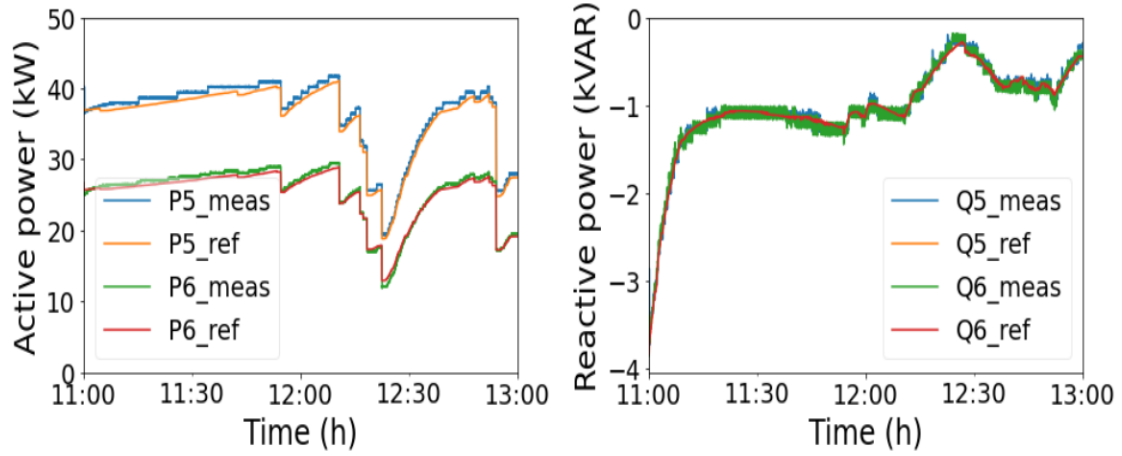
6.55% curtailment

Experimental Results

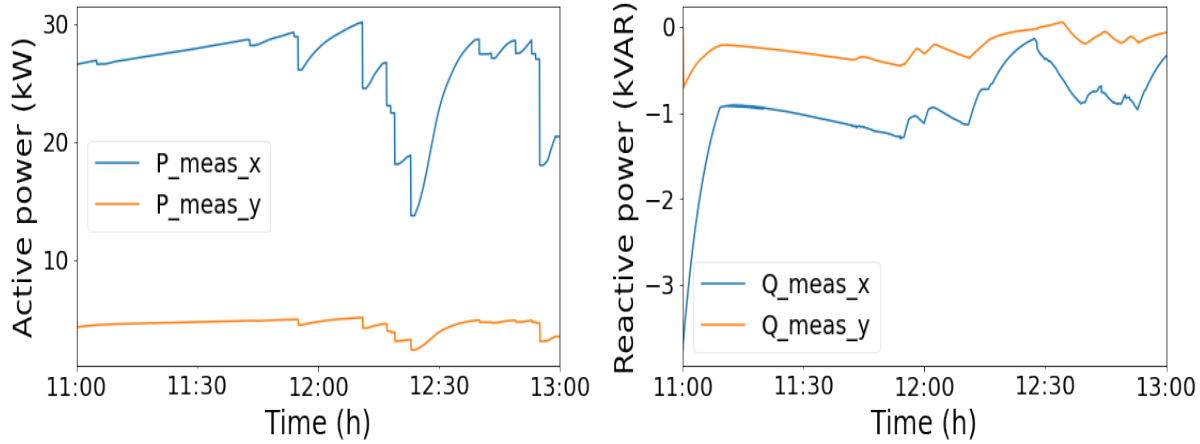
PHIL results: DER Rack #1-4



PHIL results: DER Rack #5-6



Results of two selected simulated PV



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Conclusions

- This panel presented the performance evaluation of various grid solutions for DER integration using an advanced HIL platform with realistic testing environment.
- HELICS is the key tool to integrate all the software pieces and hardware devices together.
- The experimental tests demonstrate that the grid solutions function well to maintain system voltages within the target limits

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