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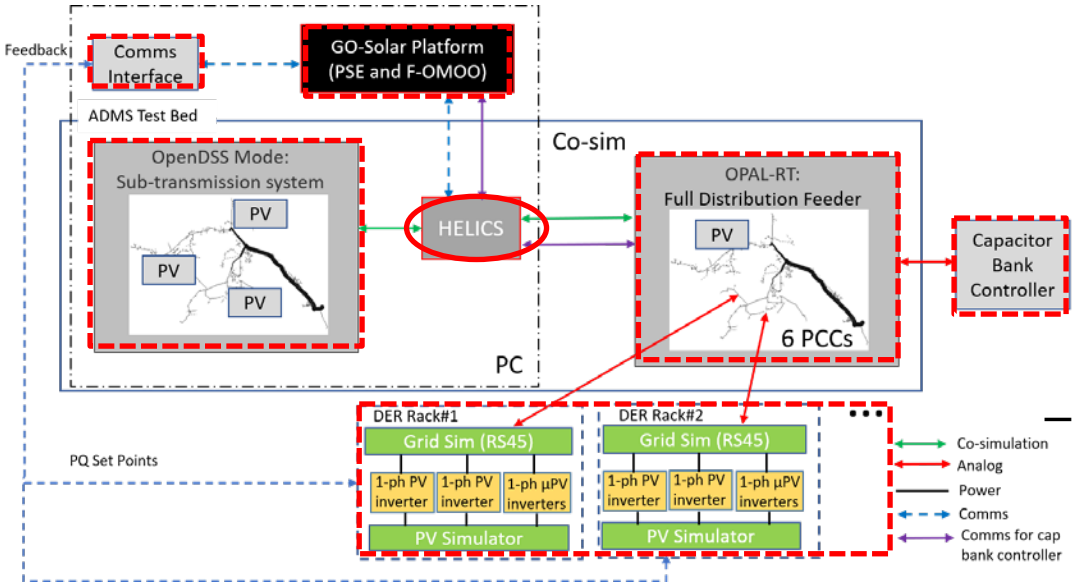
Performance Evaluation of an Advanced Distributed Energy Resource Management Algorithm

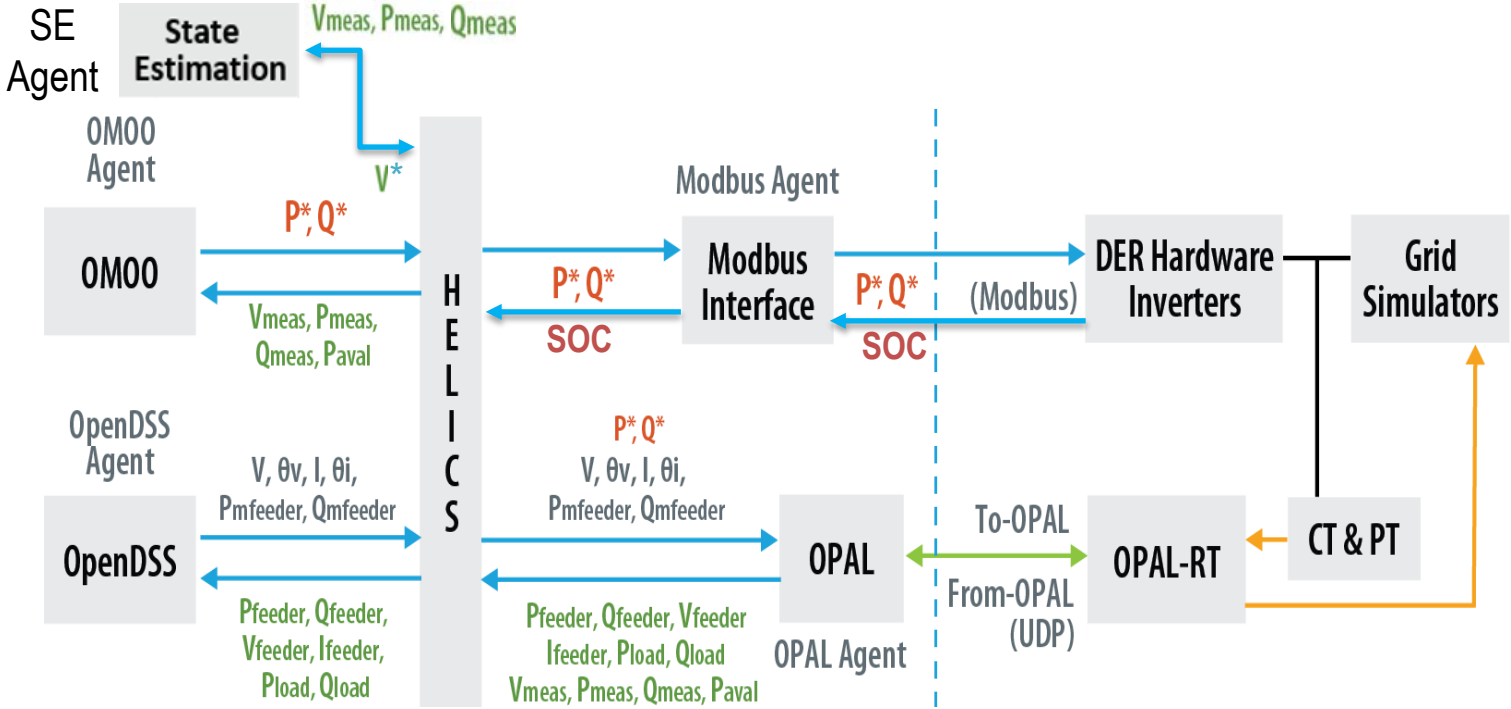
Jing Wang, Jeff Simpson, Rui Yang, Bryan Palmintier, Soumya Tiwari, Yingchen Zhang
National Renewable Energy Laboratory
Jing.Wang@nrel.gov

HIL Evaluation Overview

- Objective: Validate the control and optimization solution against a simulated real-word distribution system in a realistic testing environment
  - Accurate modeling of distribution system, power hardware inverters, communications
    - Co-simulation
    - Grid Optimization algorithm
    - Communication interface
    - PHIL with 6 DER Racks
    - Cap bank controller
  - Software controller interacts with the real-time simulation model and hardware inverters as if the controller were interacting with a real-world system



Schematic Diagram of the HELICS Architecture

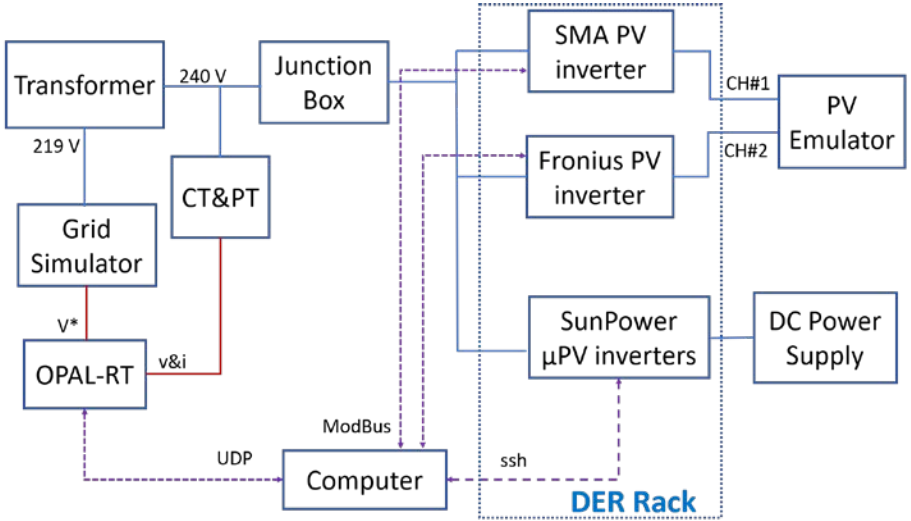


Experimental Setup – DER Racks

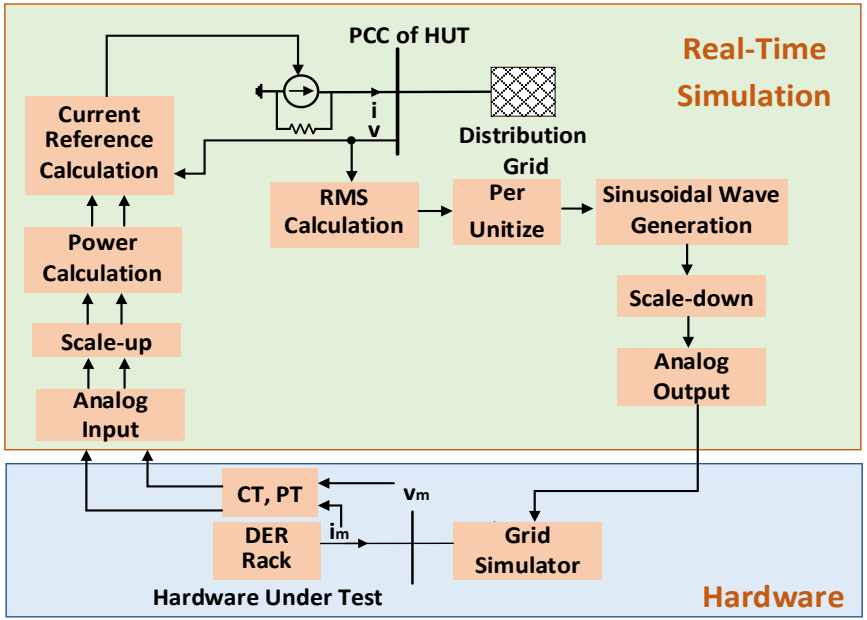
Experimental Setup – DER Racks

Rack	# Devices	Physical Devices	Total capacity	Simulated PV capacity
PHIL-1	14	(1) 3 kVA PV, (1) 5 kVS PV, (12) 320 VA µPV	11.84 kVA	23.5 kVA
PHIL-2	14	(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA µPV	11.84 kVA	19 kVA
PHIL-3	14	(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA µPV	11.84 kVA	93.9 kVA
PHIL-4	14	(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA µPV	11.84 kVA	67.6 kVA
PHIL-5	14	(1) 3 kVA PV, (1) **3 kVA PV**, (12) 320 VA µPV	9.84 kVA	119.2 kVA
PHIL-6	14	(1) 3 kVA PV, (1) **3 kVA PV**, (12) 320 VA µPV	9.84 kVA	54 kVA
Total	84	6 PCCs		

Experimental Setup – Each DER Rack/PCC

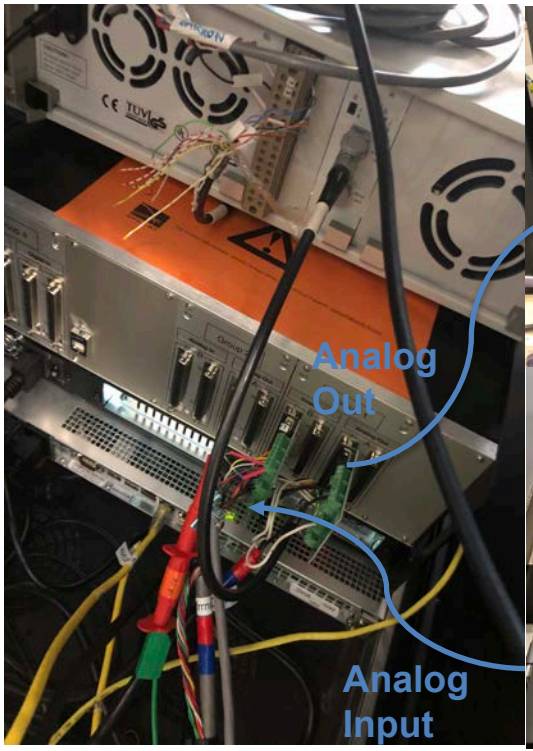


Hardware setup and connections for one DER rack



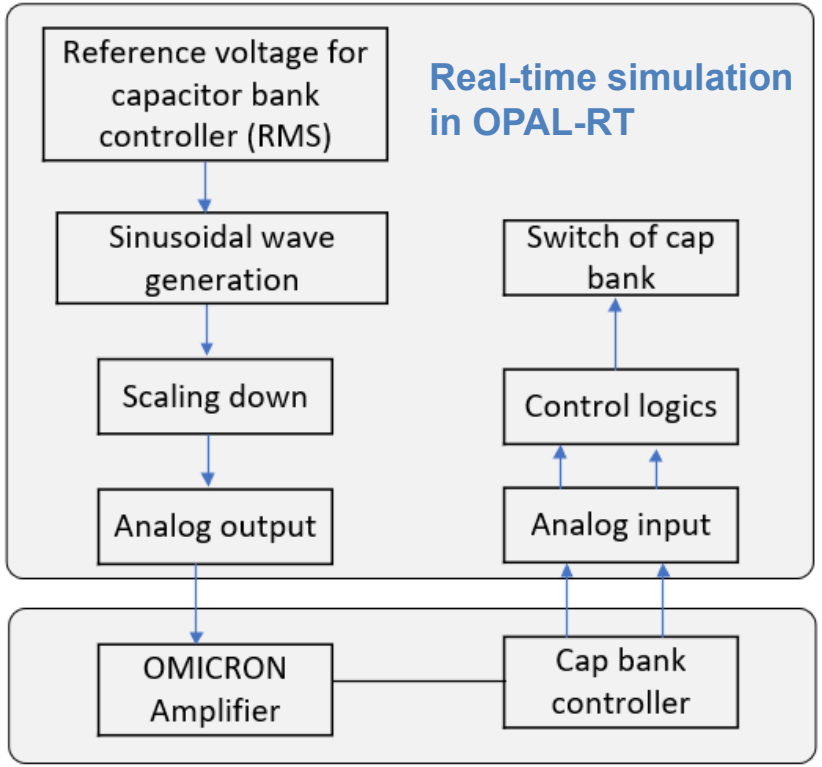
PHIL interface algorithm implemented in OPAL-RT

Experimental Setup – Capacitor Bank Controller



OPAL-RT

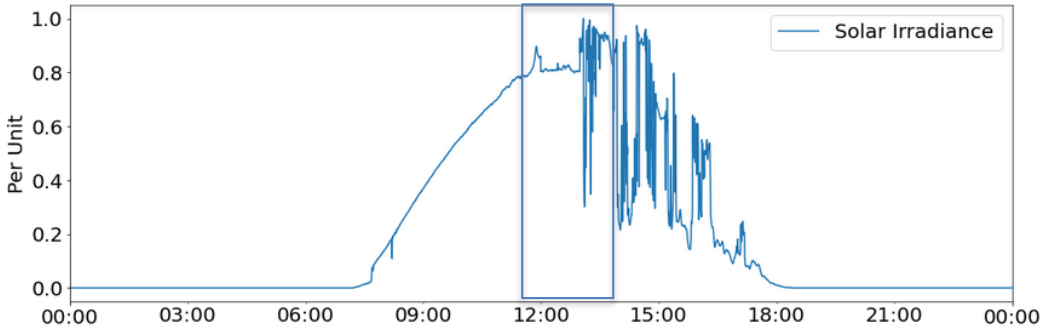
Beckwith Cap Bank Controller

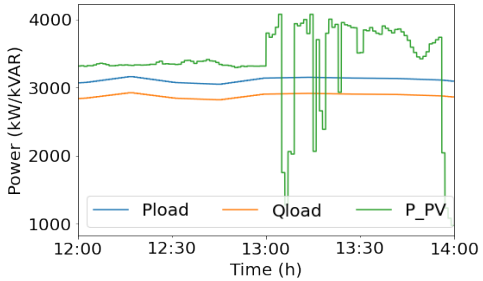


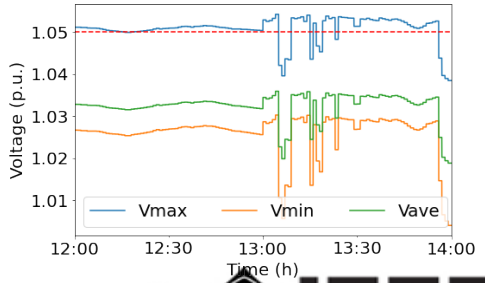
Controller to be tested

Experimental Validation – Voltage Regulation

- Distribution feeder from Hawaiian Electric Company
  - Over 2,000 nodes
  - 211 loads and 211 PVs (6 PCCs with hardware PV inverters and 205 simulated)
  - 50% PV penetration
- Testing details
  - Simulation time 12:00-14:00 2-hour run at high solar irradiance
  - Testing Scenarios
    - Smart Inverter – Volt/Var
    - 100% PV being controlled
    - 30% PV being controlled



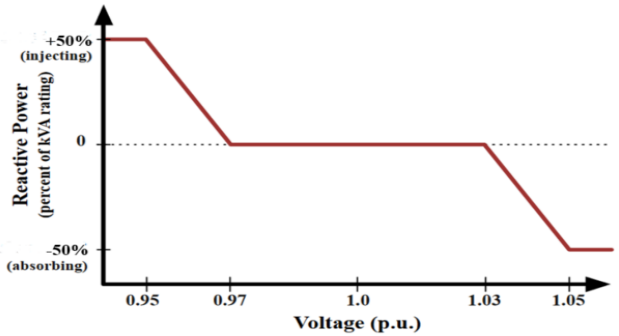




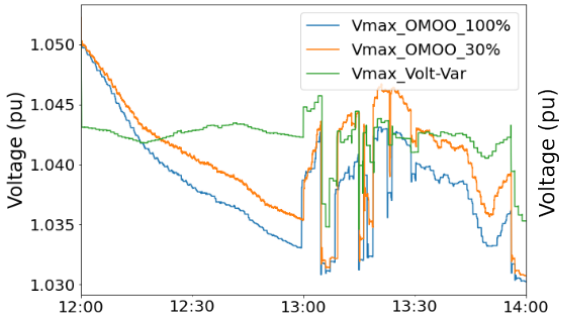
Experiment Results

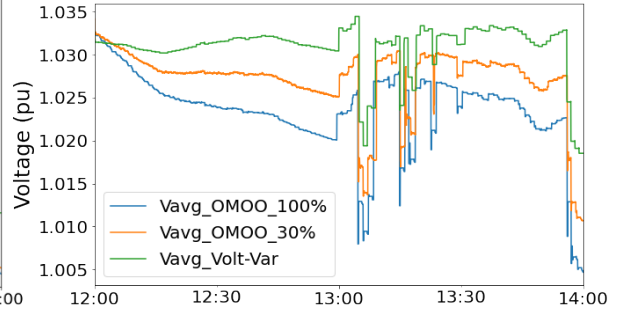
Real-time implementation details

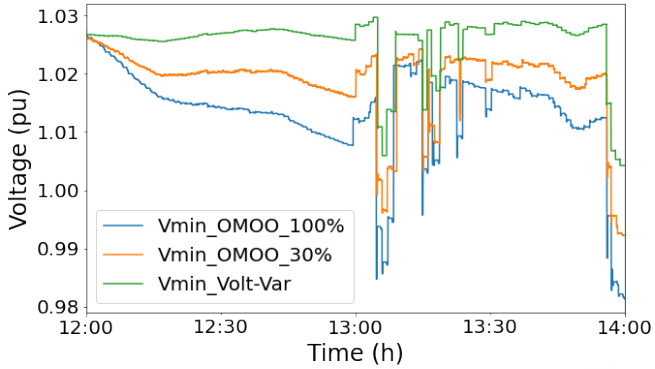
- Var Priority
- Triggered every 1 s with simulation time step 5 ms
- In total 211 PVs
- Add a deadband (0.005 p.u.) for the two slopes (0.95-0.97) and (1.03-1.05)



Results of system voltages with three scenarios



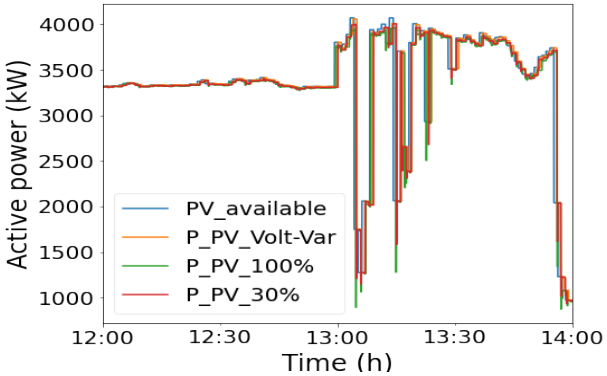


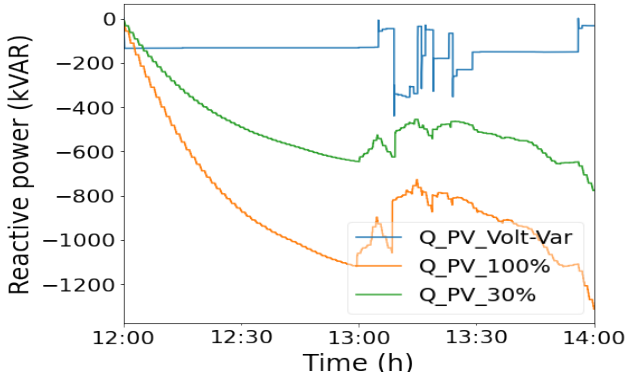


Experiment Results

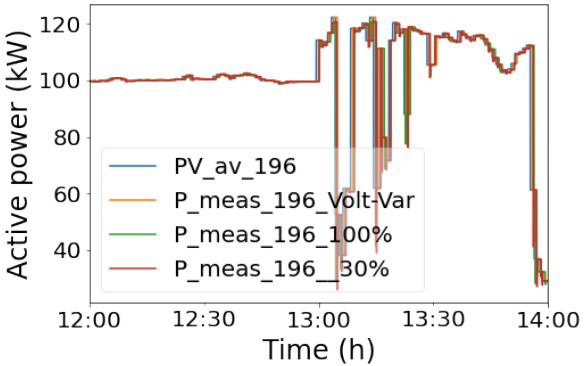
Results of Total PV measurements

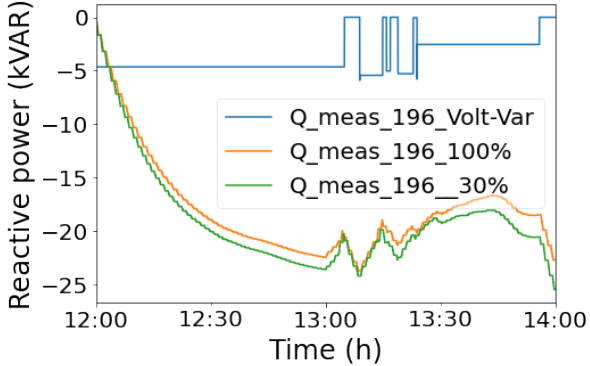
PV curtailment:
- 0.08% for volt-var
- 0.4% for 100% PV
- 0.24% for 30% PV





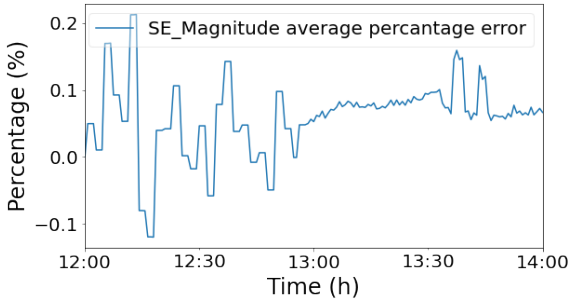
Results of one selected simulated PV

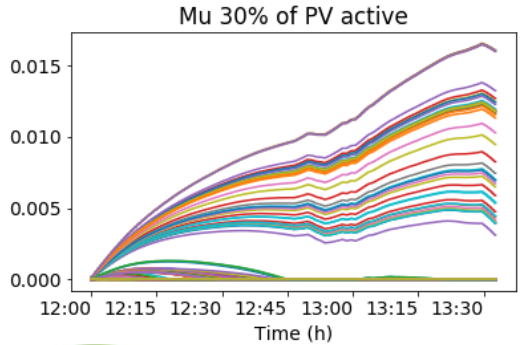


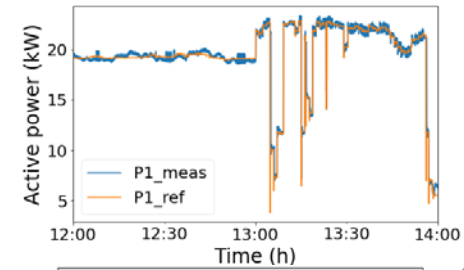


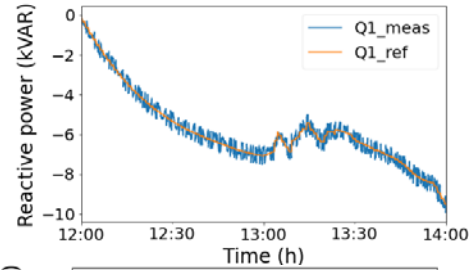
PHIL Experiment Results of 30% PV Being Controlled

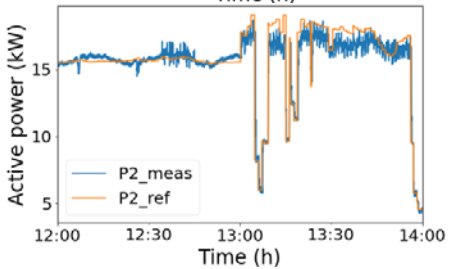
Performance of State Estimation and OMOO

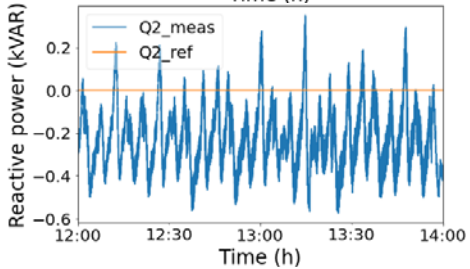


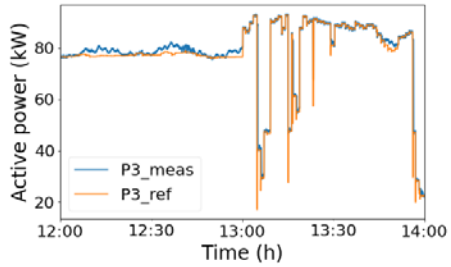


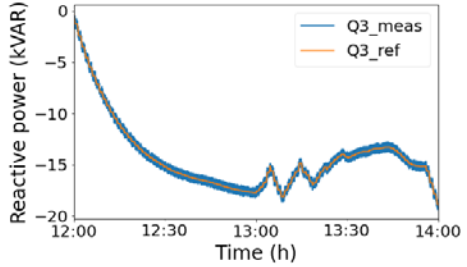








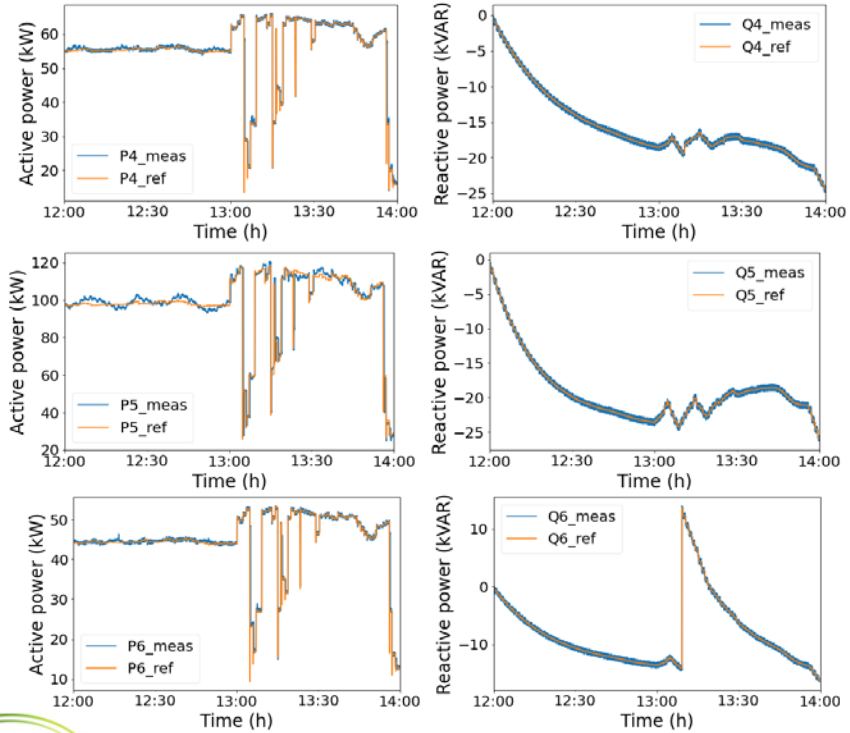




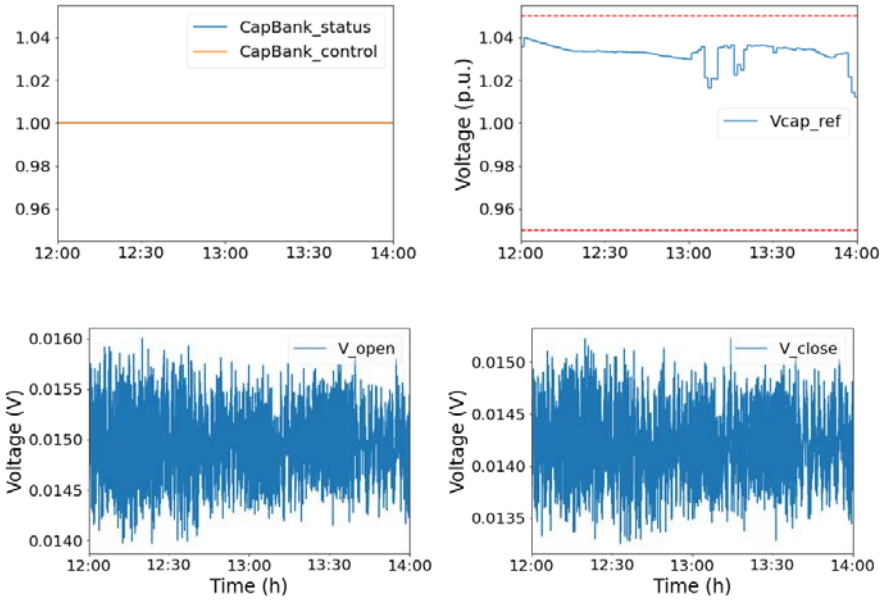
PHIL evaluation of three DER Racks (#1-#3)

PHIL Experiment Results of 30% PV Being Controlled

PHIL evaluation of another three DER Racks (#4-#6)



Results of capacitor bank controller



Conclusions

- Successful Power-hardware-in-the-loop (PHIL) testing with GO-Solar platform
  - 84 hardware DER inverters
  - standard communication protocols
  - real responses of hardware inverters
  - stability and dynamics of the GO-Solar platform
- Evaluated voltage regulation performance of the GO-Solar platform in real-time simulation
- HIL captures key real-world aspects and forced us to refine the approaches taken for GO-Solar that were not seen with the artificially tight data coupling from single feeder simulation.
- Results: Once tuned, GO-Solar Platform performs better than the smart inverter volt-var:
  - fewer voltage violations
  - reduced system voltages and improved energy savings (CVR)
  - precise voltage regulation, etc.

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