ADMS-Centric Operation for High-PV Distribution Grids

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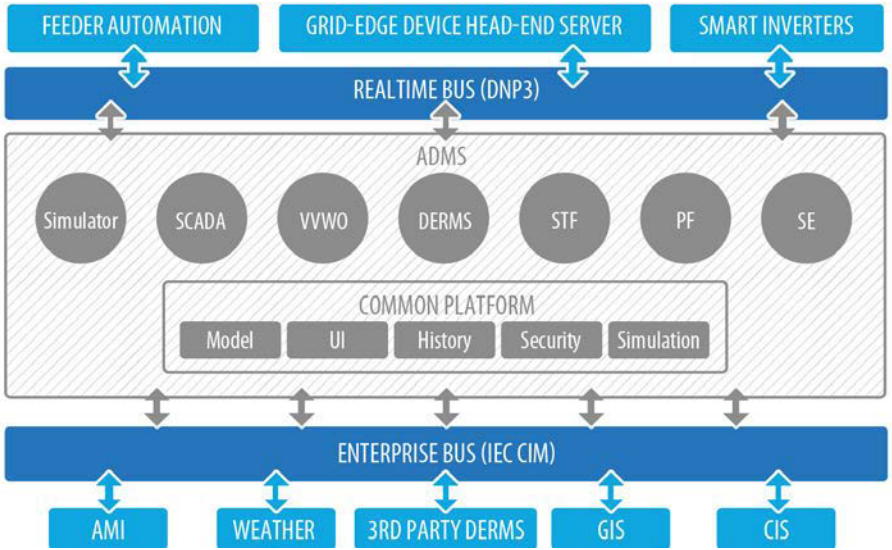
Project Objective

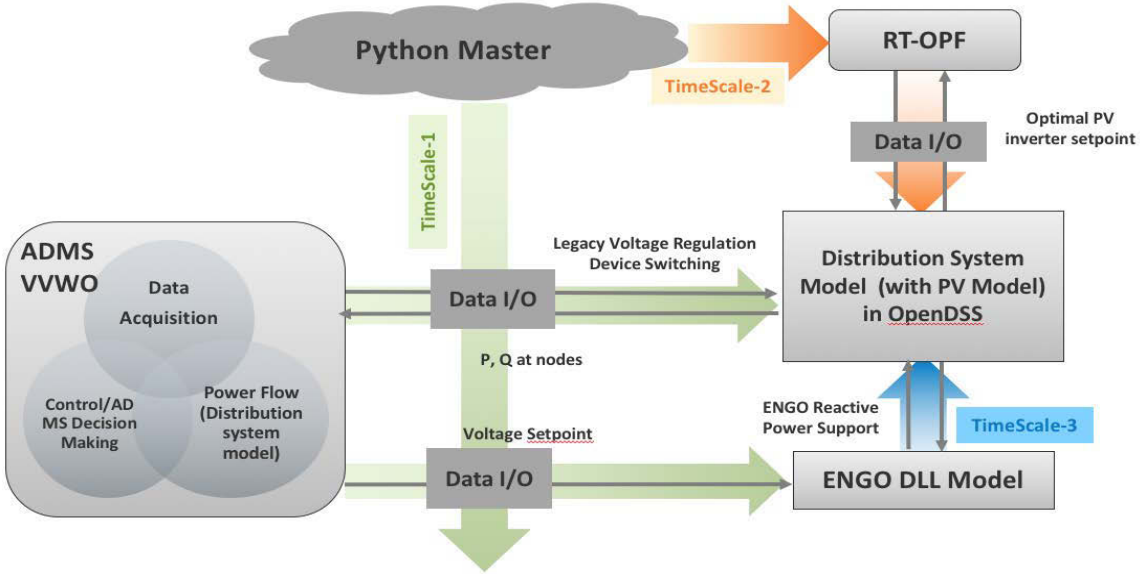
- Develop and validate a novel ***Data-Enhanced Hierarchical Control (DEHC)*** architecture for distribution grids with high PV penetration
- The DEHC architecture represents a hybrid approach of ADMS-based centralized controls, grid-edge controls and distributed controls for PV inverters



DEHC features:

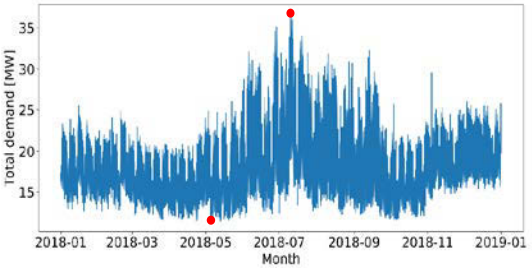
- ADMS-centered operations
- Synergistic ADMS-grid edge operations
- PV fast-regulation capabilities

DEHC Architecture

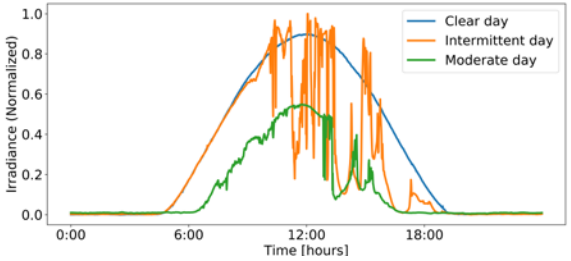


Feeder Modeling

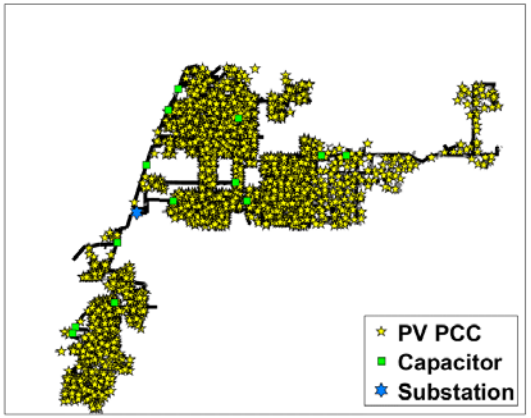
- Four feeders, 10000+ buses
- Substation LTC, no line voltage regulators
- 12 capacitor banks, 144 ENGO units
- A minimum load of ~12 MW and a peak load of ~36 MW were observed in the historical SCADA data of 2018
- Voltage-dependent load model



Historical SCADA data



PV profiles



High PV scenario

Simulation Scenarios

- Baseline: Legacy assets operate in local control mode, no ENGOs
- S1: ADMS controls both legacy assets and ENGO unit setpoints, PV smart inverters in local volt/var mode
- S2: RTOPF issues setpoints to PV smart inverters
- Quasi-static time-series (QSTS) simulation is carried out at 5-second time step resolution

Scenario	Legacy devices	ENGO units	PV smart inverters
Baseline	Local control	×	Unity power factor
S1	ADMS	ADMS	Local volt/var control mode
S2	ADMS	ADMS	RTOPF

Baseline Results

- High voltage exceedances observed at more than 400 customer locations
- No low voltage exceedances observed
- LTC was in local control mode (without line drop compensation enabled)

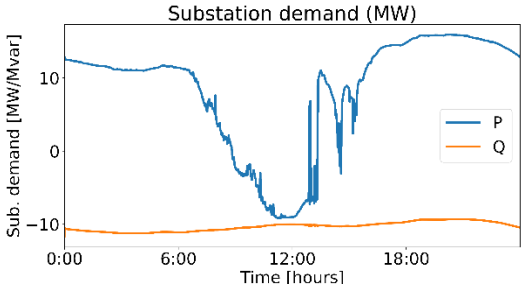


Fig. 1 Substation demand

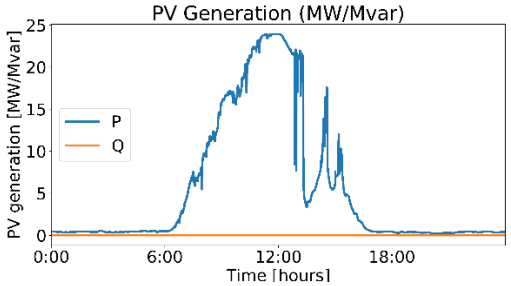


Fig. 2 Total PV generation

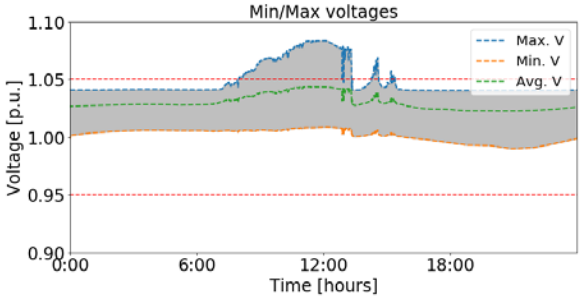


Fig. 3 Extreme voltages

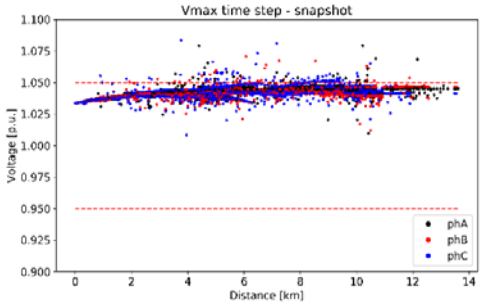


Fig. 4 Voltage profile at Vmax time step

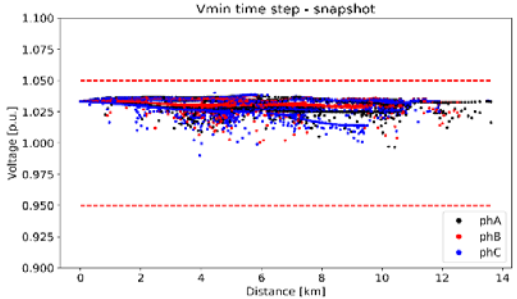


Fig. 5 Voltage profile at Vmin time step

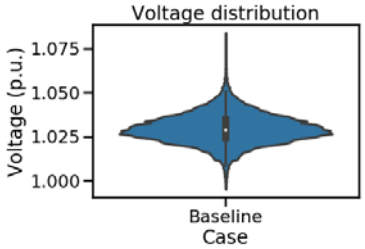
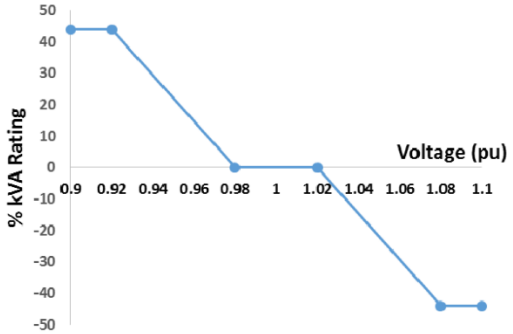


Fig. 6 Voltage distribution

S1 – Control Objectives

PV Smart Inverters



Volt/var curve shape

ADMS

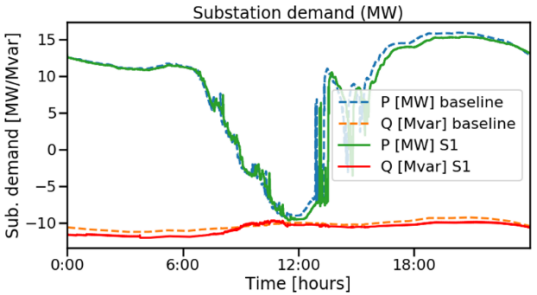
Objective: Voltage regulation

Voltage constraint limits: 114 V – 125 V

- All PV smart inverters are assumed to follow default volt/var control curve recommended by IEEE 1547 voltage regulation subgroup
- VVO is enabled in ADMS. The legacy device and ENGO setpoints from ADMS are passed to the simulated devices in OpenDSS

S1 Results

- Voltage profile is improved considerably due to ADMS lowering the LTC tap position
- High voltage exceedances observed at 26 customer locations
- Since PV inverters are operated in local volt/var control mode, the PV active power curtailment is 0%



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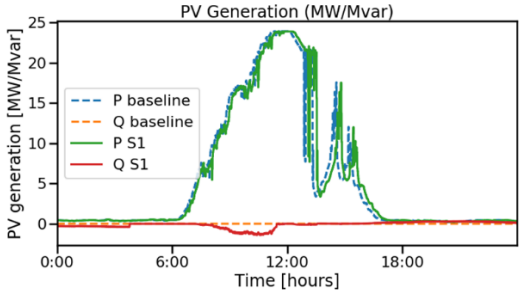
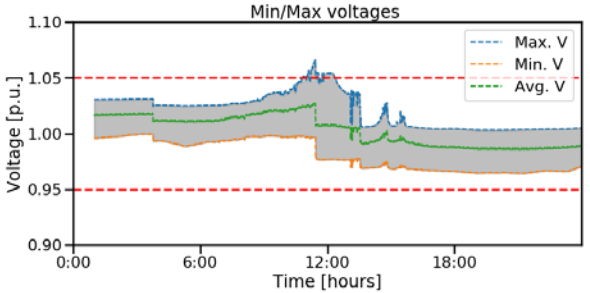


Fig. 2 Total PV generation



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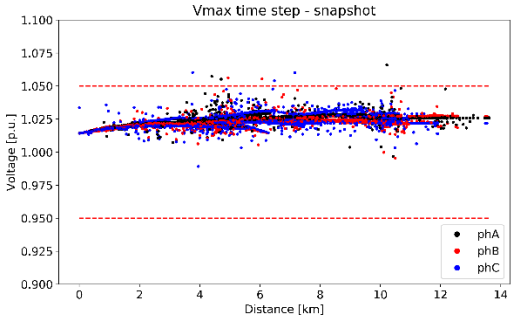


Fig. 4 Voltage profile at Vmax time step

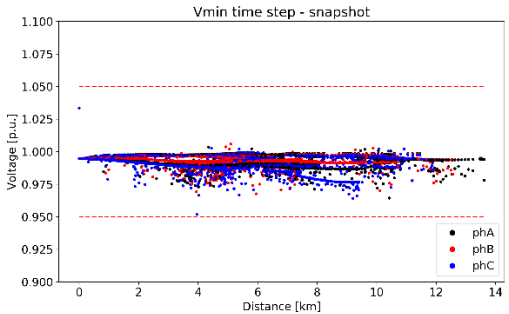


Fig. 5 Voltage profile at Vmin time step

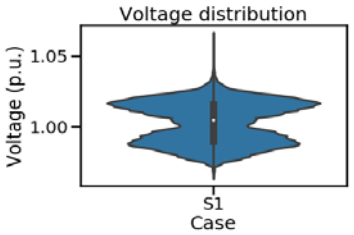


Fig. 6 Voltage distribution

S1 Results

- ADMS lowered the tap position during peak solar generation period. This resulted in effective regulation of high voltage exceedances. All the cap banks are in service throughout the day in this scenario.

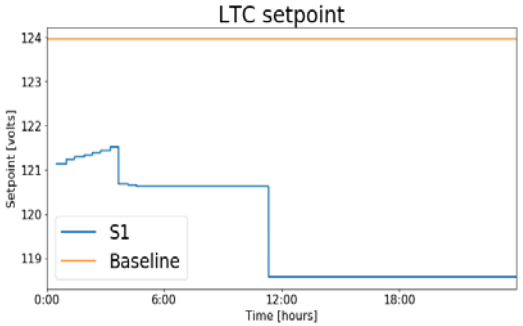


Fig. 1 LTC setpoint from ADMS

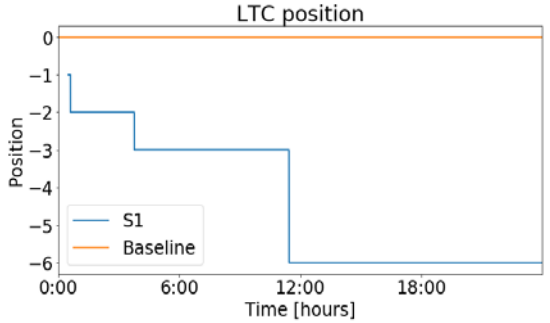


Fig. 2 LTC tap position in OpenDSS

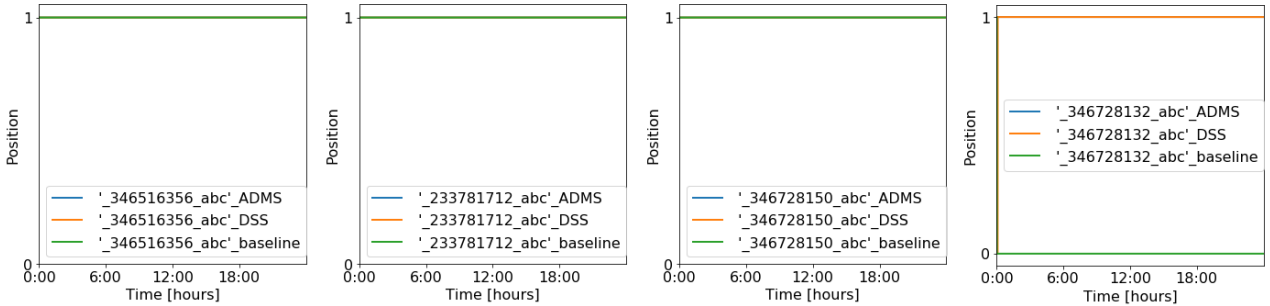


Fig. 3 Selected capacitor bank statuses

S2 – Control Objectives

RTOPF

Objective: Voltage regulation

Voltage constraints limits: 0.96 pu – 1.04 pu

$$\min_{p_j^t, q_j^t} f(\mathbf{x^t}) = \sum_{j=1}^{NPV} c_P \cdot \left(p_j^{t,max} - p_j^t\right)^2 + c_Q \cdot \left(q_j^t\right)^2$$

where, $\mathbf{x^t} = \{p_j^t, q_j^t,\ j = 1, \dots, NPV\}$, and p_j^t and q_j^t are actual active power output and reactive power output from the j^{th} PV inverter at time t. NPV is the total number of distributed PV inverters under control. $p_j^{t,max}$ is the maximum active power output that can be generated from the j^{th} PV inverter at time t. c_P and c_Q are constant coefficients, and typically $c_P \gg c_Q$.

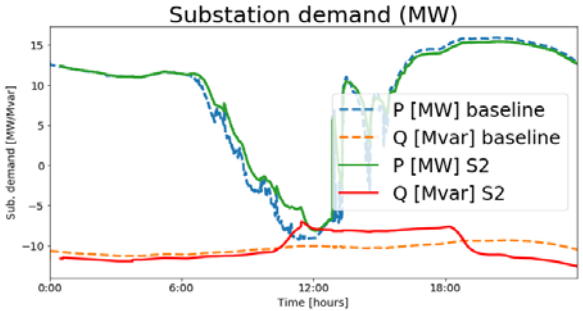
ADMS

Objective: Voltage regulation

Voltage constraint limits: 114 V – 125 V

S2 Results

- A peak active power curtailment of 4.8 MW (~20% relative to baseline peak generation of 23.9 MW) is observed compared to baseline for voltage regulation
- All the bus voltages are within limits. Legacy device setpoints are same as in S1.



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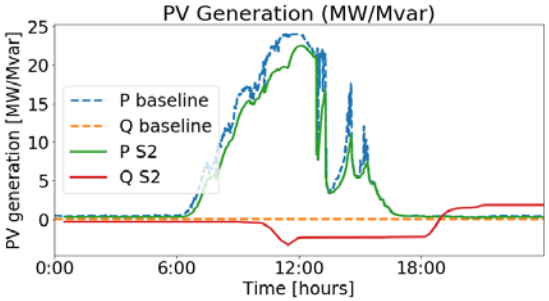

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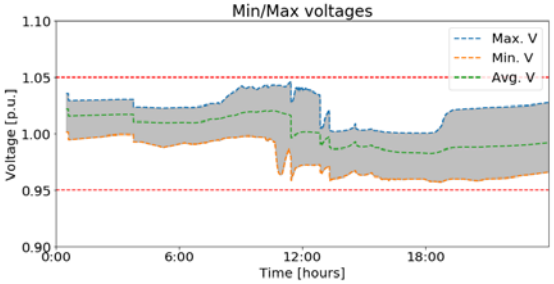
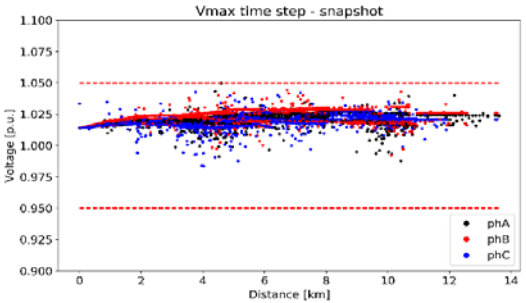


Fig. 3 Extreme voltages



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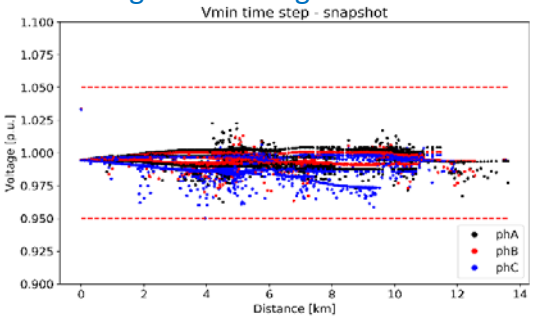

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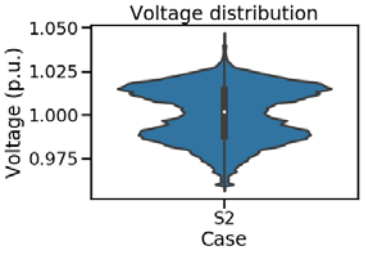
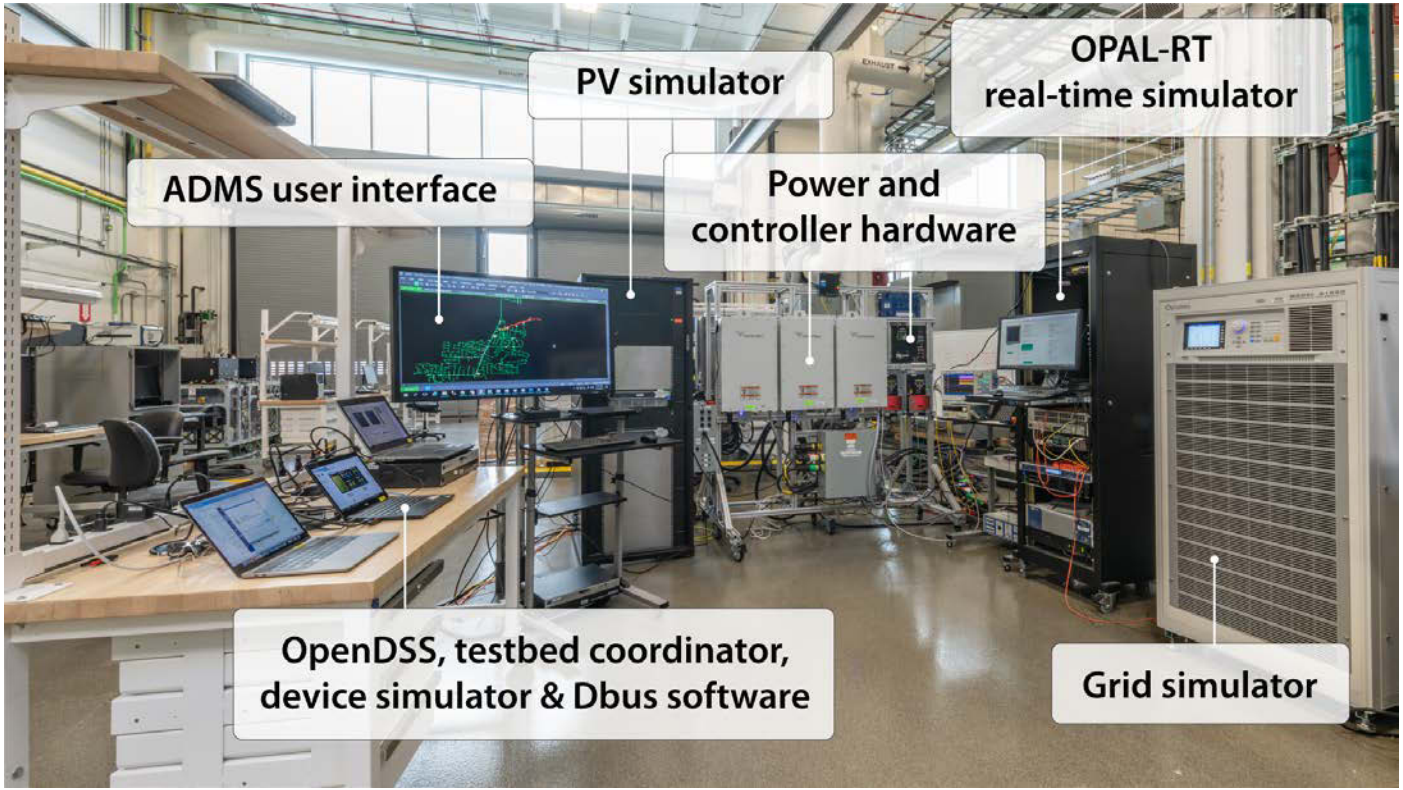


Fig. 6 Voltage distribution

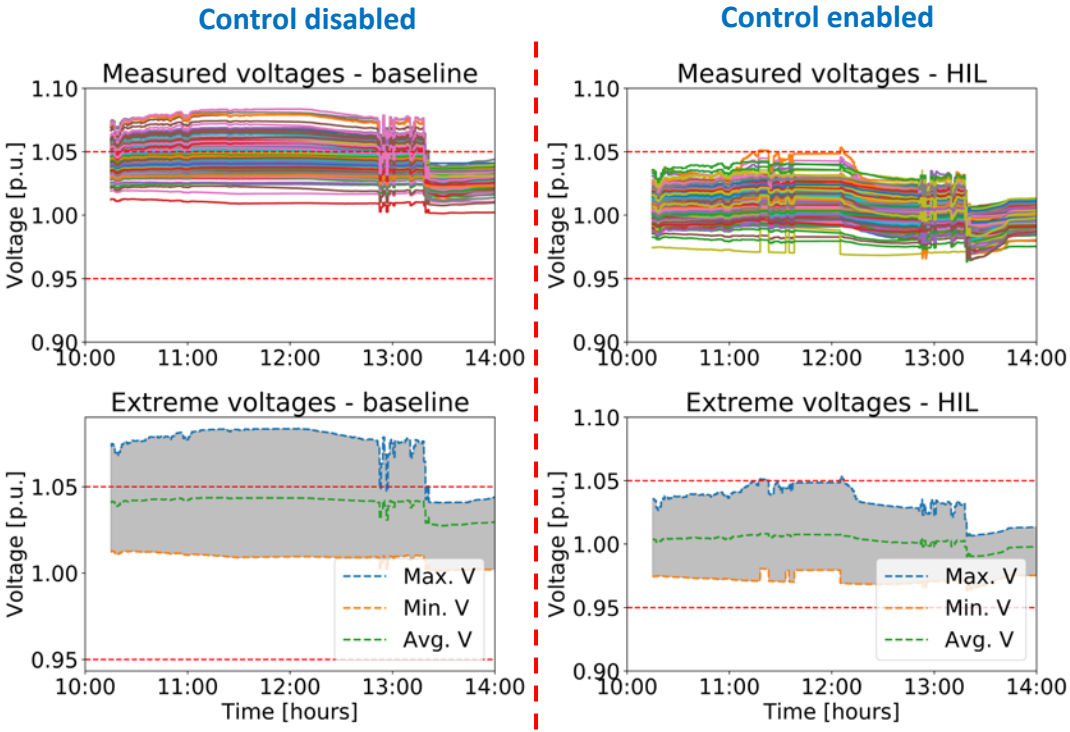
Hardware-in-the-Loop (HIL) Test Setup



Lab infrastructure for ENERGISE ECO-IDEA Project at NREL

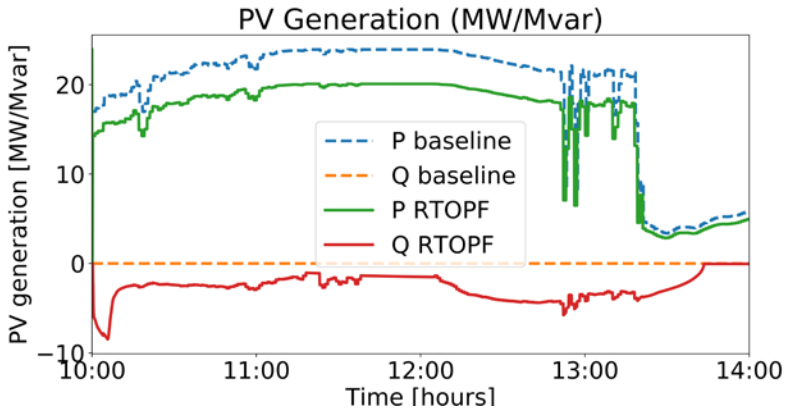
Results from HIL – System Voltages

- Experiment conducted for 4 hours from 10am to 2pm



Results from HIL – PV Generation

- The PV inverters work as expected: curtail some amount of active power to allow reactive power absorption to regulate the voltages within the ANSI limits



Total PV generation in the system

Conclusions

- The simulations demonstrate the effectiveness of DEHC architecture for voltage regulation
- The local volt/var control of PV smart inverters alone cannot resolve the voltage issues, even with ADMS control of legacy devices
- ADMS control of legacy devices coupled with fast regulation of PV smart inverters using RTOPF showed improved voltage regulation

Thank you

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