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SOLAR ENERGY TECHNOLOGIES OFFICE
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ECO-IDEA Simulations

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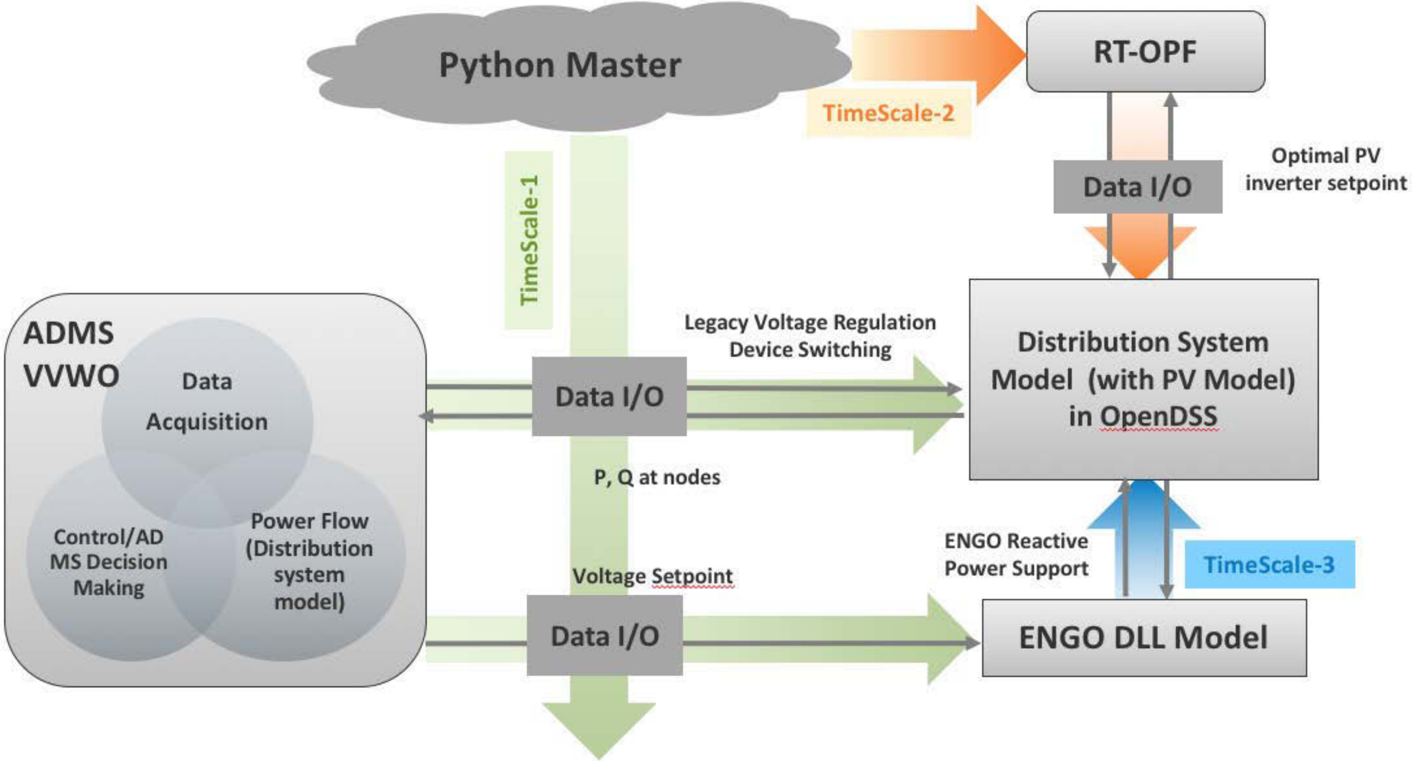
Workshop on Enhanced controls and optimization of integrated distributed energy applications (ECO-IDEA) ENERGISE project

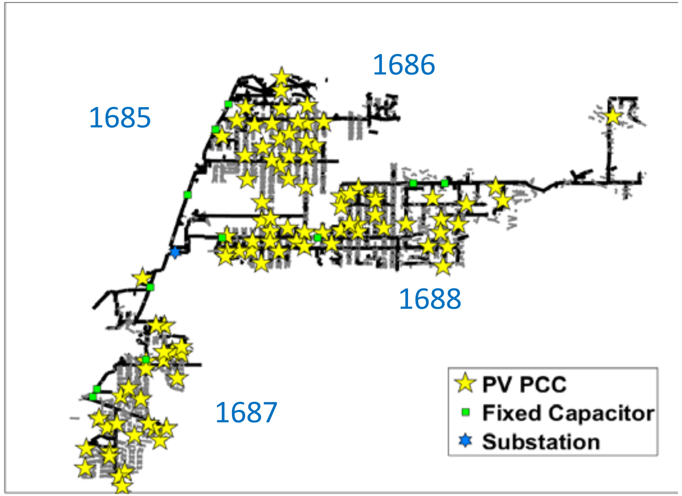
November 14, 2019

Cosimulation Framework



Feeder Details

- Four feeders: 1685, 1686, 1687, 1688
- ENGL has 13,000+ nodes in total (primary+secondary buses together)
- Characteristics:
    - Peak load: 36.6 MW
    - 1 substation load tap changer (LTC), no line voltage regulators (LVR)
    - 12 capacitor banks
      (12 x 1.2 Mvar = 14.4 Mvar)
    - 144 edge of network grid optimization (ENGO) units
- Existing photovoltaic (PV) generation:
    - 111 PVs in total
    - Peak PV generation is 3.7 MW.



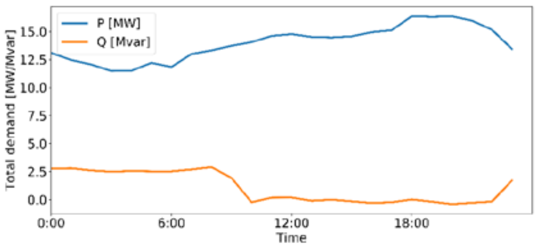
Simulation Scenarios

- Baseline: Legacy assets operate in local control mode, no ENGO units.
- S1: Advanced distribution management system (ADMS) controls both legacy assets and ENGO unit set points, PV smart inverters in local volt/VAR control mode.
- S2: Real-time optimal power flow (RTOPF) issues set points to PV smart inverters.

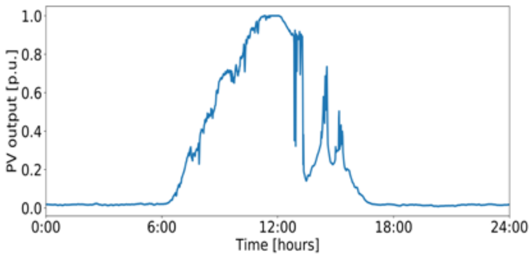
Scenario	Legacy Devices	ENGO Units	PV Smart Inverters
Baseline	Local control	×	Unity power factor
S1	ADMS	ADMS	Local volt/VAR control mode
S2	ADMS	ADMS	RTOPF

System Conditions

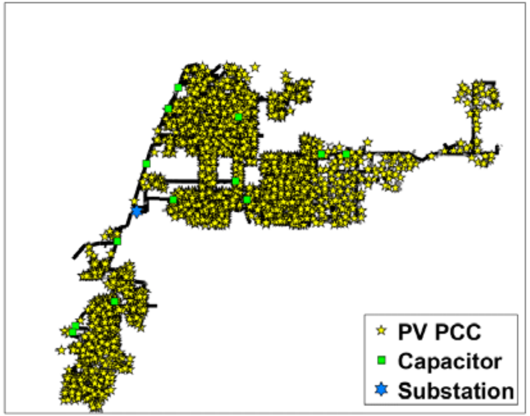
- Load profile: Minimum load of 11.48 MW was observed on May 13, 2018, in historical SCADA data
- PV profile: Moderate PV profile is selected from solar irradiance data recorded at NREL's National Wind Technology Center site
- High PV scenario is used for the simulation.
- Quasi-static time-series simulation is carried out at 5-second time step resolution.



Load demand on low-load day



Moderate PV profile

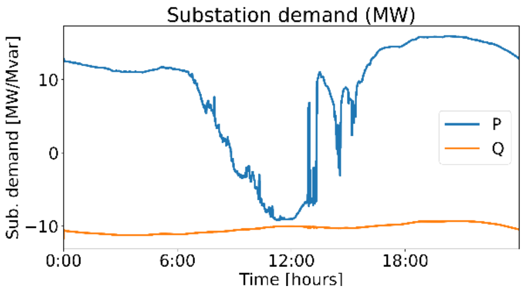


PV locations in high PV scenario

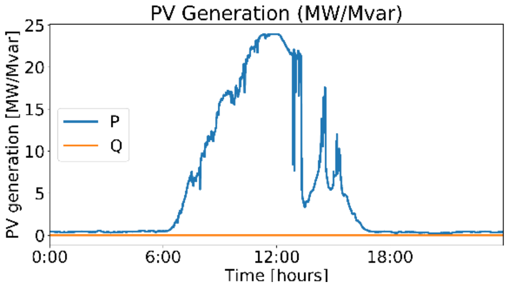
Baseline Results

- 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).

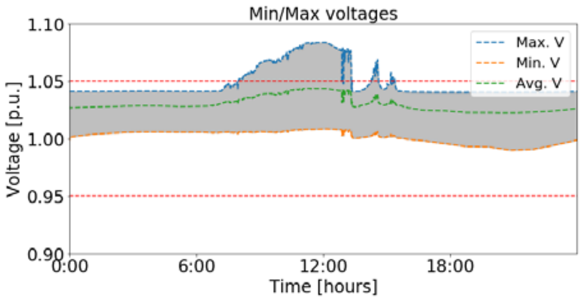
Demand at substation



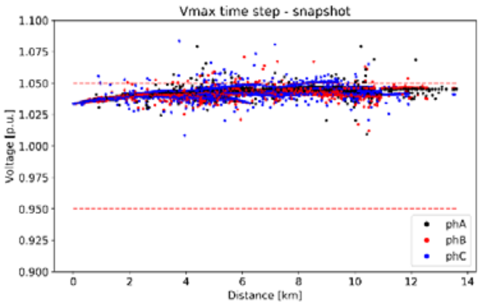
PV generation



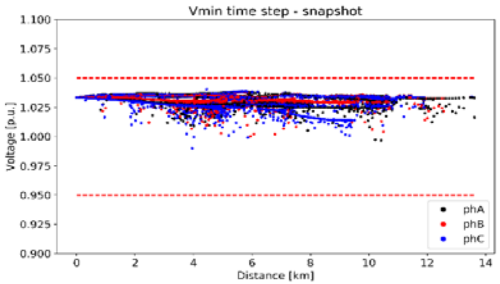
Voltage distribution

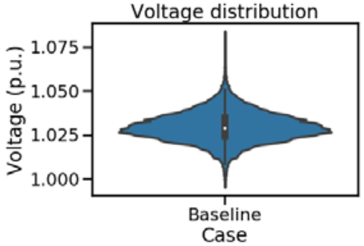


Voltage profile at Vmax time



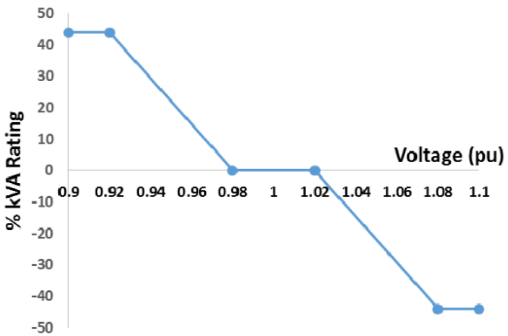
Voltage profile at Vmin time





S1: Control Objectives

PV smart inverters



Volt/var curve shape

ADMS

Objective: Voltage regulation

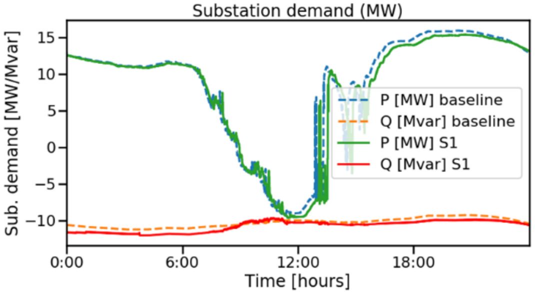
Voltage constraints: ANSI limits

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

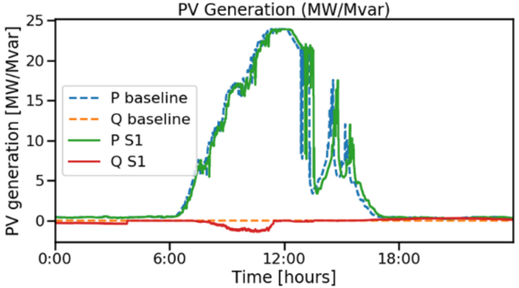
S1 Results

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

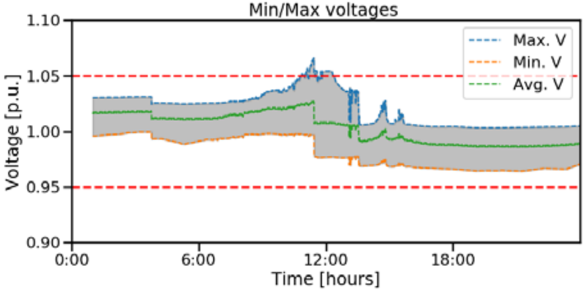
Demand at substation



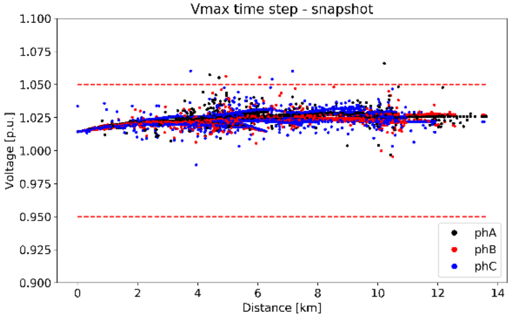
PV generation



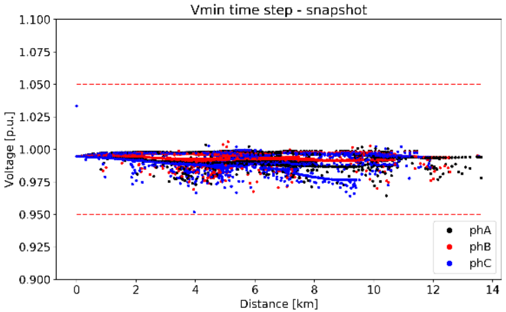
Voltage distribution

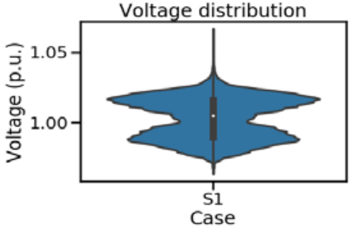


Voltage profile at Vmax time step



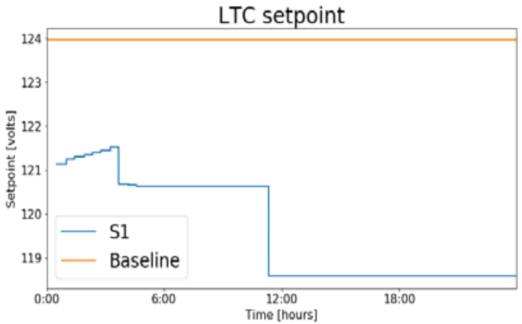
Voltage profile at Vmin time step



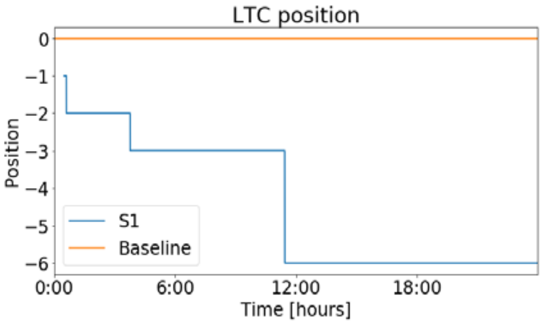


S1 Results: Legacy Device Statuses

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

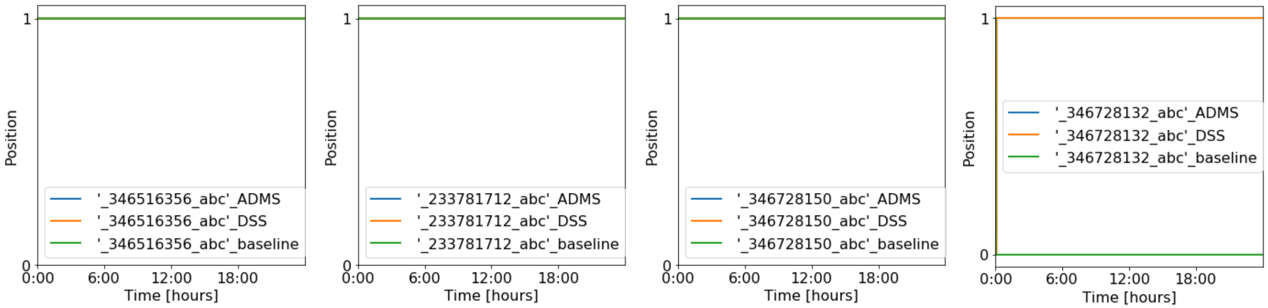


LTC set point from ADMS



LTC tap position in OpenDSS

Selected capacitor bank statuses



S2: Control Objectives

RTOPF

Objective: Voltage regulation

Voltage constraints limits: 0.96 p.u.–1.04 p.u.

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

where, $\mathbf{x^t} = \{p_j^t, q_j^t,\ j = 1, \ldots, NPV\}$, 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

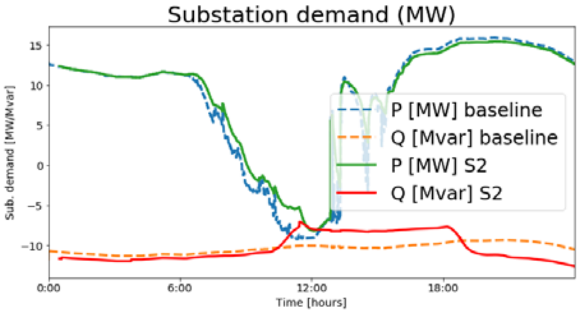
Objective: Voltage regulation

Voltage constraints: ANSI limits

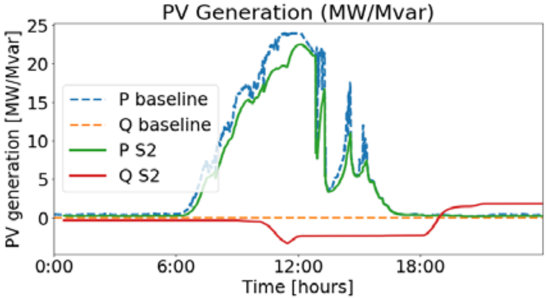
S2 Results

- 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 set points are the same as in S1.

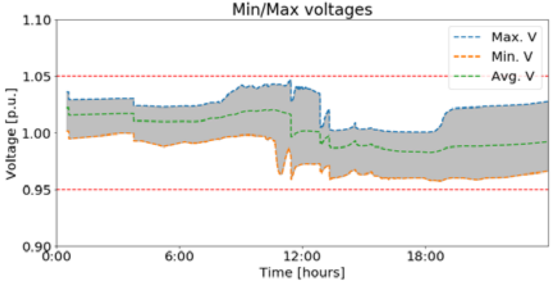
Demand at substation



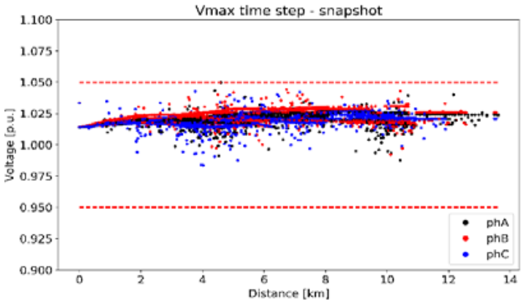
PV generation



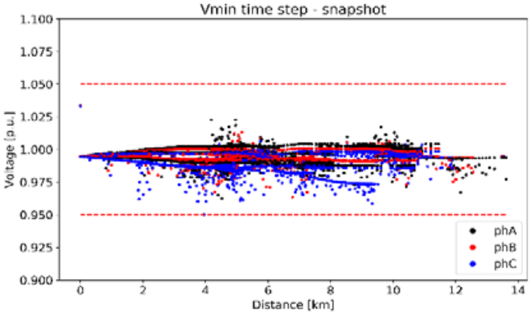
Voltage distribution

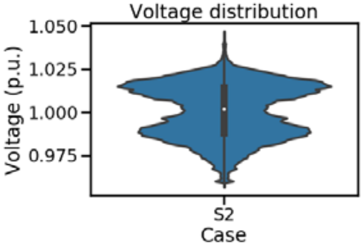


Voltage profile at Vmax time



Voltage profile at Vmin time step





Conclusions

- The simulations demonstrate the effectiveness of Data-Enhanced Hierarchical Control (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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