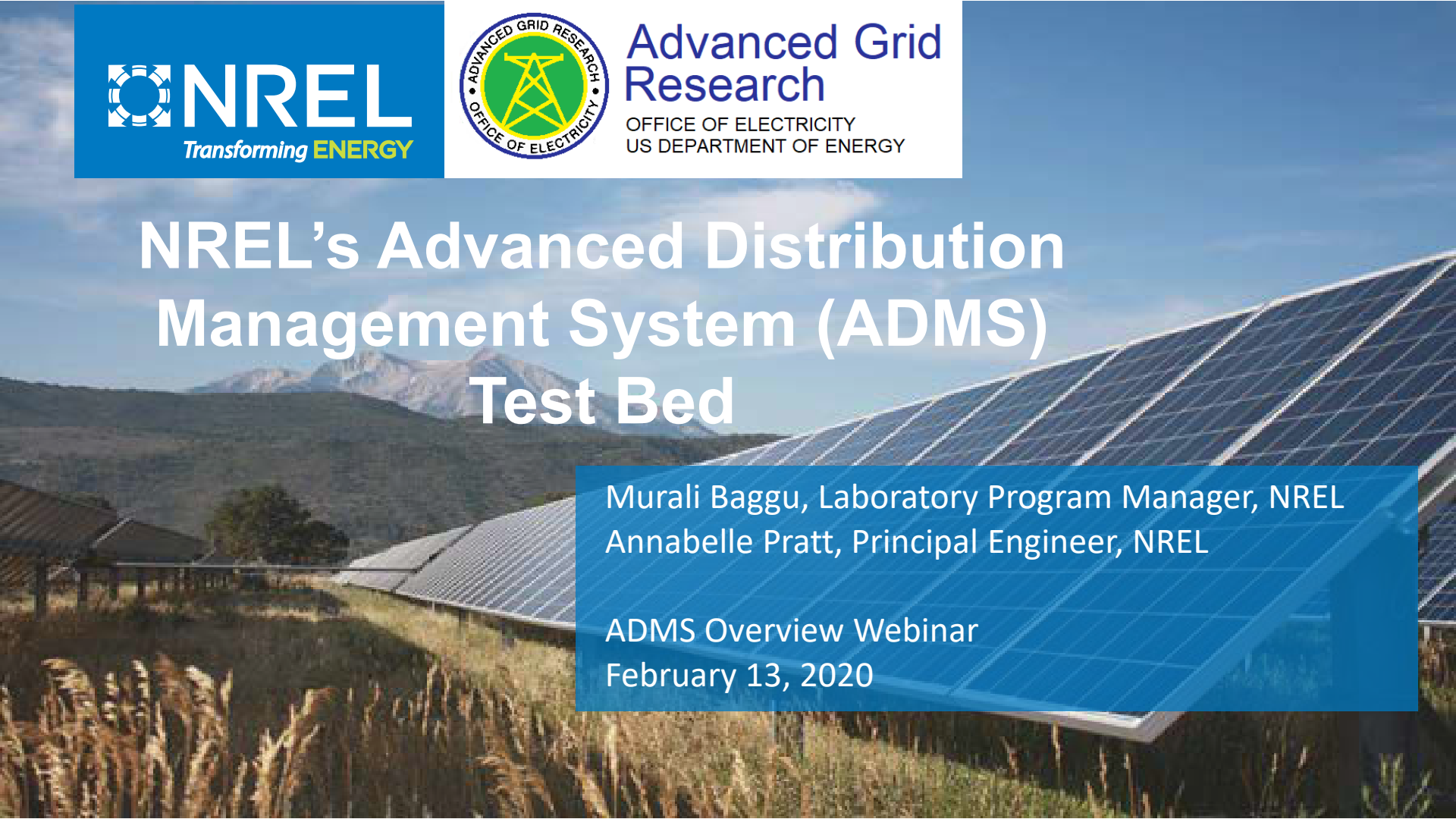

NREL Transforming ENERGY

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OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

# NREL's Advanced Distribution Management System (ADMS) Test Bed

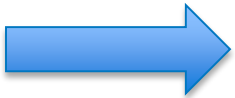
Murali Baggu, Laboratory Program Manager, NREL
Annabelle Pratt, Principal Engineer, NREL

ADMS Overview Webinar
February 13, 2020

# DOE ADMS and DERMS Core Development

*Transform utility electric distribution management systems to enable the integration and management of all assets and functions across the utility enterprise regardless of vendor or technology.*

**Today**
Closed, proprietary, vendor specific



**Future**
Open architecture, standards-based data exchange

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Four program areas:

**Platform:** Develop open-source platform; evaluate advanced applications.

**Test bed:** Build a vendor-neutral test bed to evaluate existing and future advanced distribution management system (ADMS) functionalities in a realistic setting.

**Applications:** Develop an initial suite of ADMS applications.

**Advanced control:** Develop new integrated optimization and control solutions.

# ADMS Test Bed Overview

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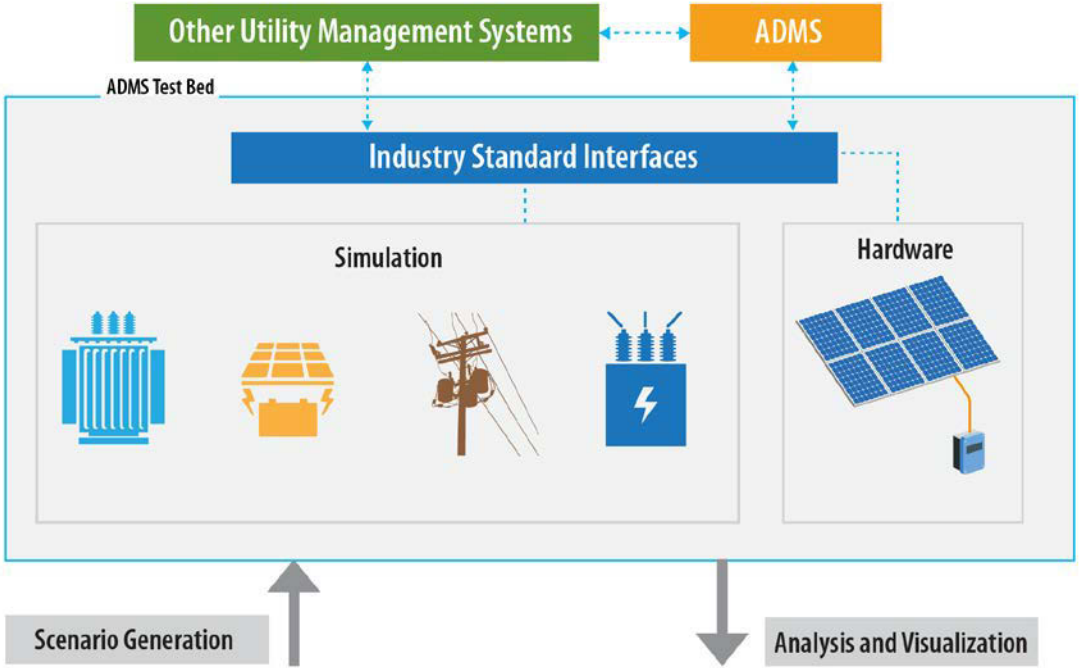
**Project description:**

- Model large-scale distribution systems for evaluating ADMS applications.
- Integrate distribution system hardware in the National Renewable Energy Laboratory's (NREL's) Energy Systems Integration Facility (ESIF) for hardware-in-the-loop (HIL) experiments.
- Develop advanced visualization capabilities.



# ADMS Test Bed Overview Cont.

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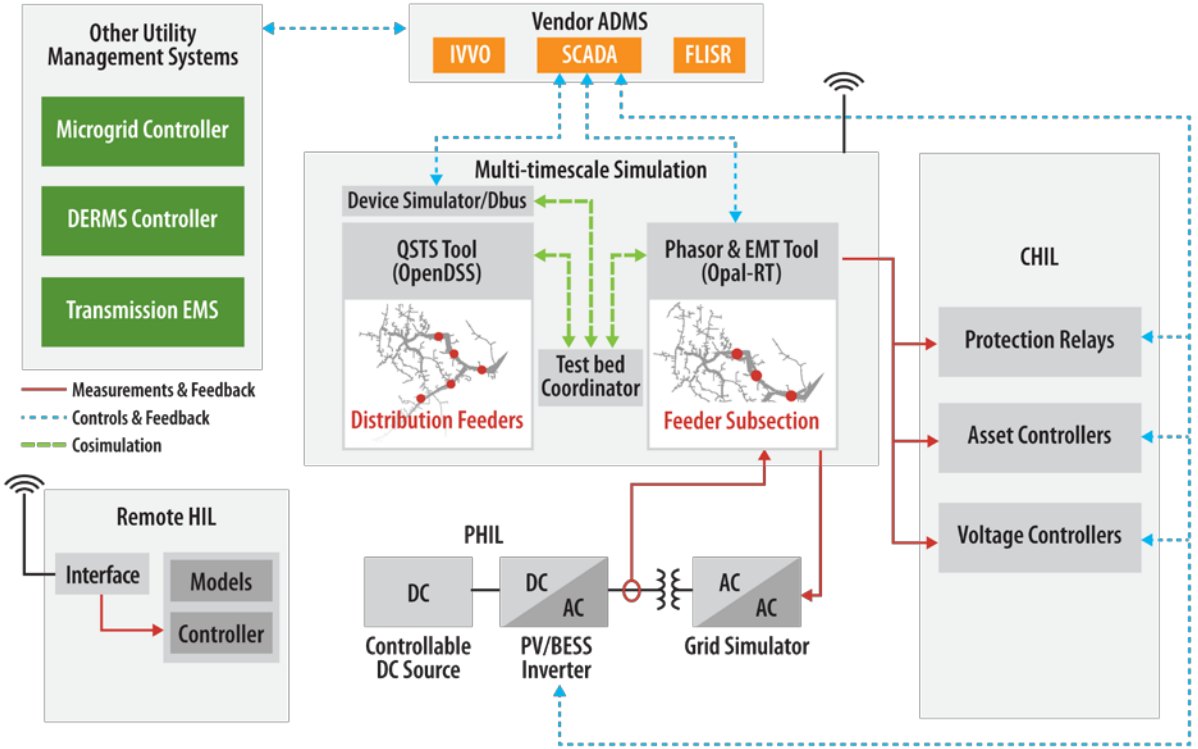

# Test Bed Setup

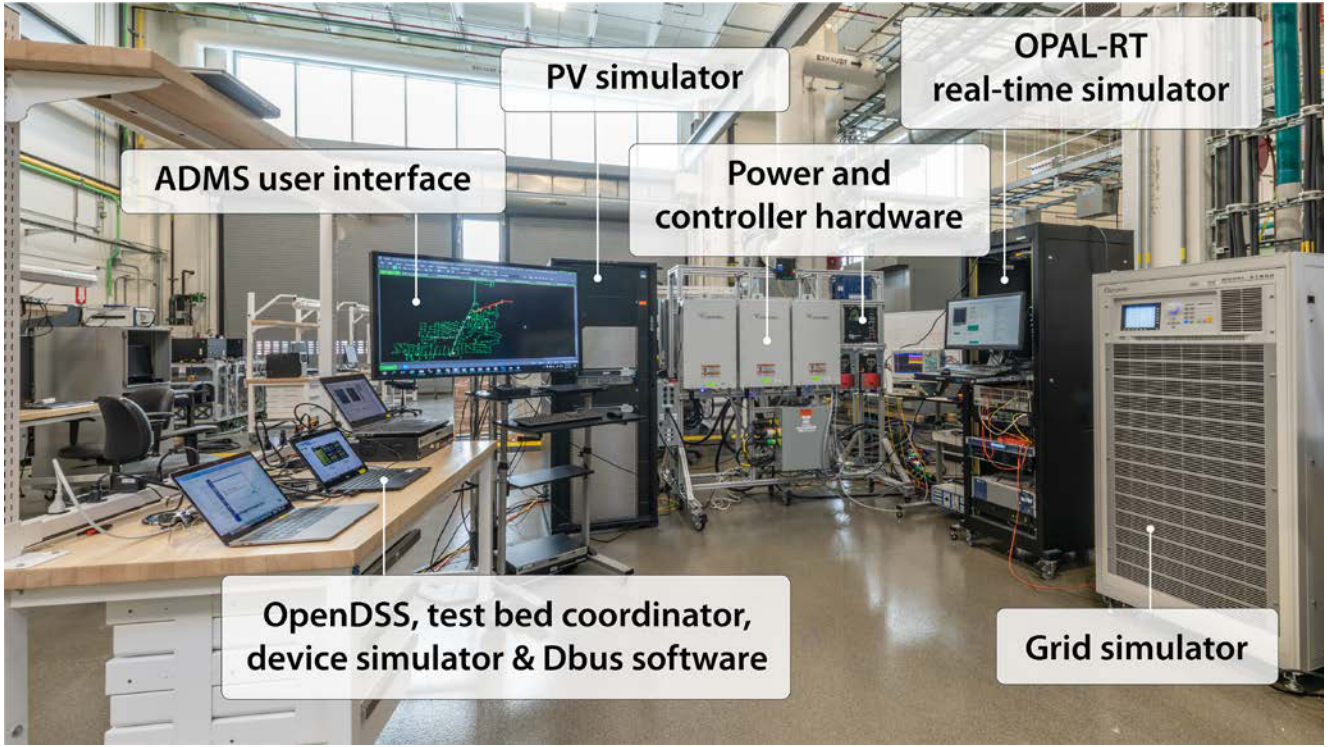


*Photo by NREL*

# Multi-Timescale Simulation

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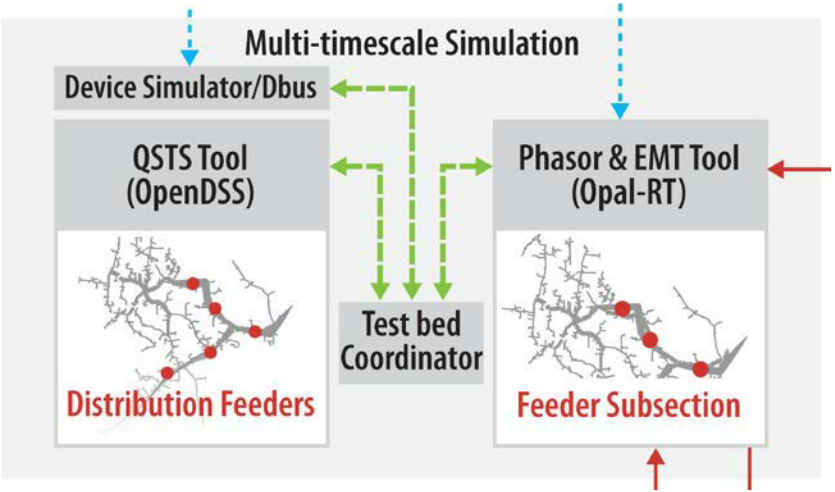
- Can select one or more simulators to fit use case.
- Can run parts of feeder in different simulators.
- <u>Currently using:</u>
  - OpenDSS by Electric Power Research Institute (EPRI)
    - Quasi-static time series (QSTS)
    - 1-s minimum time step; minutes typical.
  - ePHASORSIM by OPAL-RT:
    - Dynamic phasor
    - 1- to 10-ms time step
    - Developed load tap changer (LTC), capacitor bank, and voltage regulator models for controller-hardware-in-the-loop (CHIL)
    - Developed photovoltaic (PV) model for power-hardware-in-the-loop (PHIL).



# Multi-Timescale Simulation Cont.

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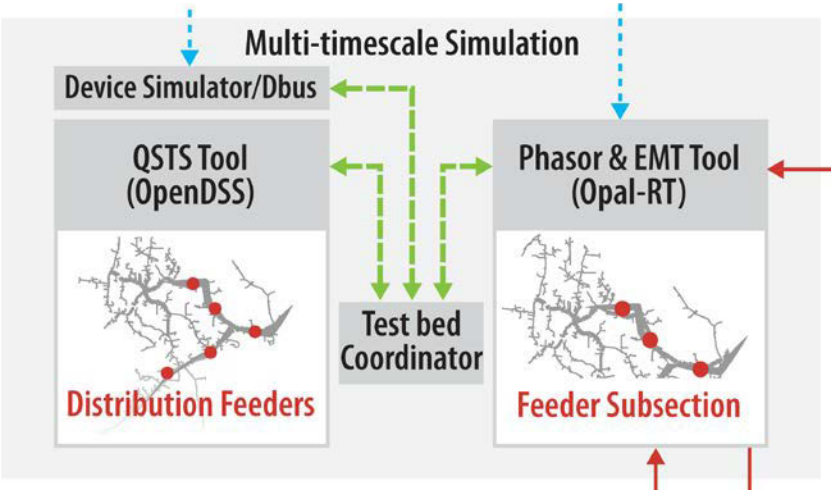
- Orchestrated by test bed coordinator software
- Written in Python
- Uses Hierarchical Engine for Large-Scale Infrastructure Co-Simulation (HELICS) framework:
  - U.S. Department of Energy (DOE) investment through Grid Modernization Initiative
  - www.helics.org



# Communications Interfaces

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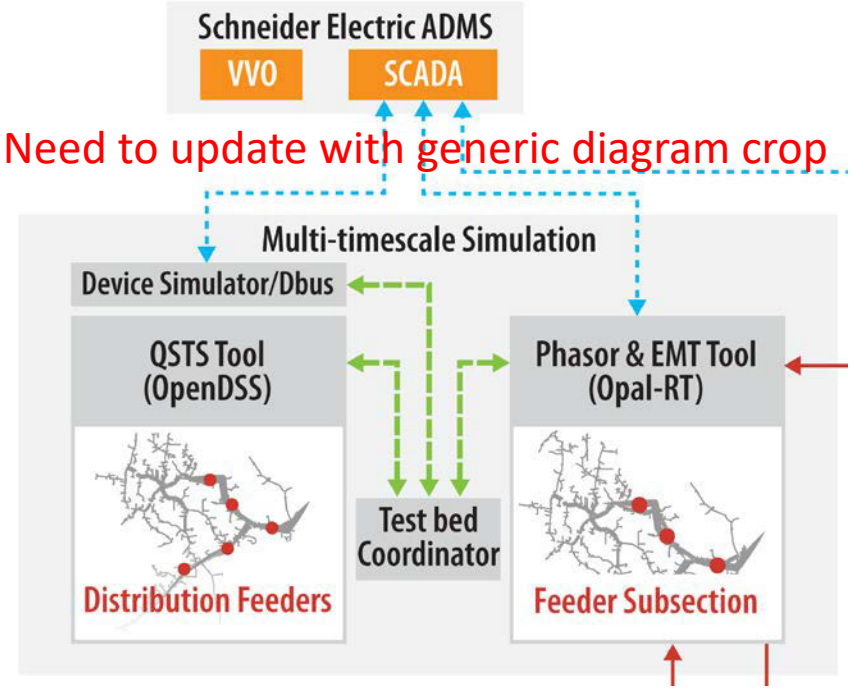
- Uses industry-standard interfaces
- ADMS to OpenDSS:
  - Device simulator developed by EPRI to provide communications interface
  - Interfaces through Dbus, a low-overhead data exchange based on TCP.
- ADMS to OPAL-RT:
  - DNP3 drivers available.



# Model Conversion Tools

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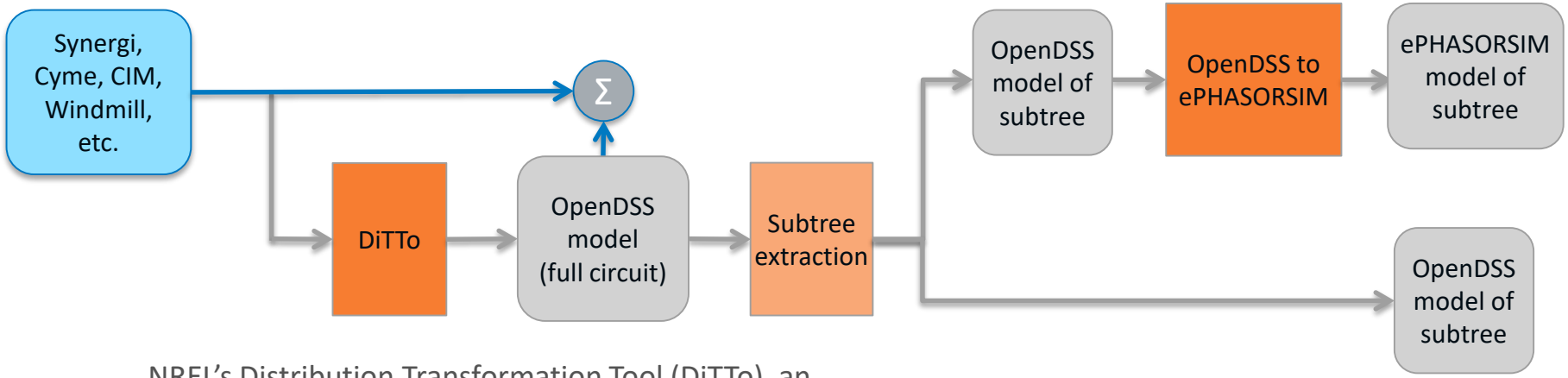
https://github.com/NREL/DSS2ePHASOR




NREL's Distribution Transformation Tool (DiTTo), an open-source framework to convert various distribution system modeling formats: https://github.com/NREL/ditto.

# Use Case 1: Objective

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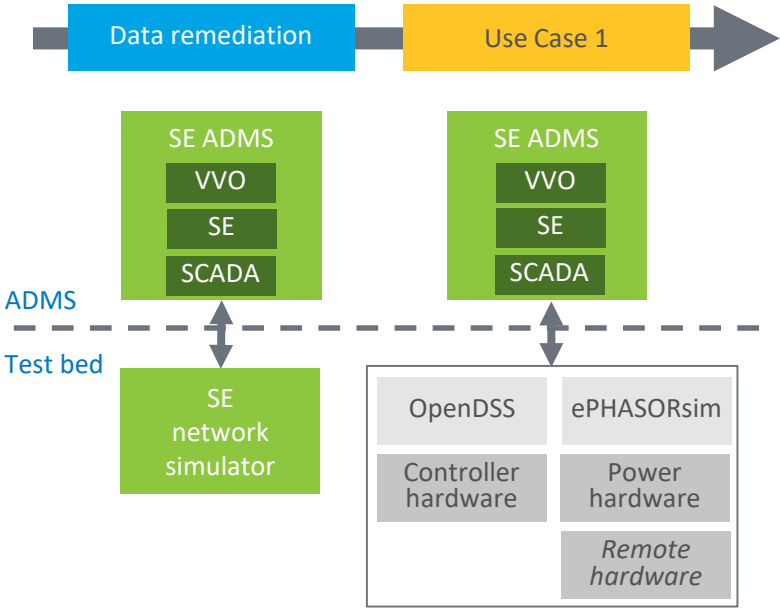
Evaluate performance of the ADMS Volt-Var optimization (VVO) application for different levels of model quality and different levels of measurement density:

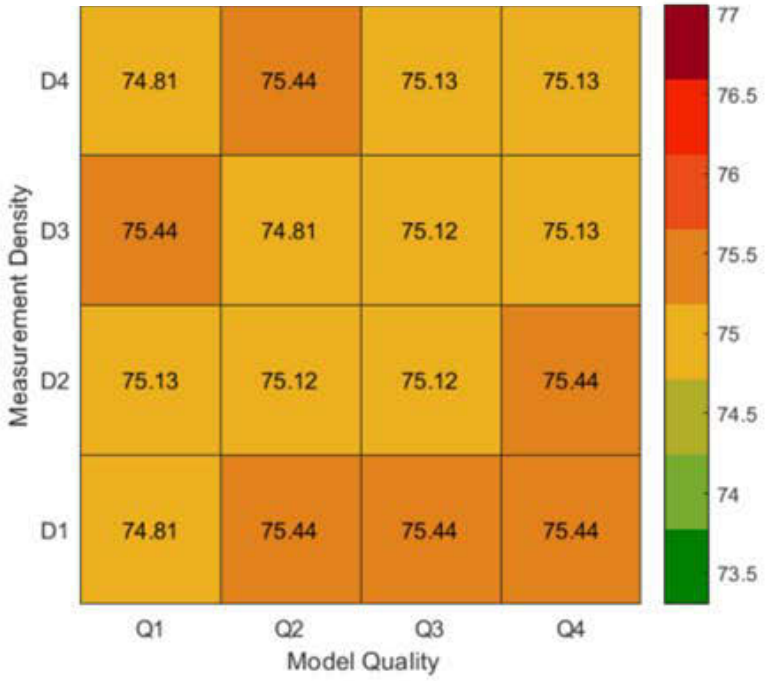
- Performance improvements from accurate model
- Offset model inaccuracies with additional telemetry
- Trade-off between model quality and telemetry density.



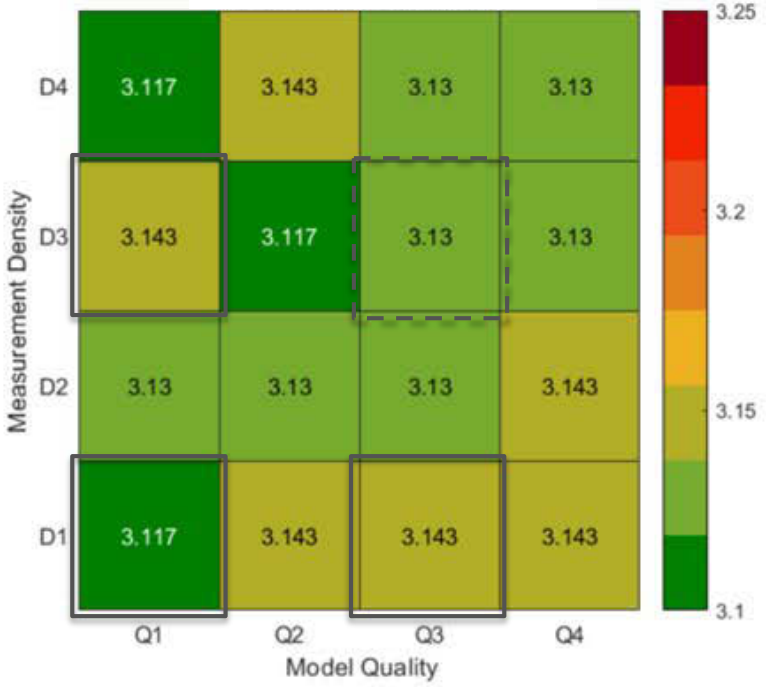
# Use Case 1: Phase 1 Simulation Results

- No significant impact for this feeder
- Other Xcel Energy feeders show more change.

Energy consumption estimates (MWh)




Power (MW, daily median)



# Use Case 1: Lab Setup

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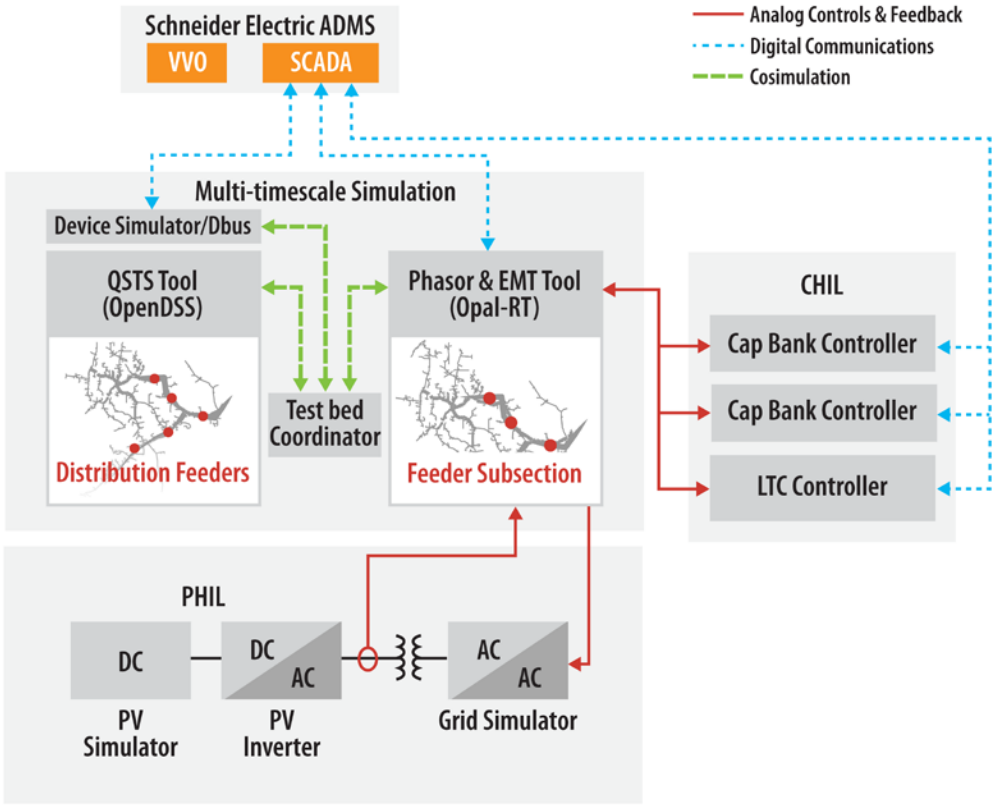
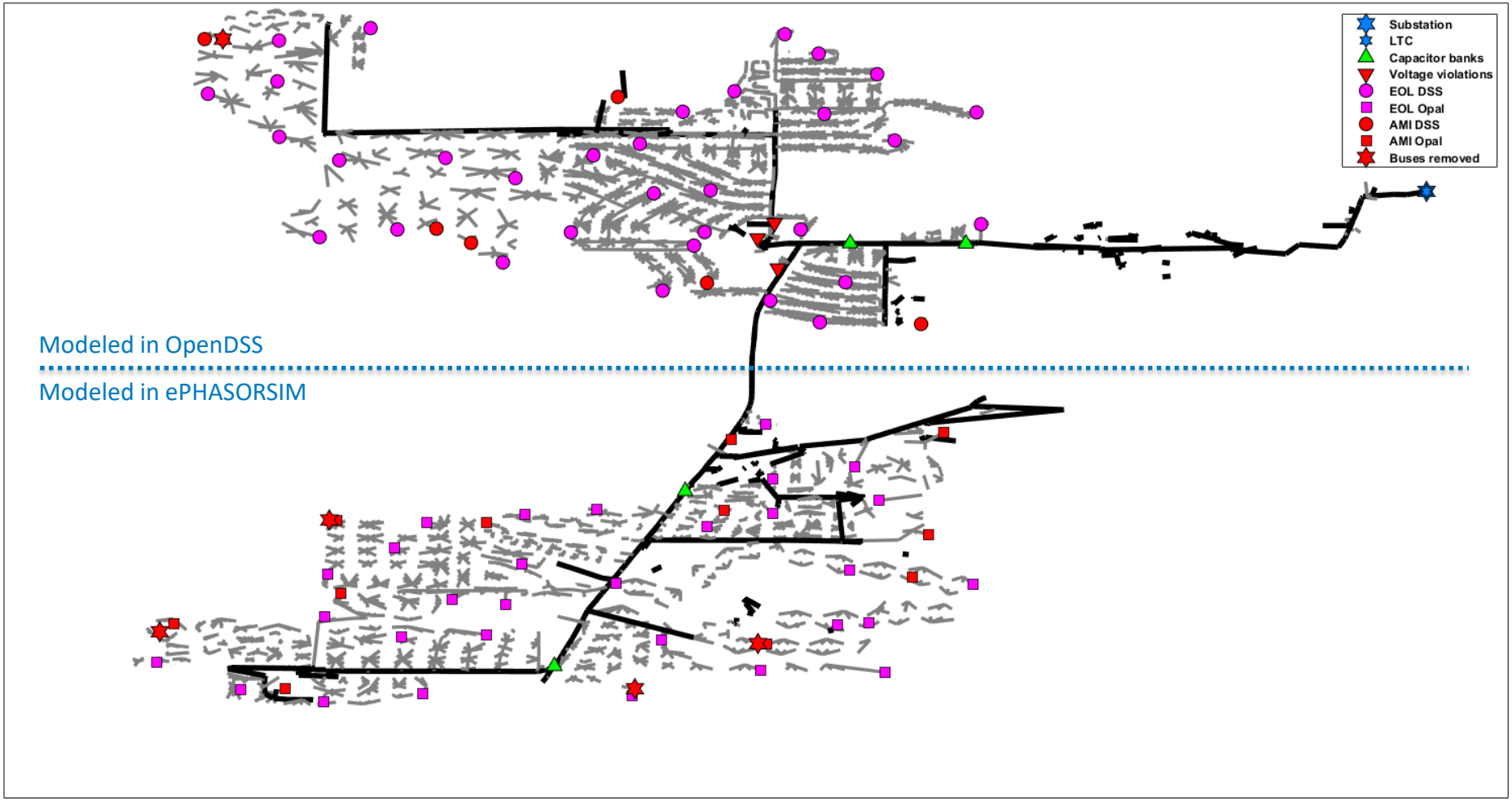



Partners:
Xcel Energy
Schneider Electric
PNNL
EPRI
Opal-RT


Substation
LTC
Capacitor banks
Voltage violations
EOL DSS
EOL Opal
AMI DSS
AMI Opal
Buses removed
Modeled in OpenDSS
Modeled in ePHASORSIM

# Light Load: Preliminary Results

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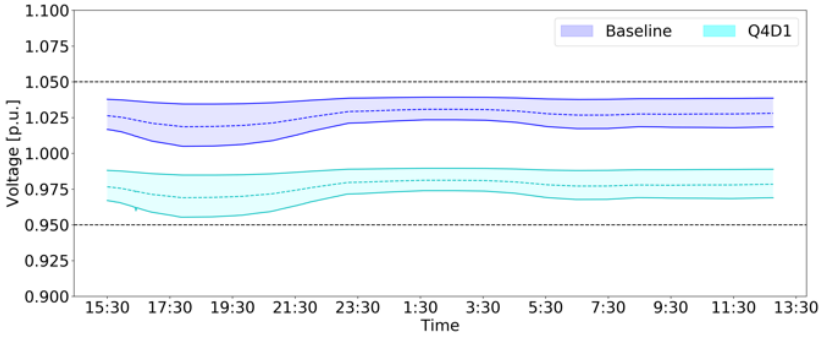
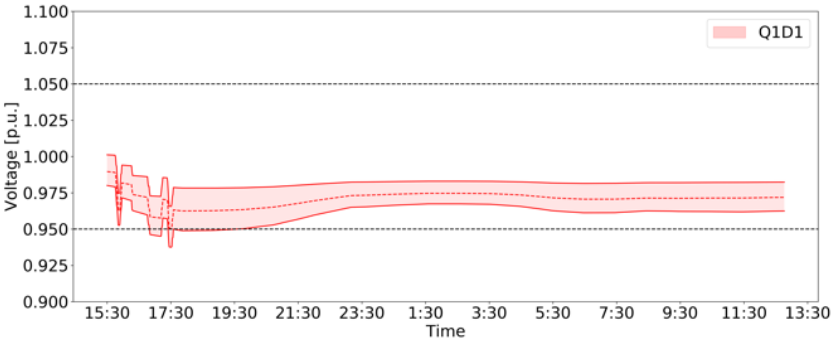
- D1: Only feeder-head measurements
- Q1: Lowest ADMS model quality
- Q4: Highest ADMS model quality.




Pratt, A., I. Mendoza, M. U. Usman, S. Tiwari, H. Padullaparti, M. Baggu, and E. Lightner. Forthcoming. “Using an Advanced Distribution Management System Test Bed to Evaluate the Impact of Model Quality on Volt/VAR Optimization.” To be presented at the 2020 IEEE Transmission and Distribution Conference and Exposition, Chicago, Illinois, April 2020.

# Use Case 2: Objective

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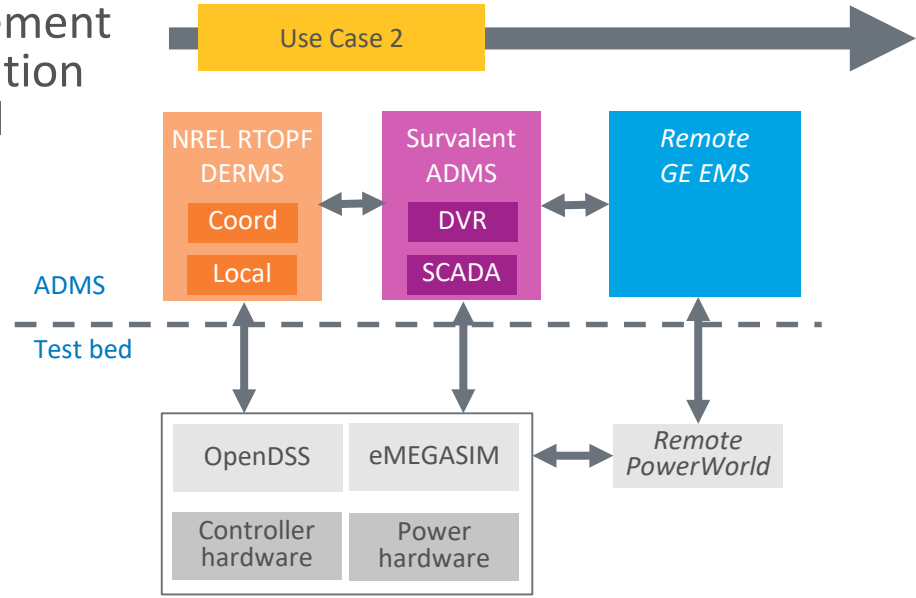
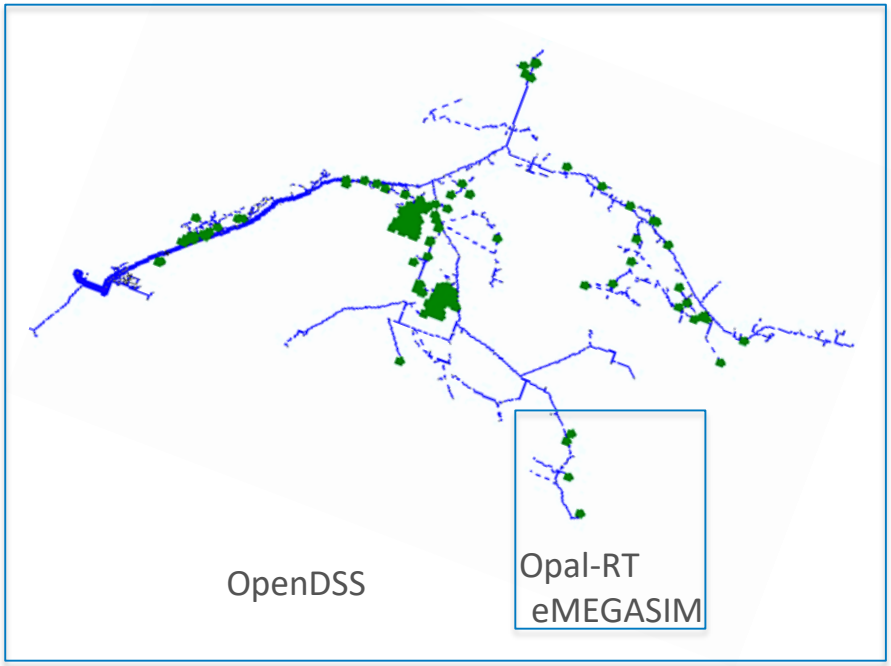
Evaluate performance of peak load management use case coordinated across ADMS, distribution energy management systems (DERMS), and energy management systems (EMS):

- Effectiveness of DERMS in complementing ADMS operations
- Communications interface between ADMS and DERMS
- Focus on municipal and cooperative utilities.



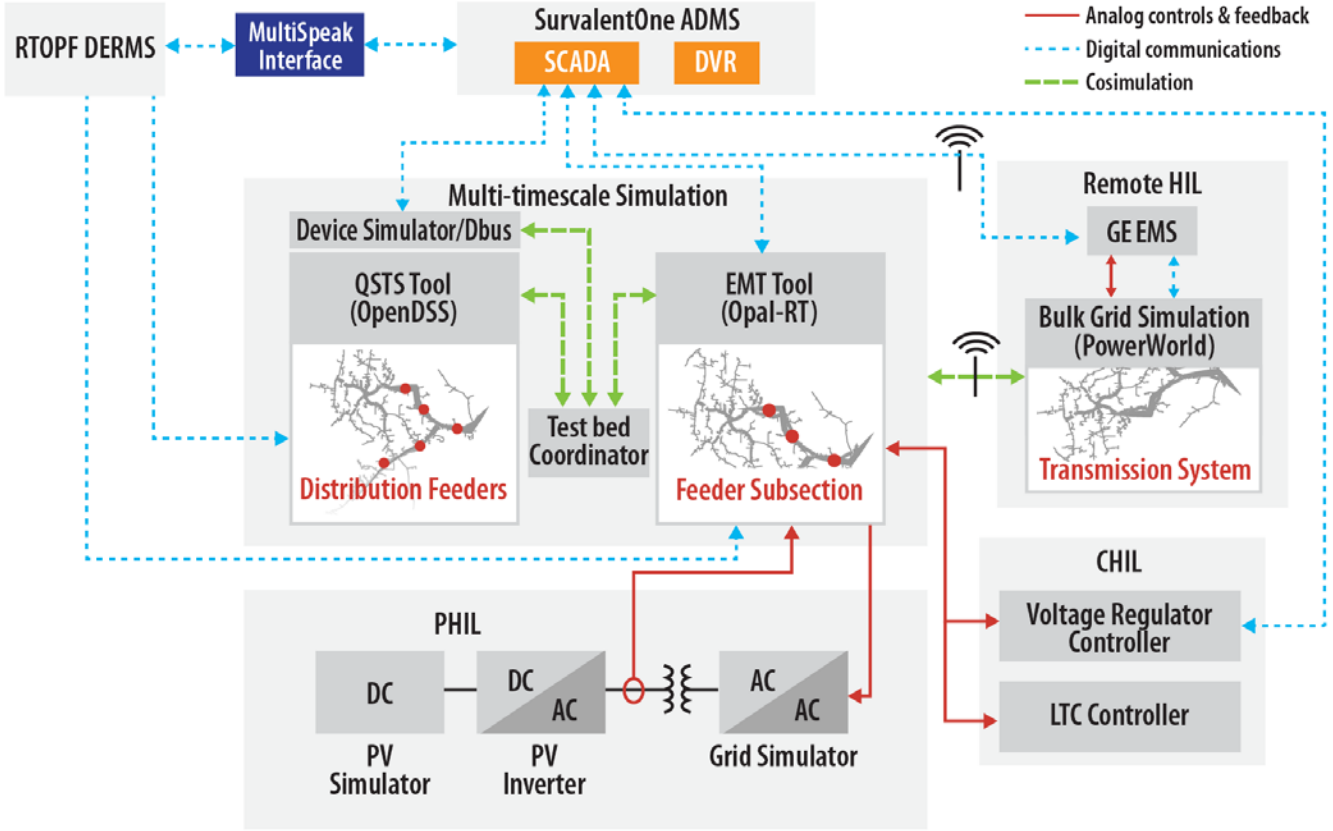
# Holy Cross Energy Feeder




Selected feeder:

- 4,039 buses
- 1,137 loads,
- peak load on 2017.01.27 8–9 a.m.
- Existing photovoltaic (PV) capacity is
  - 226 kW residential at 38 locations
  - 200 kW PV power plant

# Use Case 2: Lab Setup




Partners:

Holy Cross Energy

Survalent

NRECA

PNNL

EPRI

Opal-RT

Advanced Grid Research

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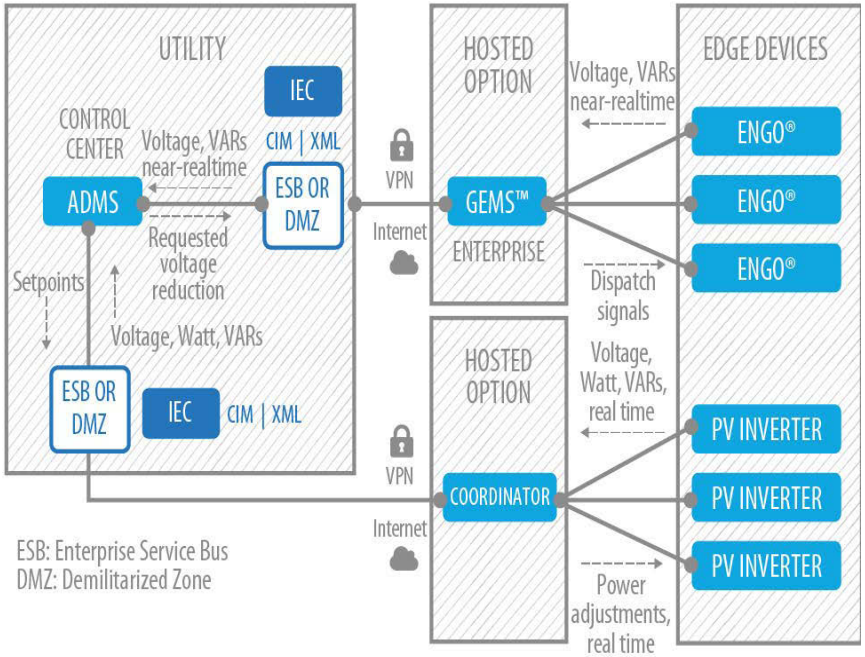
# ENERGISE ECO-IDEA Project

- The project targets developing and validating 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
- Comprehensive situational awareness
- Cybersecure and interoperable.




SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Data-Enhanced Hierarchical Hardware-in-the-Loop Test Setup

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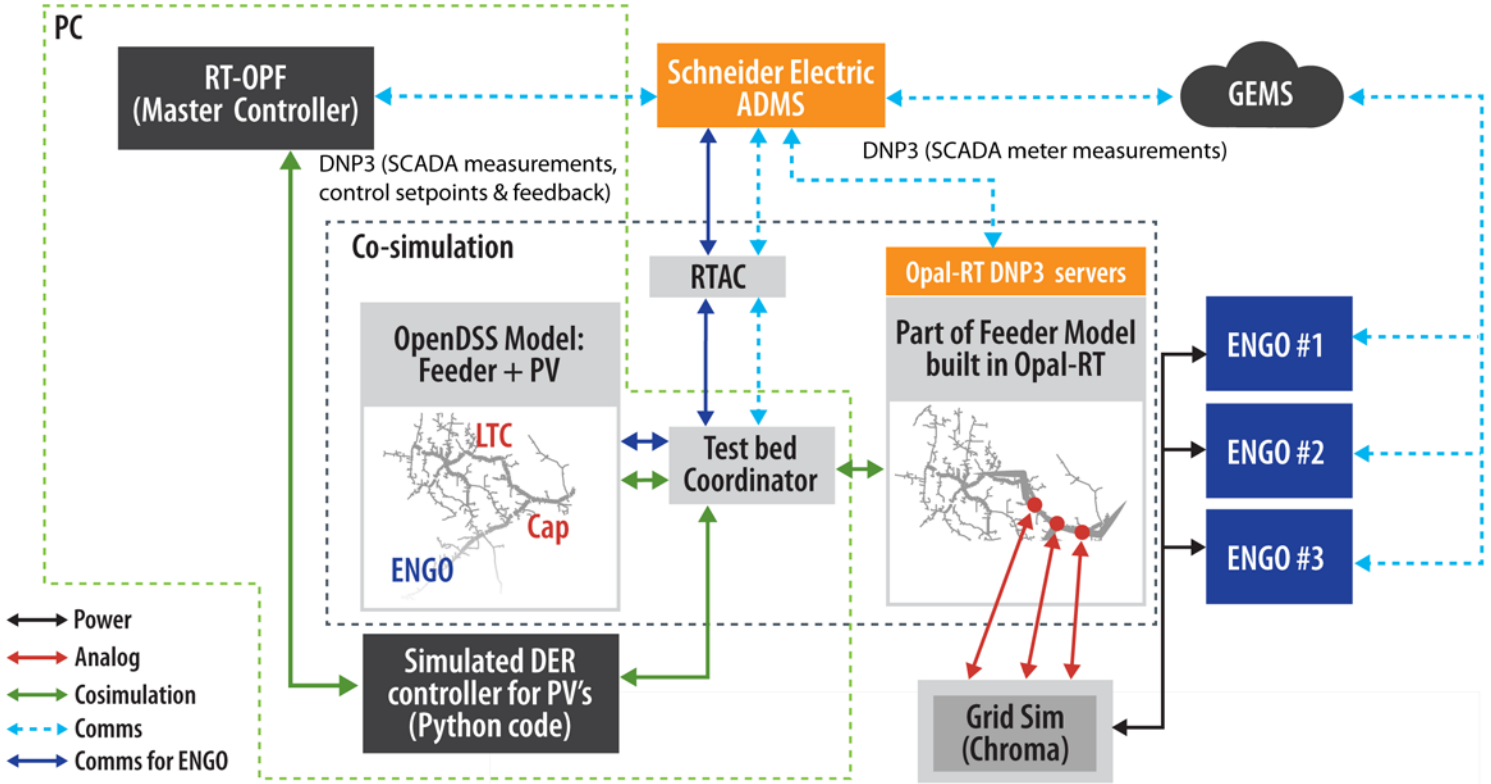
U.S. Department Of Energy




Partners:
Xcel Energy
Schneider Electric
EPRI
Varentec

# Hardware-in-the-Loop Test

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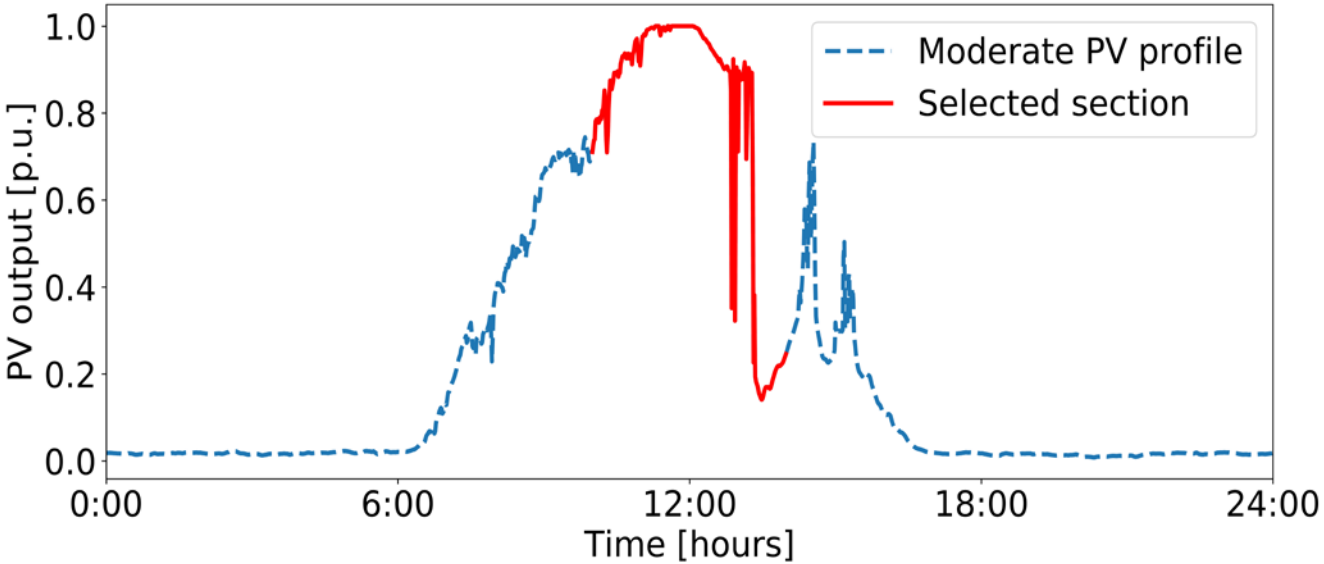
**Test scenario: Evaluate DEHC functionality of coordinated controls to achieve desired voltage profile (0.95–1.05 p.u.).**

Test condition: Moderate PV profile day, from 10:00–14:00.

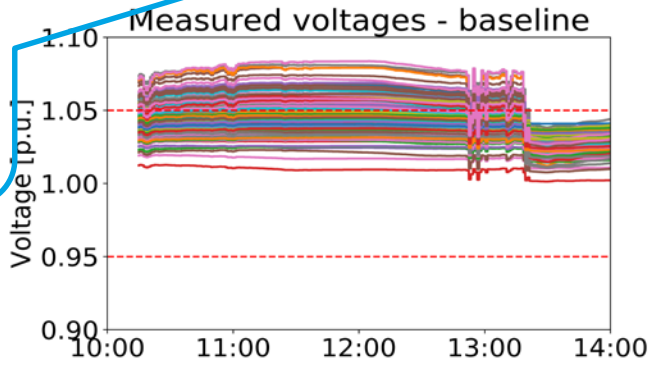


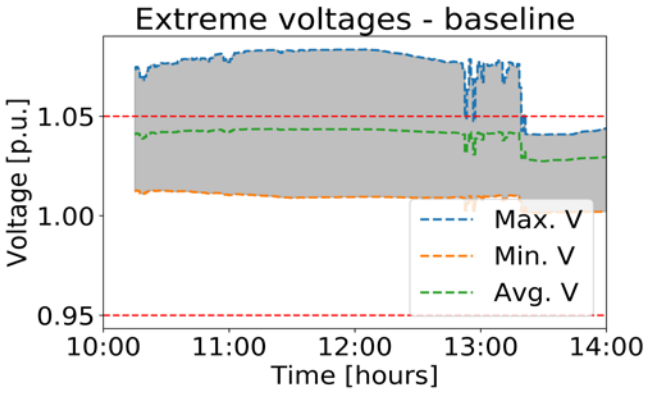
# Hardware-in-the-Loop Test Results

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

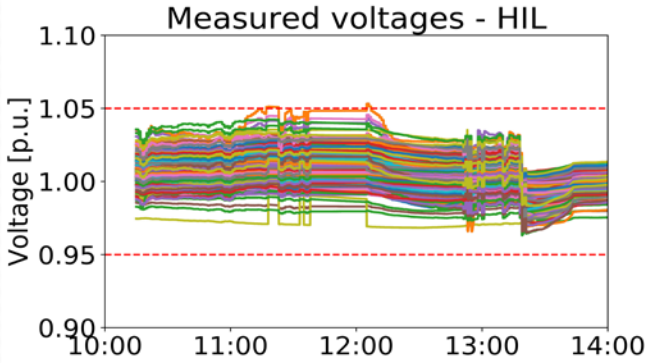
No ADMS control: LTC and cap. bank local control, no ENGOs, PV local control

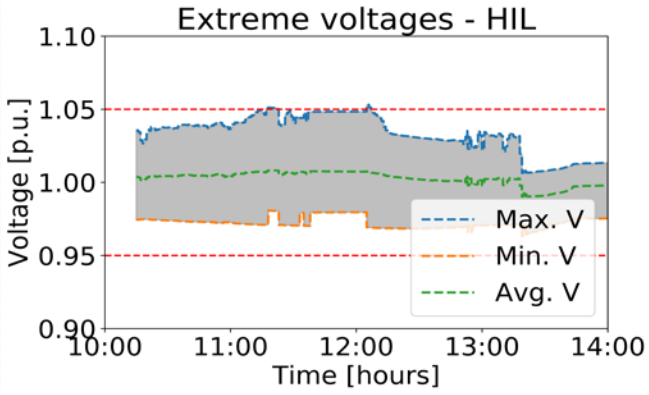
## Baseline




## DEHC operation HIL test



# Hardware-in-the-Loop Test Results

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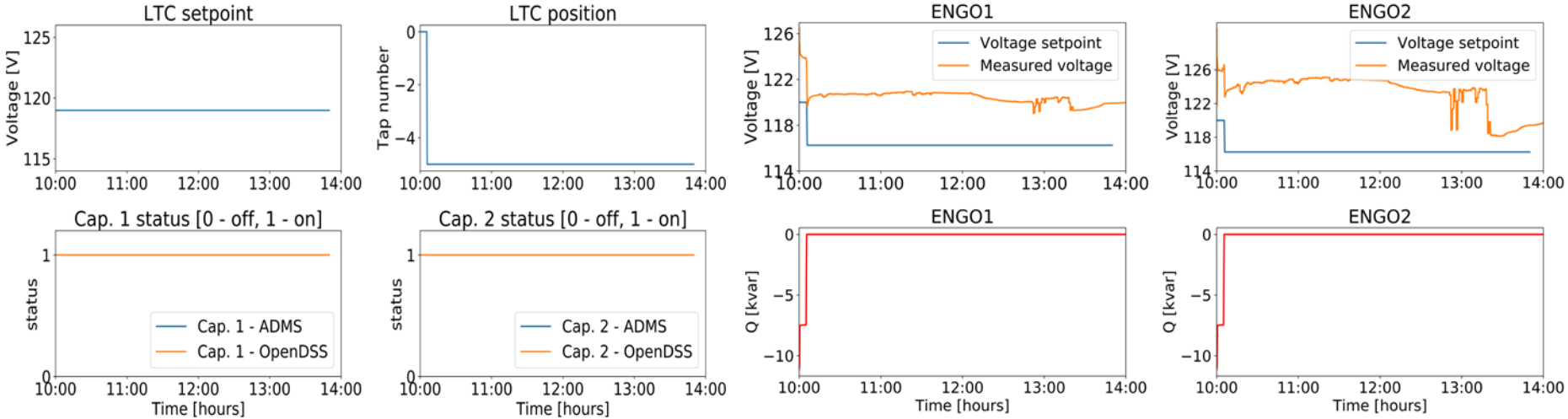


- ADMS sets the tap position of the LTC very low (-5) to reduce the system voltage.
- ADMS gives priority to the LTC to regulate the system voltage before changing commands to the capacitor banks.

# Hardware-in-the-Loop Test Results

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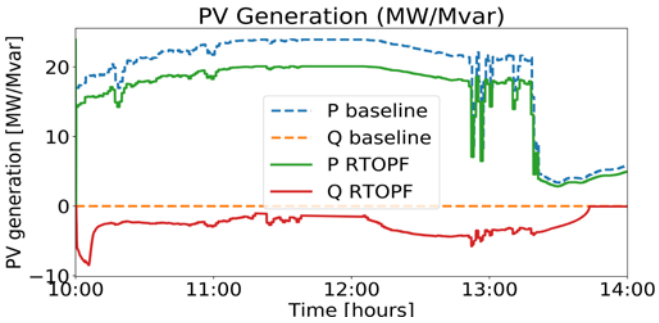
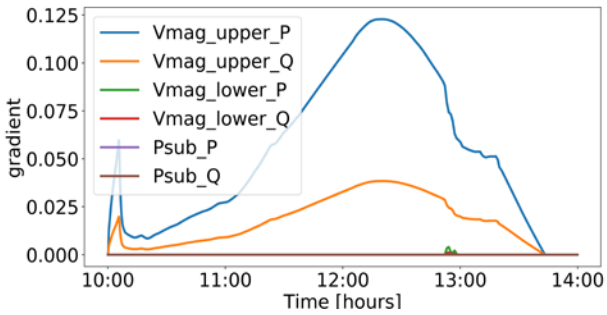
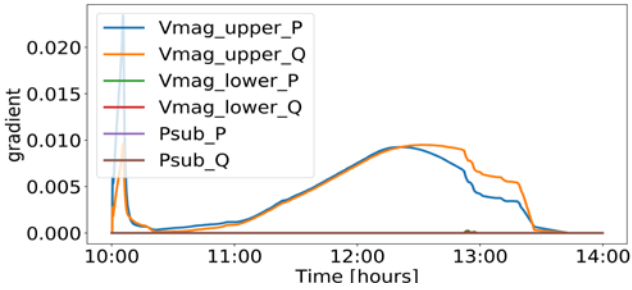
## Total PV generation



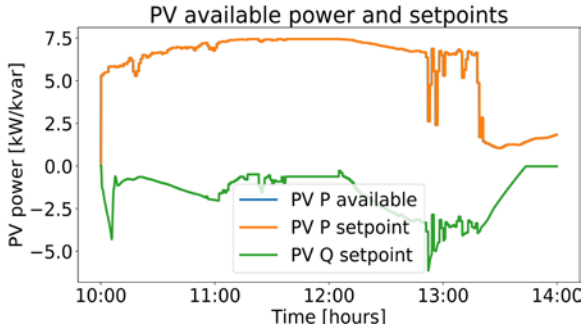

## RTOPF coordinator outputs

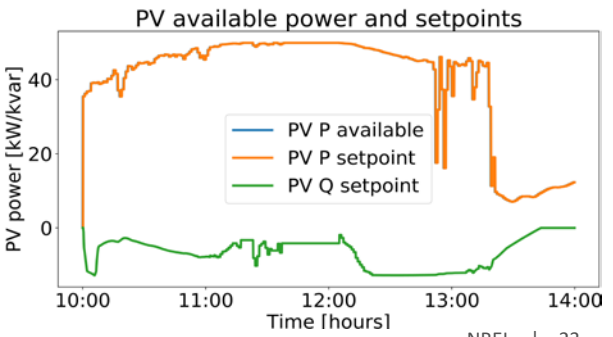



- The Real-Time Optimal Power Flow (RTOPF) algorithms (coordinator and local controllers) converge and work as expected to regulate system voltages,

## RTOPF PV local controller outputs



# Hardware-in-the-Loop Test Results

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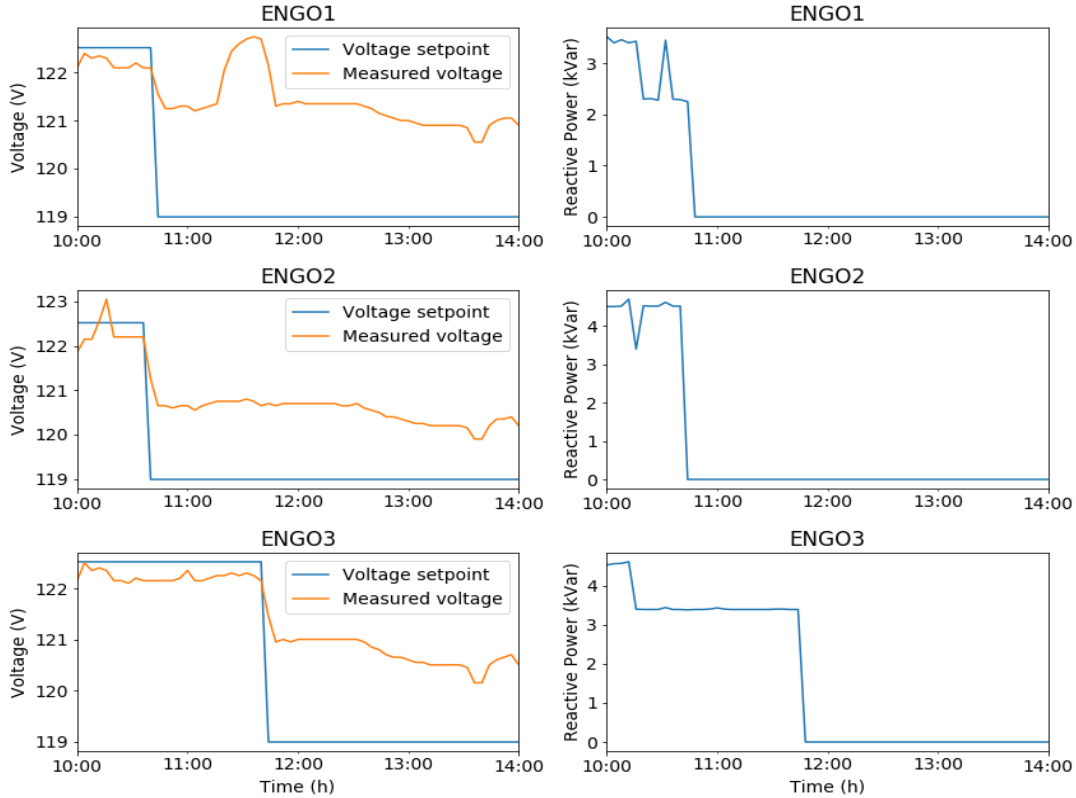
## Hardware ENGOs




- The Edge of Network Grid Optimization units (ENGOs) inject reactive power only when the voltage set point is higher than its measured voltage. This is as expected.

# ADMS Test Bed Use Case Development

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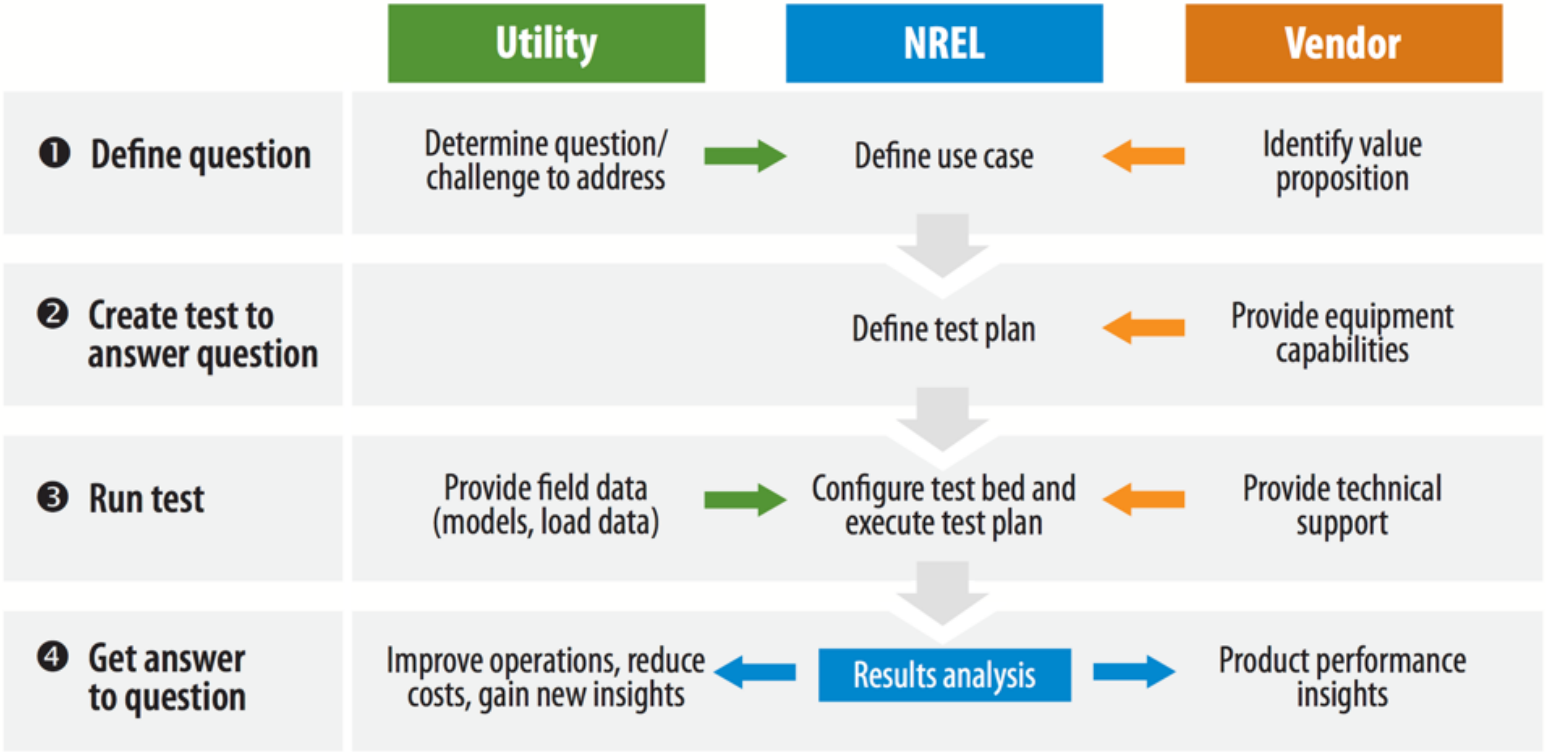

# Thank you

Annabelle.Pratt@nrel.gov

www.nrel.gov

NREL/PR-5D00-75936



This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Electricity, Advanced Grid Research & Development and the Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# Data Collection and Management

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- Architected and implemented data management tools
- C++ code on GitHub (https://github.com/NREL/rts-vis-app and https://github.com/NREL/rts-data)
- 3-D visualization also developed.

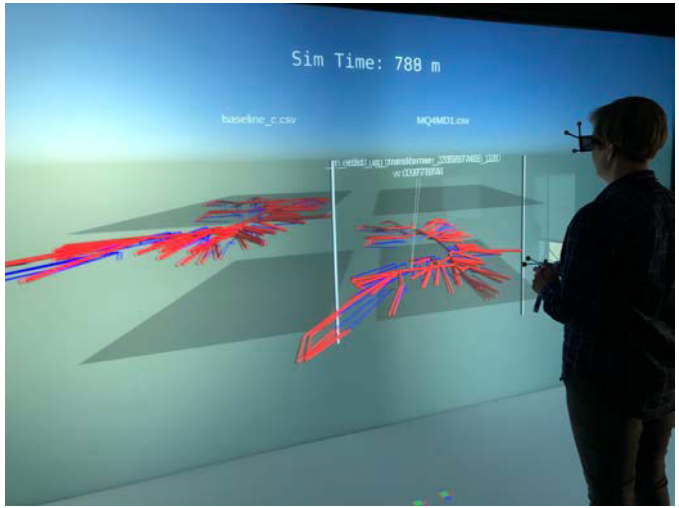
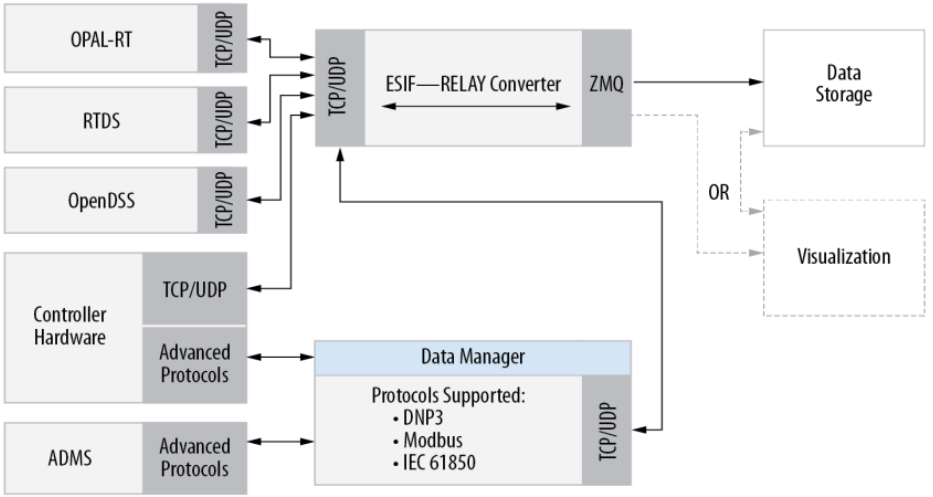



*Photo by NREL*



# Use Case 1: ADMS Test Bed Setup Cont.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- Experiments run from 15:30 until 13:30 p.m. to allow almost 24-hour simulation and changeover time
- ADMS can control LTC and four capacitor banks:
  - LTC in OpenDSS using LTC CHIL
  - Two in OpenDSS using device simulator software
  - Two in Opal-RT, one using capacitor bank controller CHIL and one simulated in ePHASORSIM (can run second as RHIL to PNNL).

# Light Load: Preliminary Results

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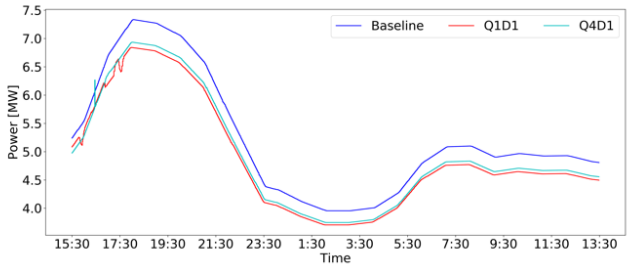


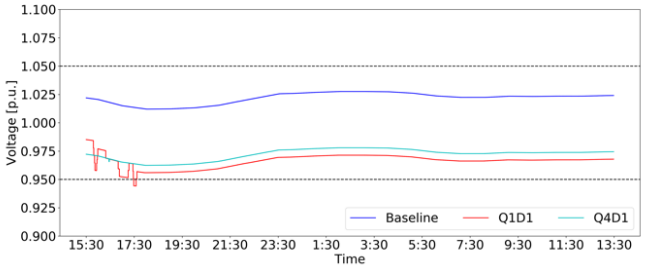


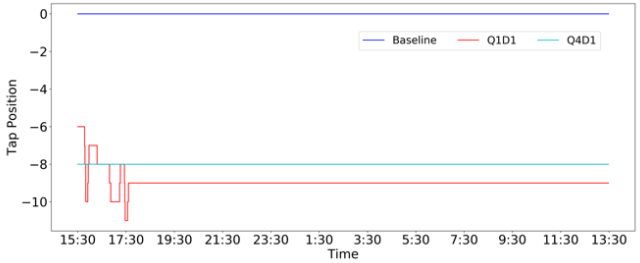

# Light Load: Metrics

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| | Number of Capacitor Changes | Number of LTC Tap Changes | Energy Savings (%) | Number of Voltage Violations |
|---|---|---|---|---|
| **Baseline** | 0 | 0 | N/A | 0 |
| **Q4D1** | 0 | 54 | 6.1 | 1702 |
| **Q4D3** | 0 | 47 | 4.6 | 12 |

# Levels of Model Quality


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- **Level 1 (Q1) –** Base-level data extracted from the Xcel Energy GIS adjusted just enough for power flow convergence.
- **Level 2 (Q2) –** In addition to Level 1, field verification at select locations to obtain wire size/material (if unknown), capacitor, regulator, recloser, and step transformer attributes (locations noncontiguous).
- **Level 3 (Q3) –** In addition to Level 2 remediation, phasing information collected through field verification at select locations.
- **Level 4 (Q4) –** In addition to Level 3, field confirmation performed for each primary circuit to obtain distribution transformer attributes, identifying new assets not shown in the GIS data and identifying assets that no longer exist in the field.

# Levels of Measurement Density


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**Level 1 (D1)** – Feeder head and tail-end measurements.

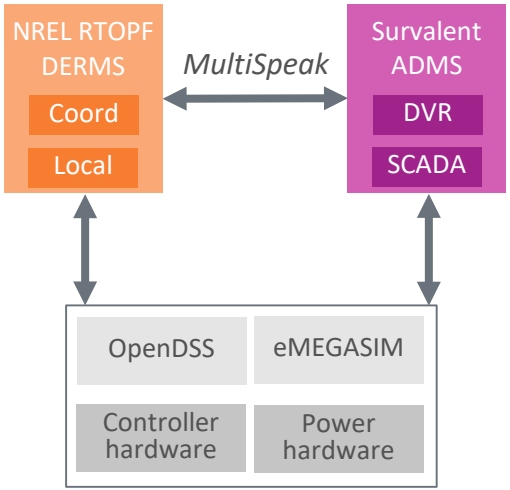
**Level 2 (D2)** – Measurements from Level 1, voltage regulators, capacitor banks, reclosers, and one tail-end voltage sensor (AMI sensor) per feeder with communications.

**Level 3 (D3)** – Measurements from Level 2 and a total of 10 AMI sensors per feeder.

**Level 4 (D4)** – Measurements from Level 2 and a total of 20 AMI sensors per feeder.

# ADMS and DERMS Coordination with MultiSpeak

1. Voltages and feeder head powers
2. Load management request and *feeder head power references*
3. Distributed energy resource (DER) group capacity.

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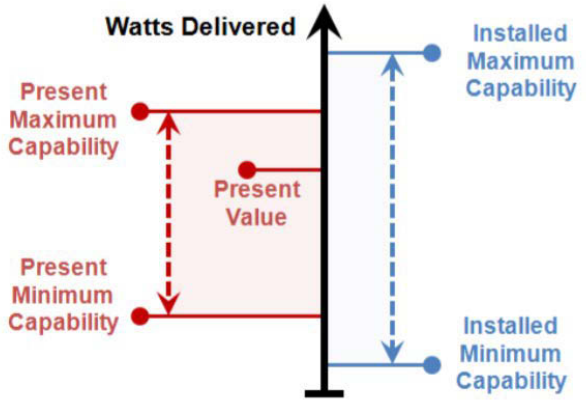
# DERMS Capacity and Status Monitoring

The National Rural Electric Cooperative Association has defined a method in MultiSpeak to communicate DER capacity:

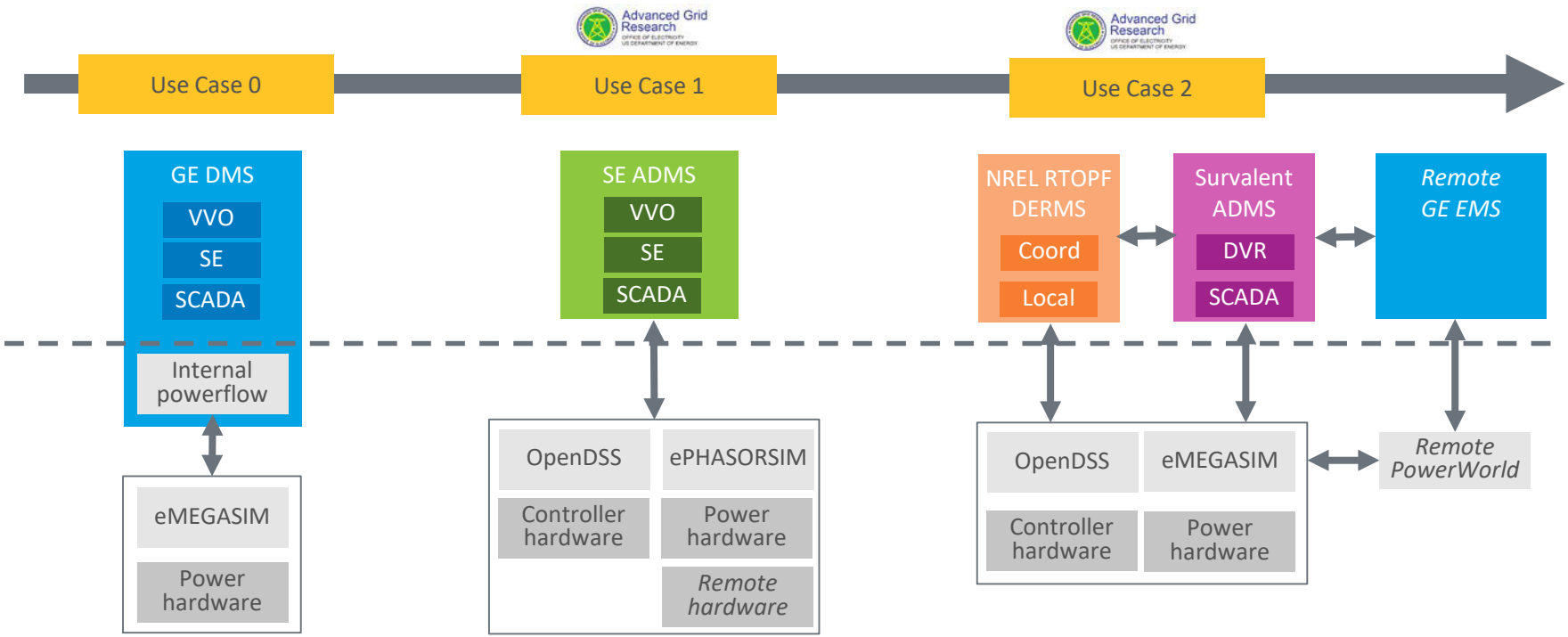
- Made available in MultiSpeak sandbox for the project
- ADMS can use this to determine DERMS power set points.
- Based on EPRI's *Common Functions for DER Group Management, 3rd Ed.*

**The purpose of this function is to read/report the present status of a DER group:**

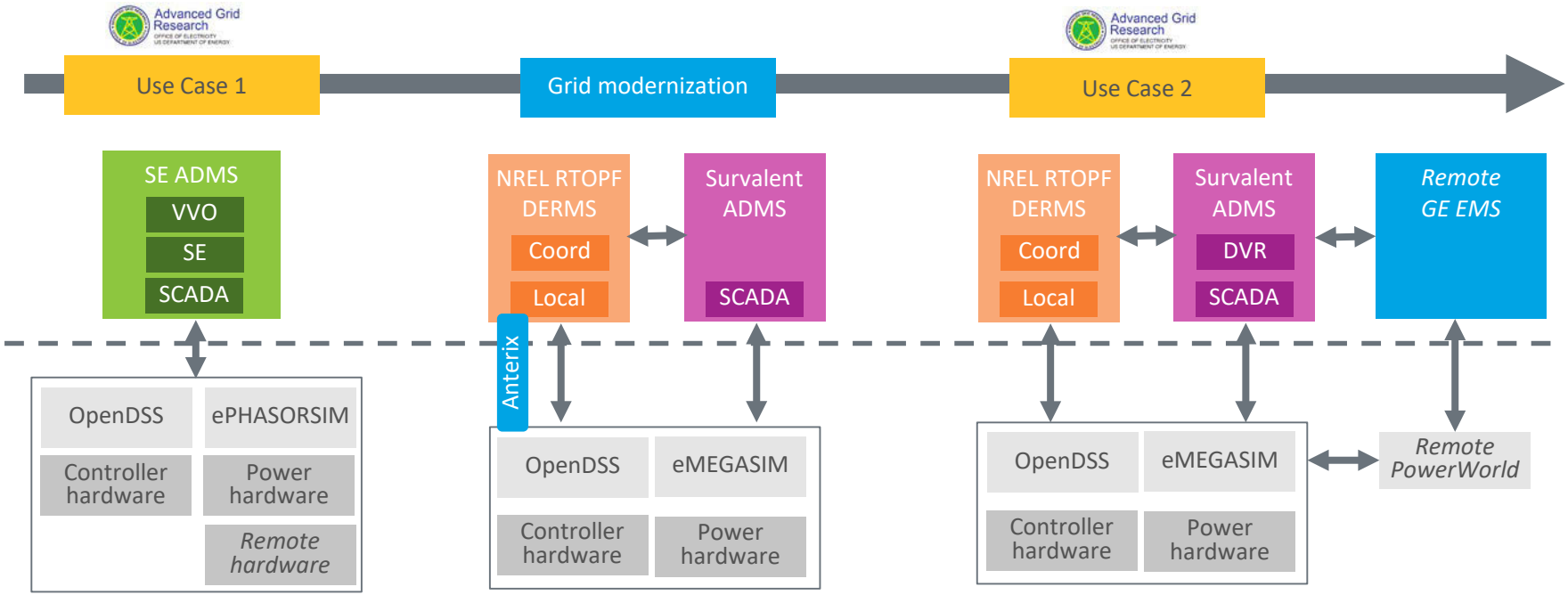
- Present value
- Maximum value to which it can presently be adjusted
- Minimum value to which it can presently be adjusted.



# ADMS Test Bed Capability Development

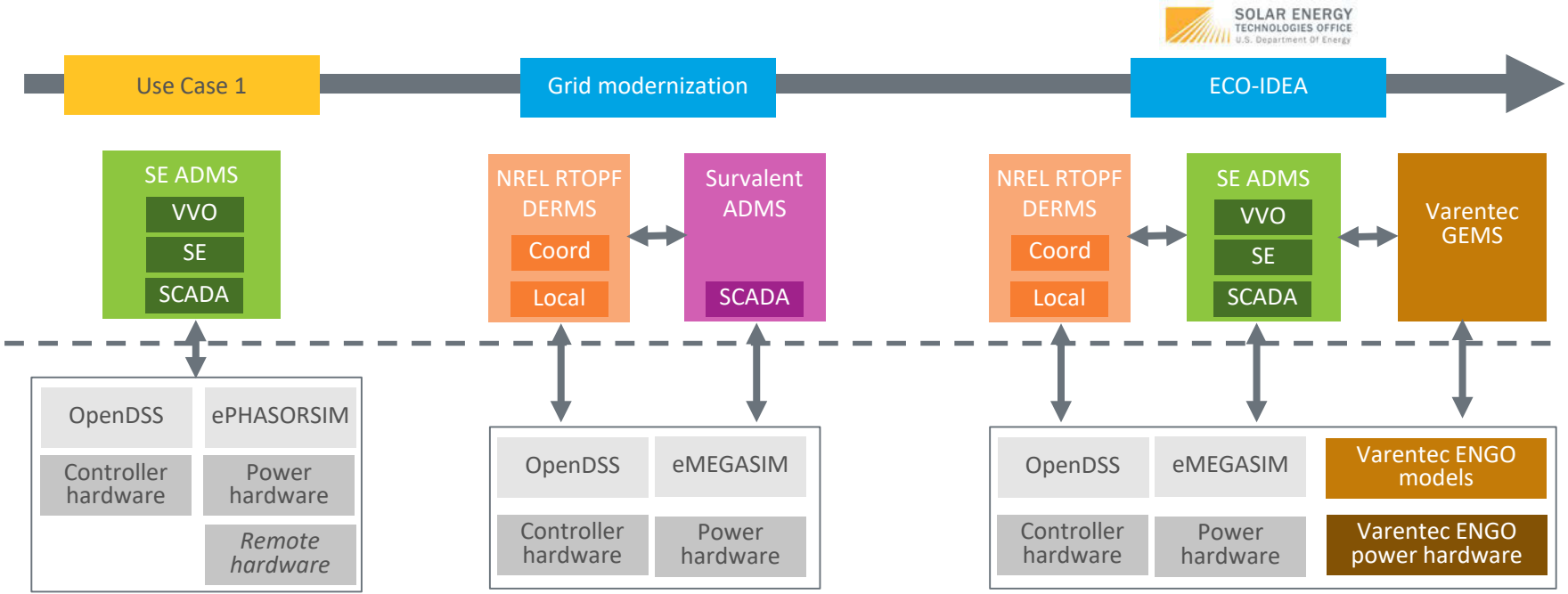


# Projects Using Test Bed Capabilities




- Grid modernization via control and optimization using DERs: ADMS + DERMS
- Evaluating Anterix wireless communications system for utility applications.

# Projects Using Test Bed Capabilities Cont.




- Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE) ECO-IDEA:
  - ADMS + DERMS for PV + Varentec devices.