NREL Transforming ENERGY

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ADMS Test Bed Updates

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December 9, 2021

ADMS Test Bed Webinar Series

Contents

- ADMS Test Bed Overview
- ADMS Model Quality Impact Evaluation
  - Data Remediation Project
  - ADMS Test Bed Use Case
- Future Use Cases and Events

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ADMS Test Bed Overview

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		**Future**
Closed, proprietary, vendor specific	→	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.

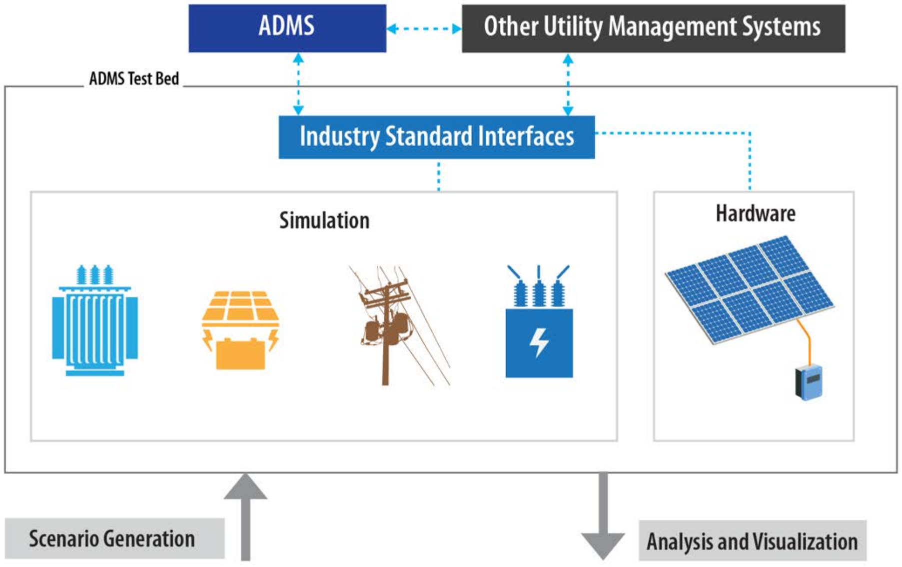
ADMS Test Bed

Goal: Accelerate industry adoption of ADMS to:

- Improve normal operations with high distributed energy resources (DERs)
- Improve resilience and reliability.

Approach: Partner with utilities and vendors to evaluate specific use cases and applications to:

- Set up a realistic laboratory environment
- Simulate real distribution systems
- Integrate distribution system hardware
- Use industry-standard communications
- Create advanced visualization capability.



ADMS Test Bed

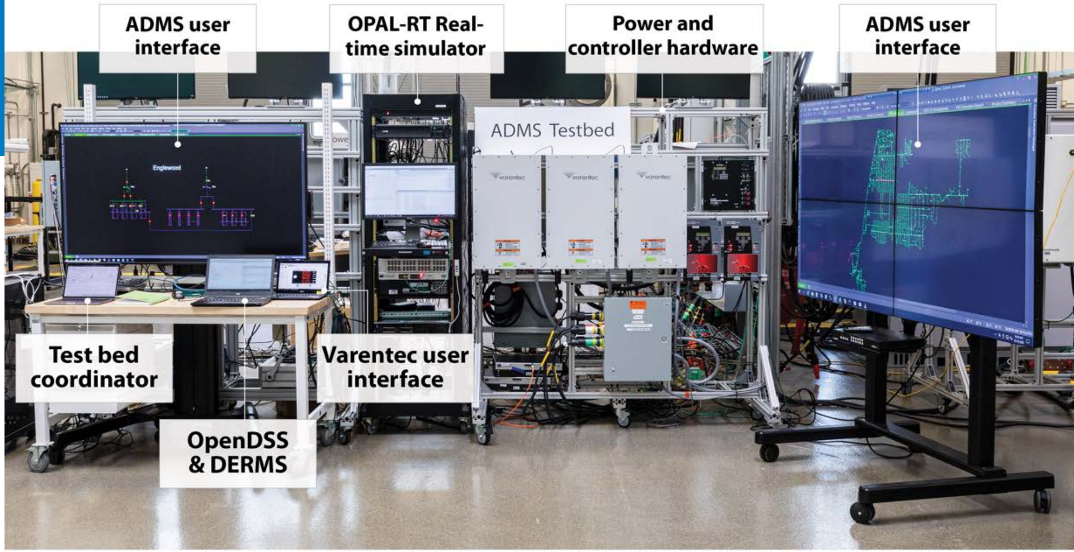
Expected outcome:

Increased industry confidence in ADMS technology through:

- Laboratory demonstration of applications for specific use cases
- Analysis and potential application to other utilities.

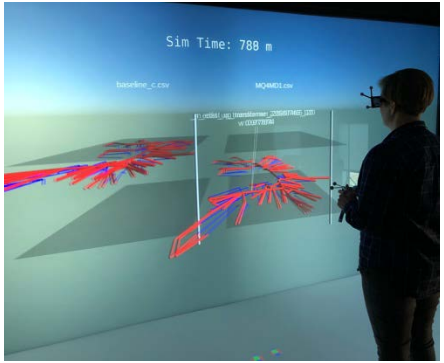
ADMS Test Bed capabilities include:

- Multi-timescale co-simulation using HELICS (OpenDSS/OPAL-RT/RTDS)
- Hardware integration
- Communications interfaces
- Data collection and visualization.



Photos by NREL

2D real-time visualization



3D visualization

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ADMS Test Bed Use Cases

- Peak load management with ADMS and DERMS
  - Holy Cross Energy/Survalent
- **ADMS network model quality impact on VVO**
  - **Xcel Energy/Schneider Electric**
- AMI-based, data-centric grid operations
  - SDG&E + GridAPPS-D
- FLISR in the presence of DERs
  - Central Georgia EMC/Survalent → March 2022
- Federated DERMS for high PV system
  - Southern Company/Oracle + GridAPPS-D → June 2022
- T&D co-optimization for enabling ADN to support bulk grid
  - Xcel Energy + GridAPPS-D → April 2022

ADMS test bed capabilities used by:

- Non-wires alternatives
- ECO-IDEA
- GO-SOLAR
- SolarExpert
- FAST-DERMS
  - SDG&E, Oracle, EPRI + GridAPPS-D → Feb 2023
- Resilient Operation of Networked Microgrids (RONM)
  - SDG&E, Cobb EMC → Nov 2022
- REORG
  - Holy Cross Energy, Minsait ACS → Mar 2024
- PV Integration using a Virtual Airgap (PIVA)
  - GridBright, SDG&E → Sep 2024

ADMS Model Quality Impact Evaluation

Model Quality & ADMS Deployment

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- Model quality is very important to maximize the impact and value from ADMS grid optimization applications
- GIS is a typical source for ADMS
- Model & data clean up – can be up to 25% of ADMS implementation costs
- Upkeep of models during operation is a critical need

Some important questions...

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- What level and what types of data cleanup need to be performed for successful deployment of ADMS advanced applications?
- Can the need for data cleanup be offset by deploying additional sensors?
- Can sensors such as advanced metering infrastructure (AMI) be used in addition to SCADA points to improve ADMS optimization results?
- What is the impact of reduced data quality on ADMS optimization applications such as VVO?

ADMS Model Quality and VVO

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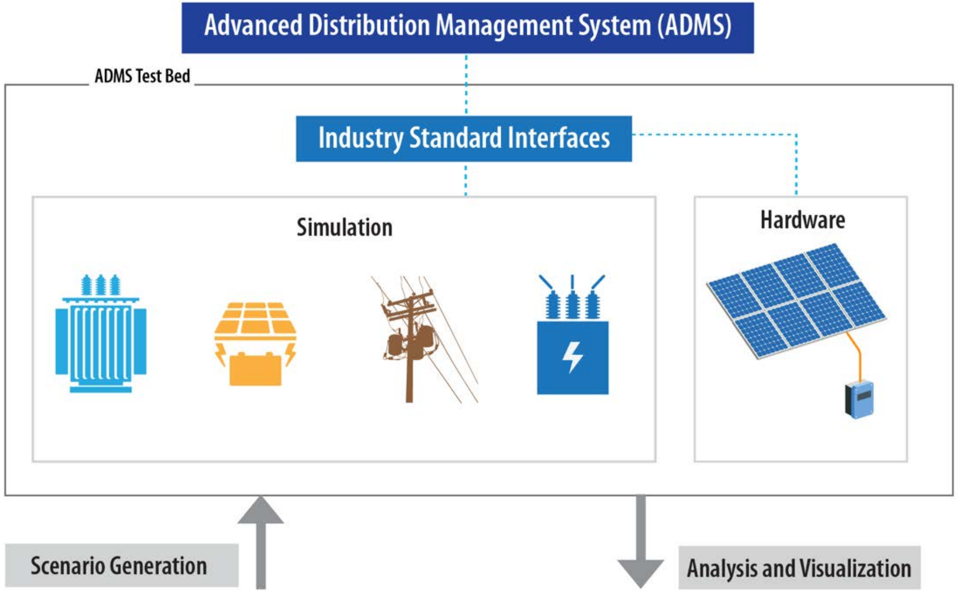
<u>Objective:</u> Evaluate the performance of the ADMS volt/VAR optimization (VVO) application for different levels of model quality and different levels of measurement density, specifically:

- Measure performance improvements from more accurate model
- Study model inaccuracies offset with additional telemetry
- Determine trade-off between model quality and telemetry density.



<u>Partners</u>: Xcel Energy, Schneider Electric, PNNL, EPRI, Opal-RT

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Background

- Schneider Electric offers VVO that can be deployed as rule-based or as model-based:
  - Model-based provides more accurate and granular results which is better for systems with high photovoltaic (PV) penetration.
- For simulation on test bed, selected:
  - Two data quality levels: changes network model within ADMS
  - Two measurement density levels: changes whether AMI measurements are considered.
  - Based these on preliminary simulation-only results from **data remediation project**.

Data Remediation project

Santosh Veda

Test Setup

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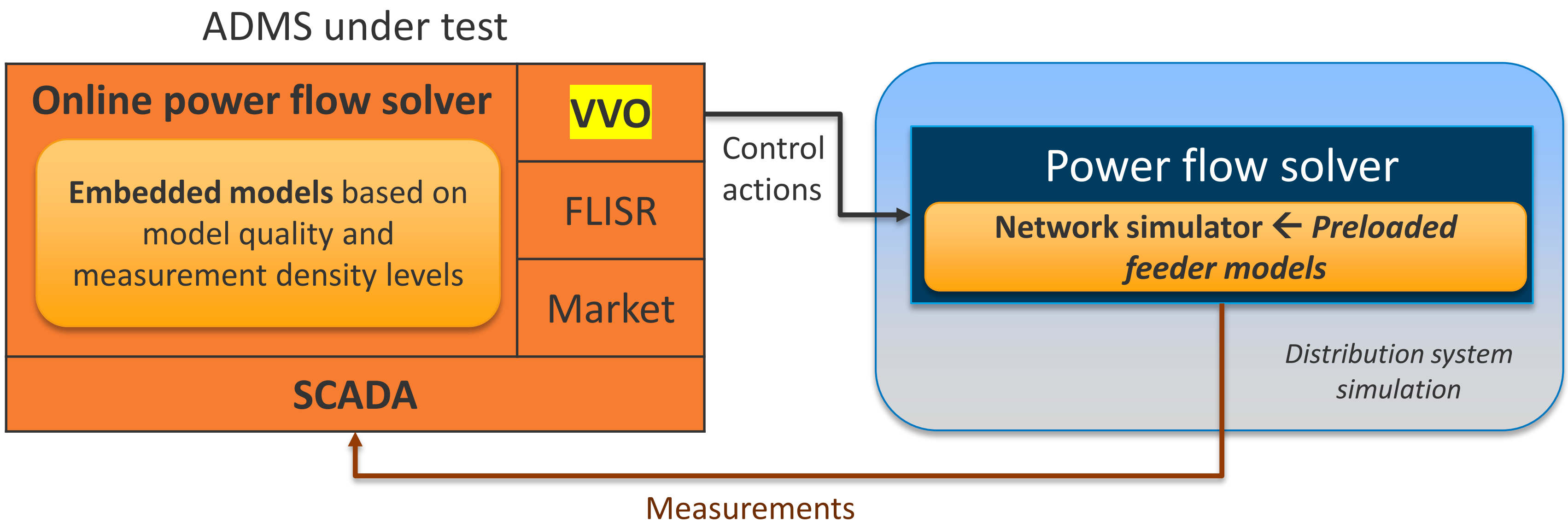

Levels of Model Quality

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- **Level 1 (Q1)**: Base-level data extracted from the Xcel Energy Geographic Information System (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 (advanced metering infrastructure [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.

Test Setup: VVO Settings

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Xcel Energy use case: Conservation Voltage Reduction (CVR)

Objective functions

- ***Energy consumption reduction***
- Peak demand reduction
- Power factor improvement
- Active power losses reduction
- Consumer voltage improvement
- VAR control

Constraints

- Consumer voltage
- Medium voltage
- AMI voltage
- Power factor measurements
- Voltage unbalance index

Test Setup: Daily Simulations

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- **VVO configuration**: Select objective/constraints
- **Feeder**: Select feeder to perform VVO (CVR)
- **Days**: Select days (load profiles, loading levels)
- **Data**: Collect required data for post-processing

Selected Feeders

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Feeder	Type	Circuit Miles (apprx.)	Customers (#)	Underground (UG %) / Overhead (OH %)	Peak Load (MW, apprx.)
Feeder 1	Rural	80	1571	54/46	1.07
Feeder 2	Rural	125	2143	70/30	7.13
Feeder 3	Semi-urban	47	2799	87/13	6.73
Feeder 4	Urban	22	477	13/87	12.34
Feeder 5	Urban	14	351	25/75	11.3
Feeder 6	Urban	61	2880	73/27	12.46

VVO Control and Measurement

- Participating controllable devices:
  - Ganged Load Tap Changers at substation
  - Ganged medium voltage 1200 kVAr capacitor banks
- Participating telemetry devices:
  - Reclosers, remote fault indicators
  - AMI meters

Test Metrics

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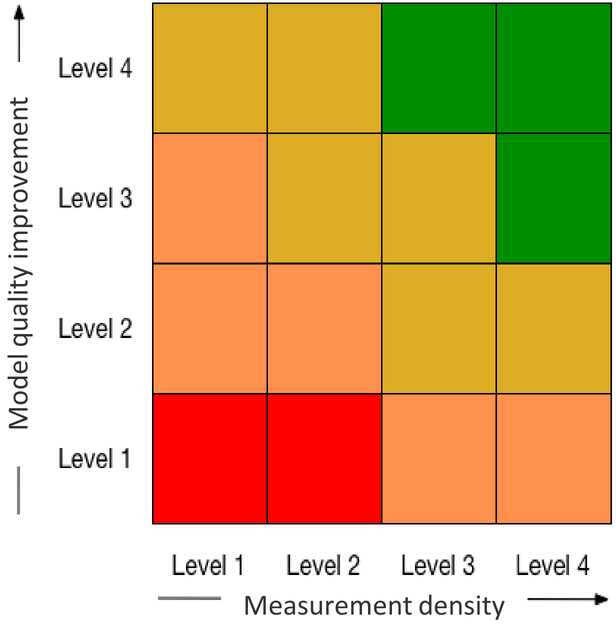
Test Metric	Description
CVR energy reduction	Feeder energy consumption before and after application of CVR
System average voltage fluctuation index	Average voltage fluctuations for all nodes within the time period. Represents the flatness of the voltage profile
System control device Operation index **Capacitor bank operations, load tap changer (LTC), or voltage regulator operations**	i. Number of times the capacitor banks were turned on or off ii. Number of times the LTC/voltage regulators were operated
System energy loss index	Ratio of total energy loss during the entire simulation time to the total load
Power factor	Power factor computed at selected nodes

Expected outcome



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Results: Voltage Reduction

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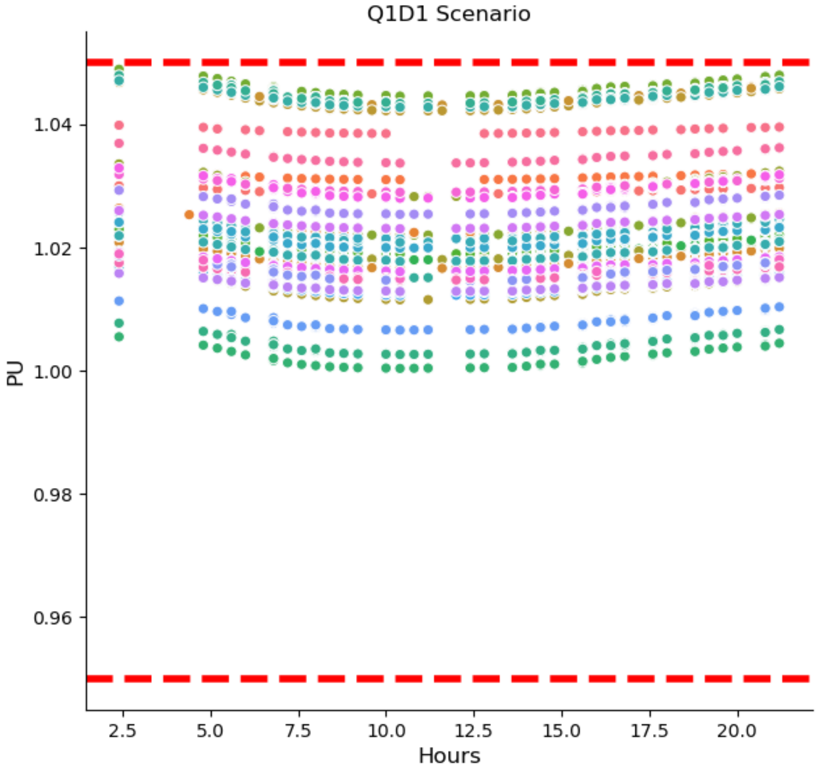
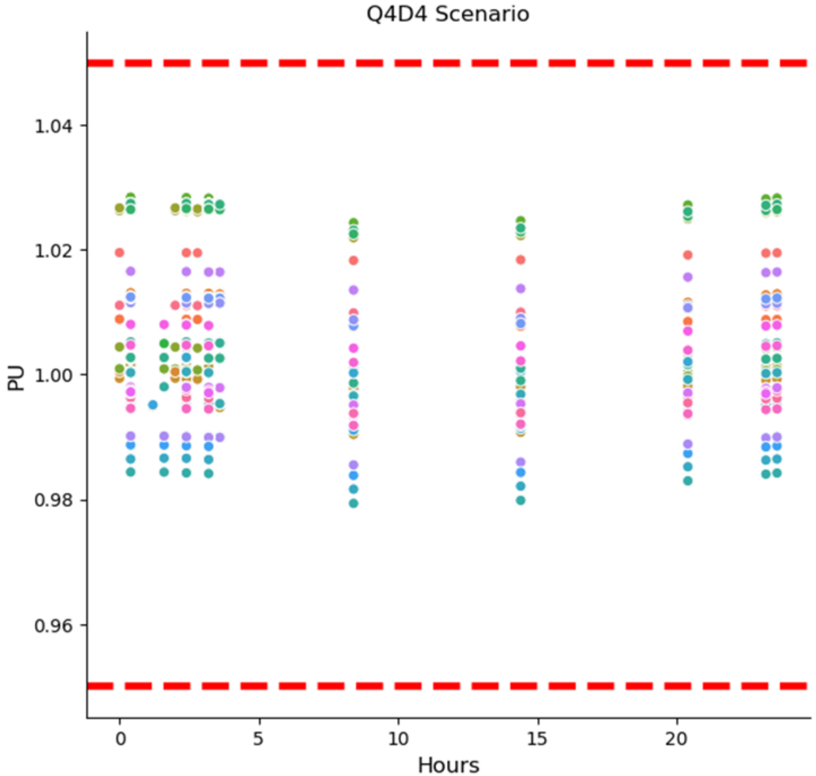
Feeder 1 (rural, even mix of underground and overhead assets)





Results: Voltage Violations

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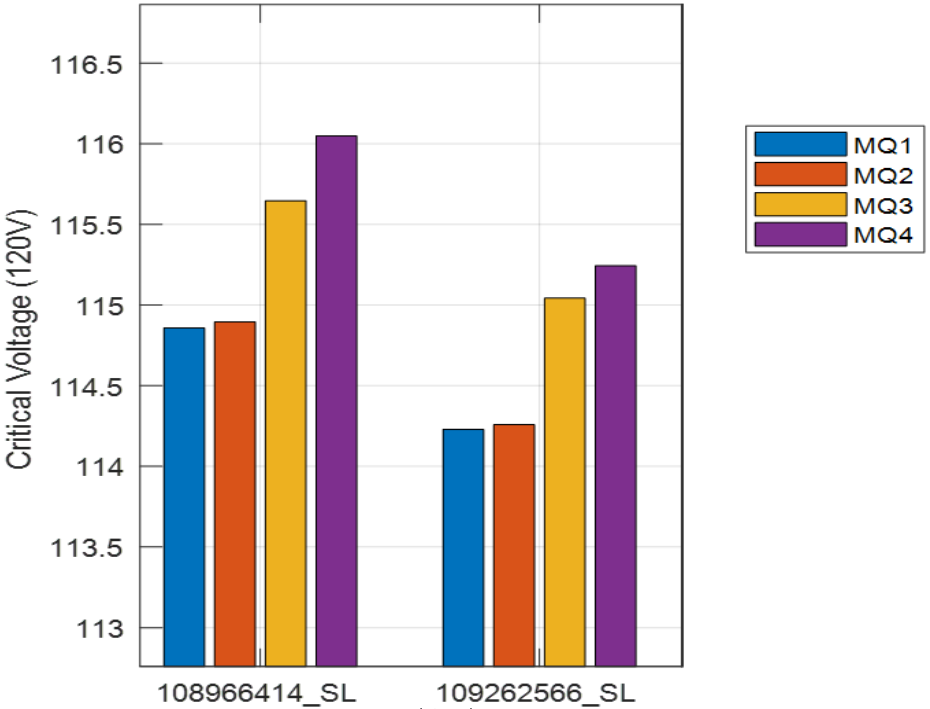
Feeder 1 (rural, even mix of underground and overhead assets)



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Results: Energy Savings with VVO

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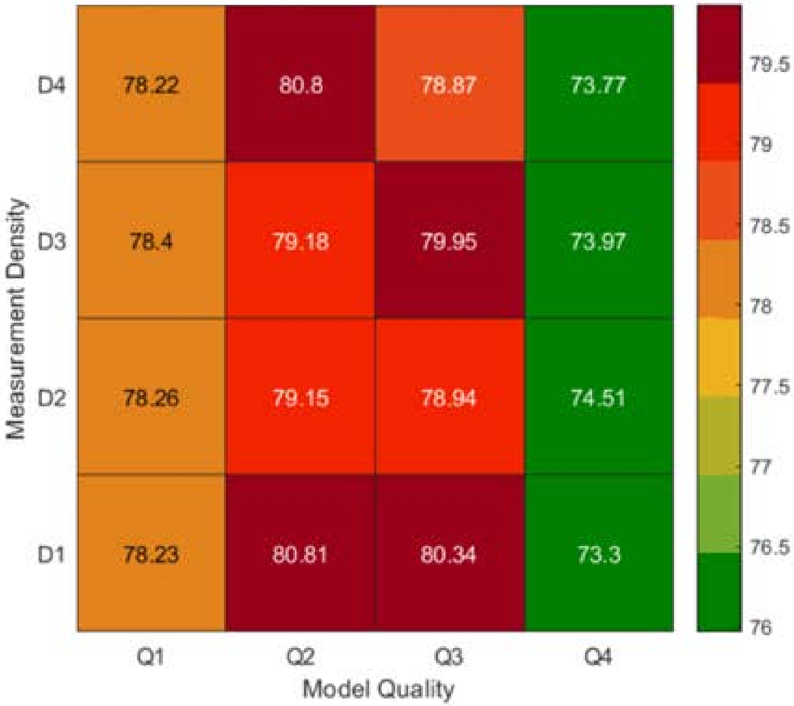
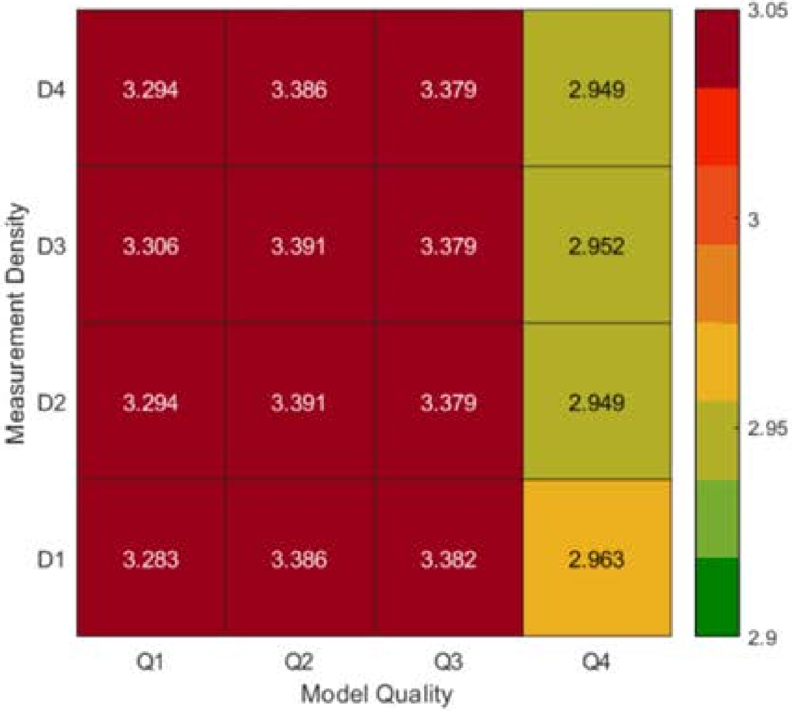
Feeder 1 (rural, even mix of underground and overhead assets)

Energy consumption estimates (MWh)



Power (MW, daily median)



Results: Energy Savings with VVO

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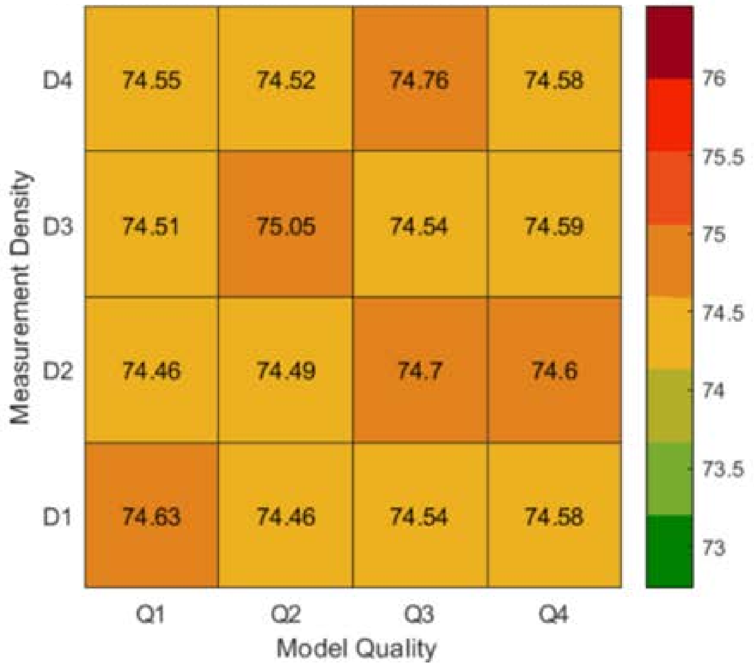
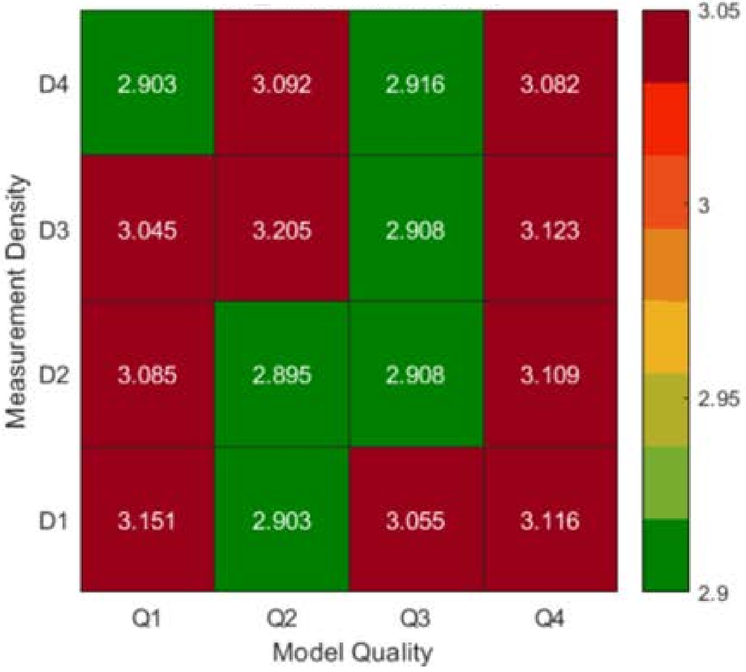
Feeder 2 (rural, mostly underground assets)

Energy consumption estimates (MWh)



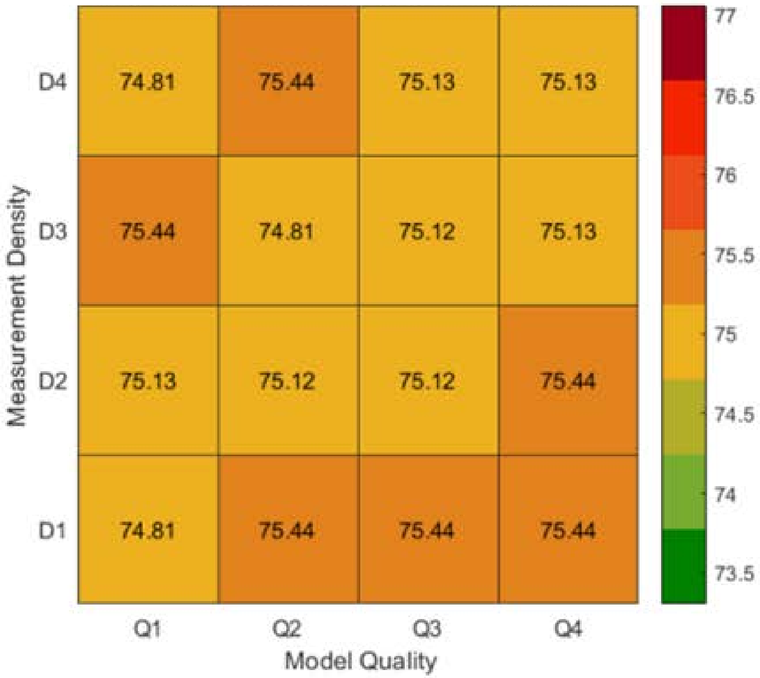
Power (MW, daily median)



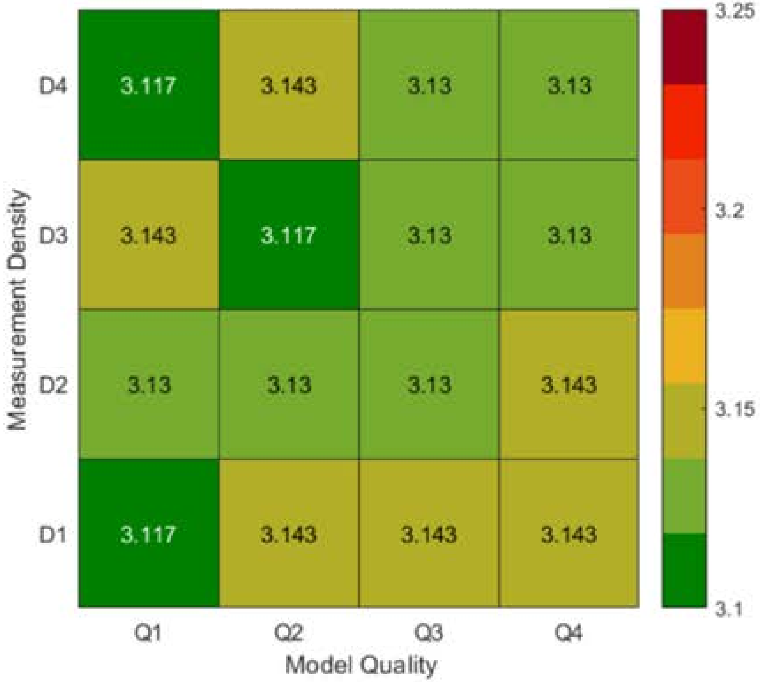
Results: Energy Savings with VVO

Feeder 6 (longest urban, 73% underground assets)

Energy consumption estimates (MWh)



Power (MW, daily median)



Findings

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- Impacts of feeder features
- Impacts of model quality
- Impacts of measure-ment density
- Impacts of loading conditions

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Summary of Findings

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- **Model quality** improvements are less evident on urban feeders because they are relatively new and have been field-verified in recent years.
- **Rural feeders** show better improvement on energy savings under VVO application with different levels of model improvement.
- For a **long feeder**, VVO might not have a significant impact due to narrow margin to reduce voltage/energy consumption at feeder-end locations unless more devices are available to remotely control.
- **Measurement density levels** generally have less pronounced impact than model quality levels.
- With same VVO settings, **high-loading conditions** might create more voltage violations than **low-loading** conditions with same model quality.

Model Quality Use Case

Annabelle Pratt

ADMS Model Quality and VVO

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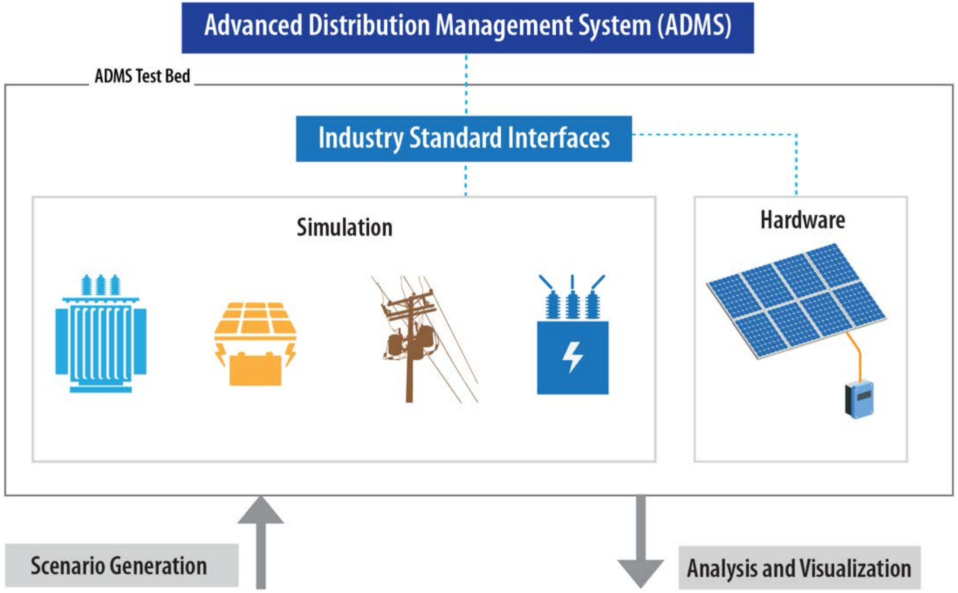

Partners: Xcel Energy, Schneider Electric, PNNL, EPRI, Opal-RT

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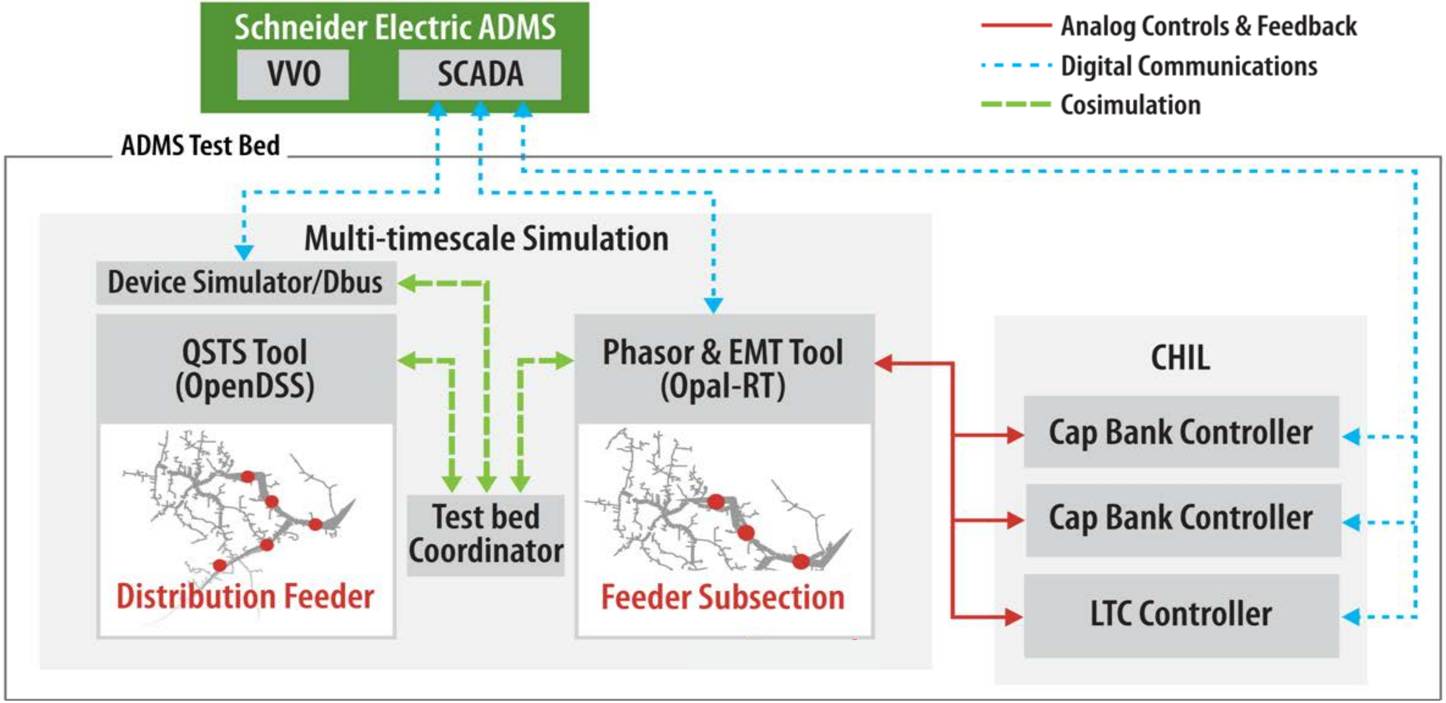
ADMS Test Bed Setup



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Feeder Information

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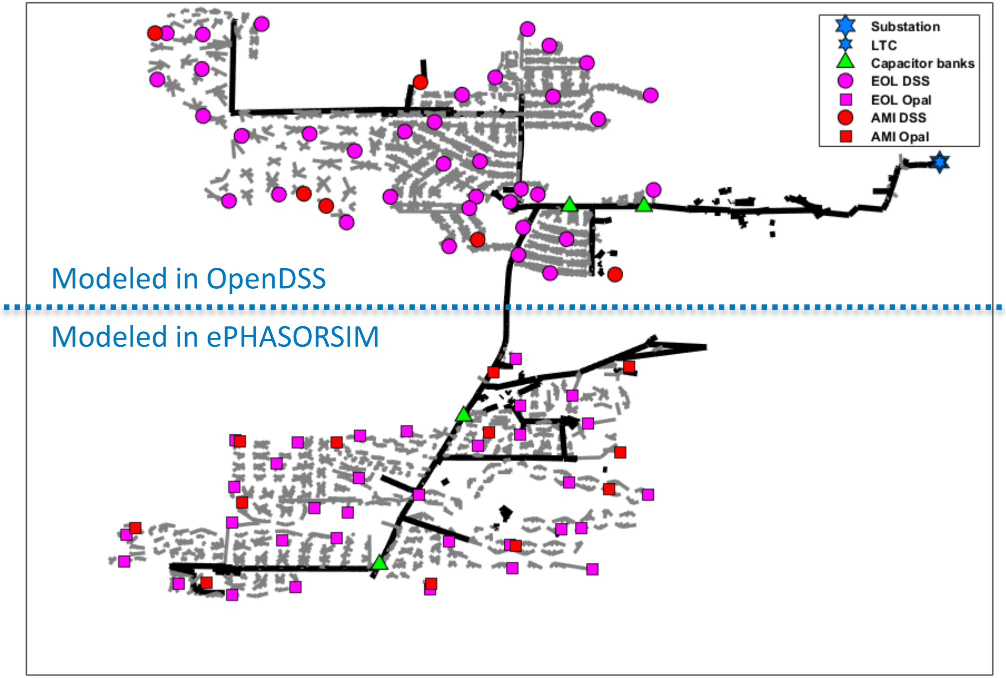
- Xcel Energy feeder 6:
  - 61.59 miles; 2,880 customers; 73% underground; 27% overhead



Feeder Information Continued

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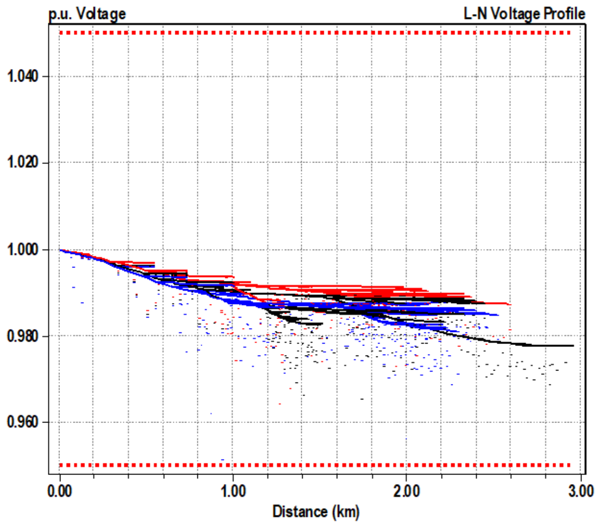
- Winter weekday load profile for light load:
  - Approx. 6.5-MW peak; scaled to historical data for February 7
- Summer weekday for heavy load:
  - Approx. 12.5-MW peak; scaled to historical data for June 26
- Baseline run without VVO activated, then with VVO activated:
  - VVO objective = energy reduction
- ADMS enabled to control load tap changer and four capacitor banks

Model Conversion

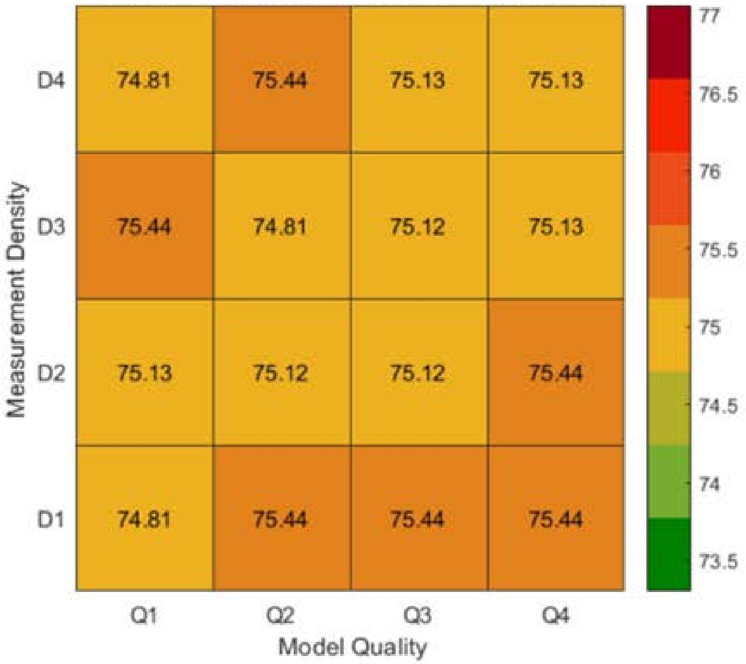
- Xcel Energy feeder converted from CIM to OpenDSS
  - Validating against Synergi model from Xcel
  - Tool to convert from OpenDSS to ePHASORSIM completed



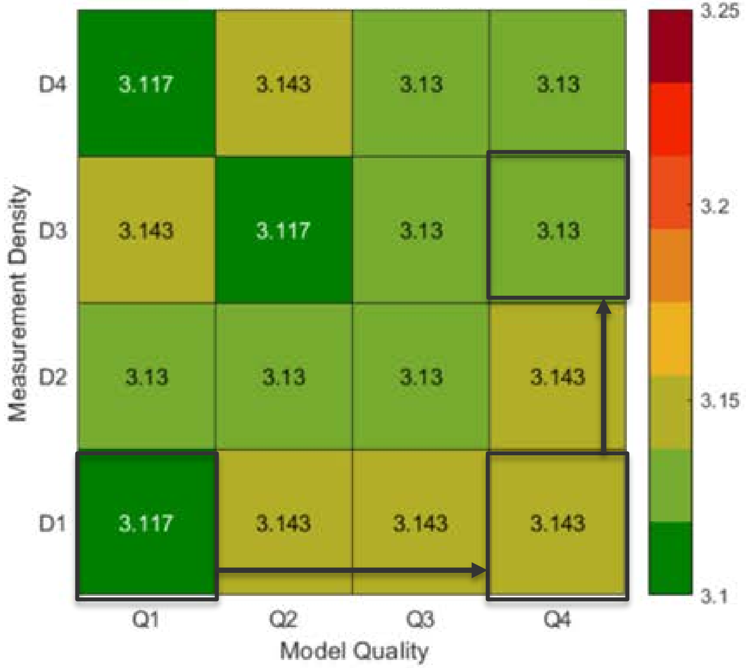
Phase 1 Light Load Simulation Results

- Completed simulations with two model qualities and two measurement densities.

Energy consumption estimates (MWh)

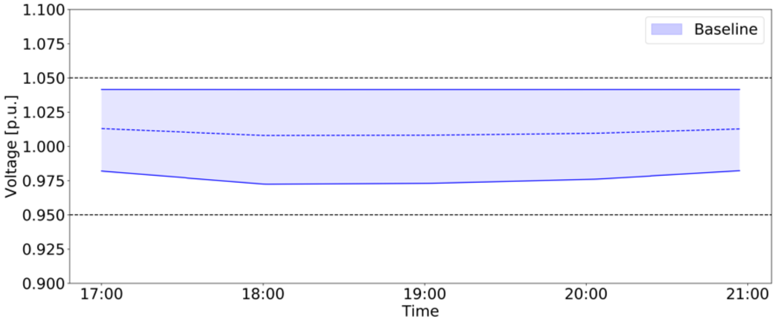


Power (MW, daily median)



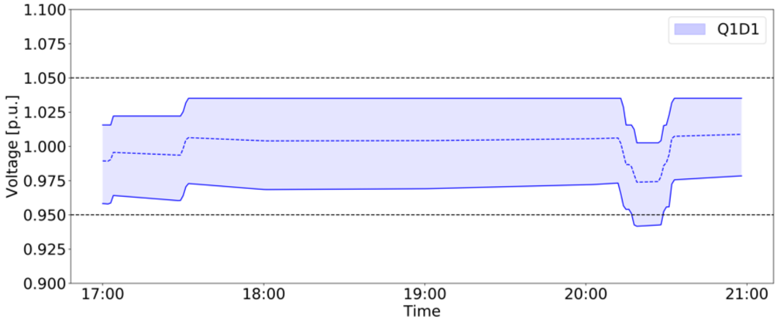
Heavy Load Results

Baseline (No VVO)



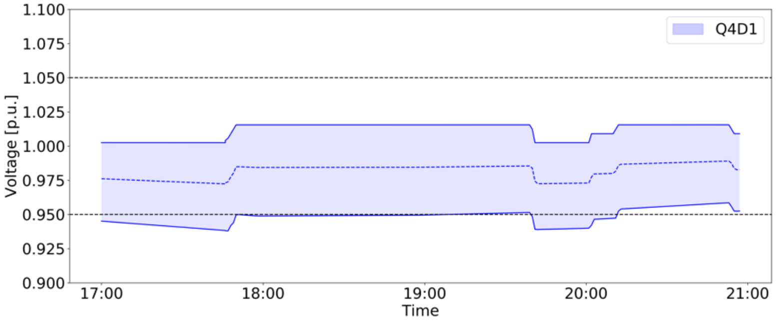
Activate VVO

Q1D1 (Low quality; Feeder head only measurements)



Improve model

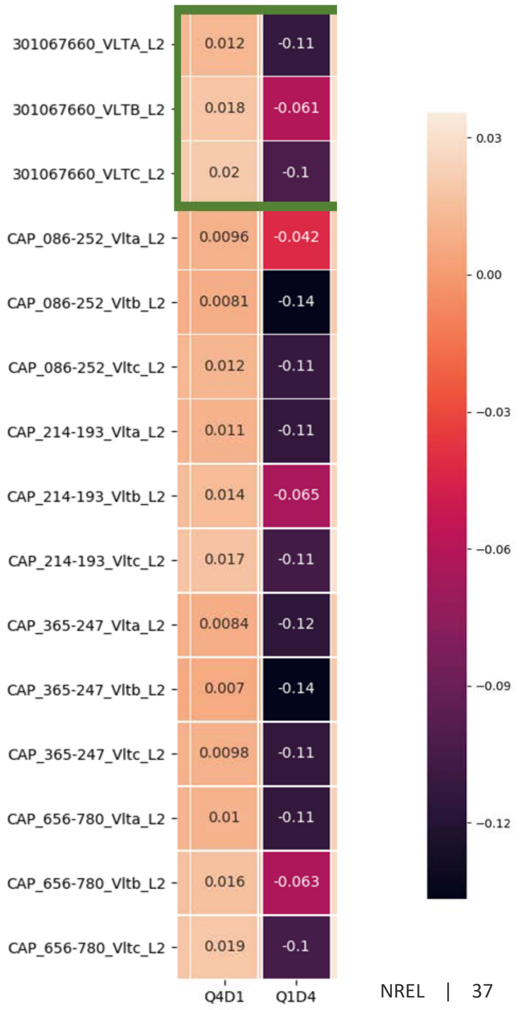
Q4D1 (High model quality; Feeder head only measurements)



Model Quality Impact

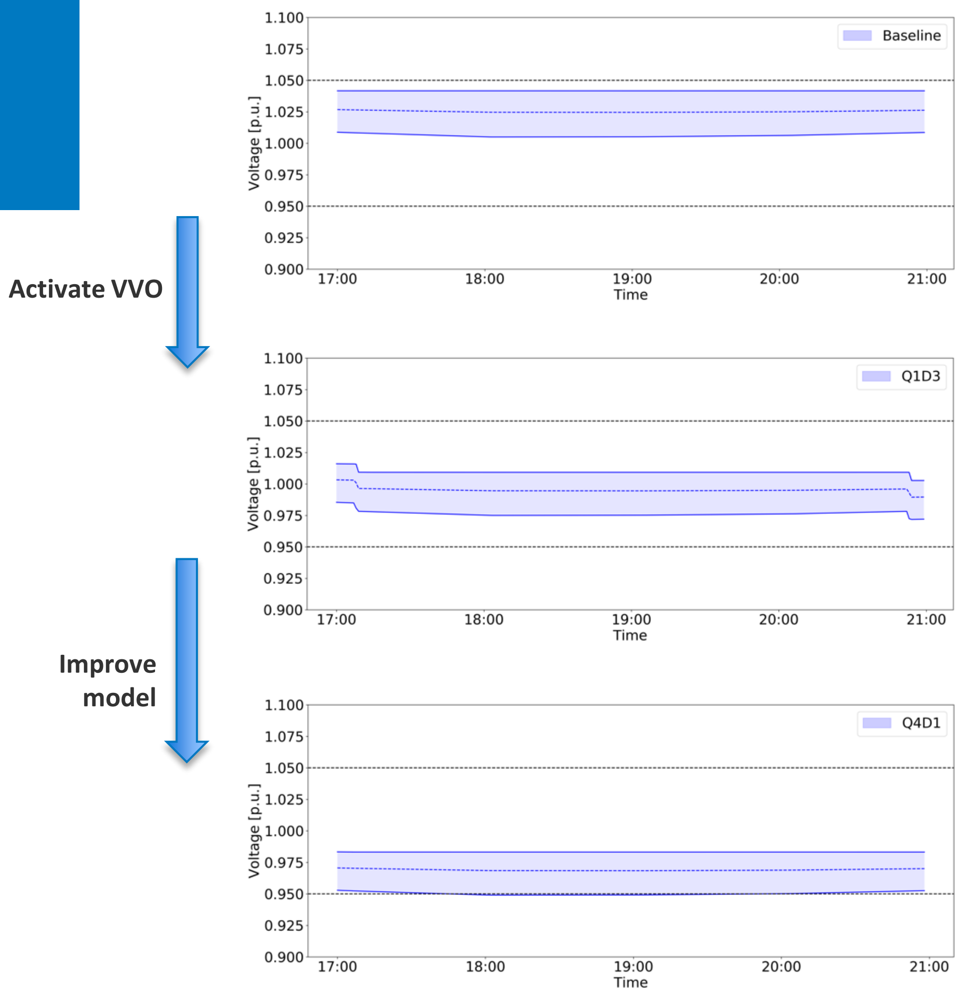
Results from data remediation project:

- Voltage drop between the substation and the different measurement locations
- Voltage drops higher for Q1 than Q4
- Similar for light load

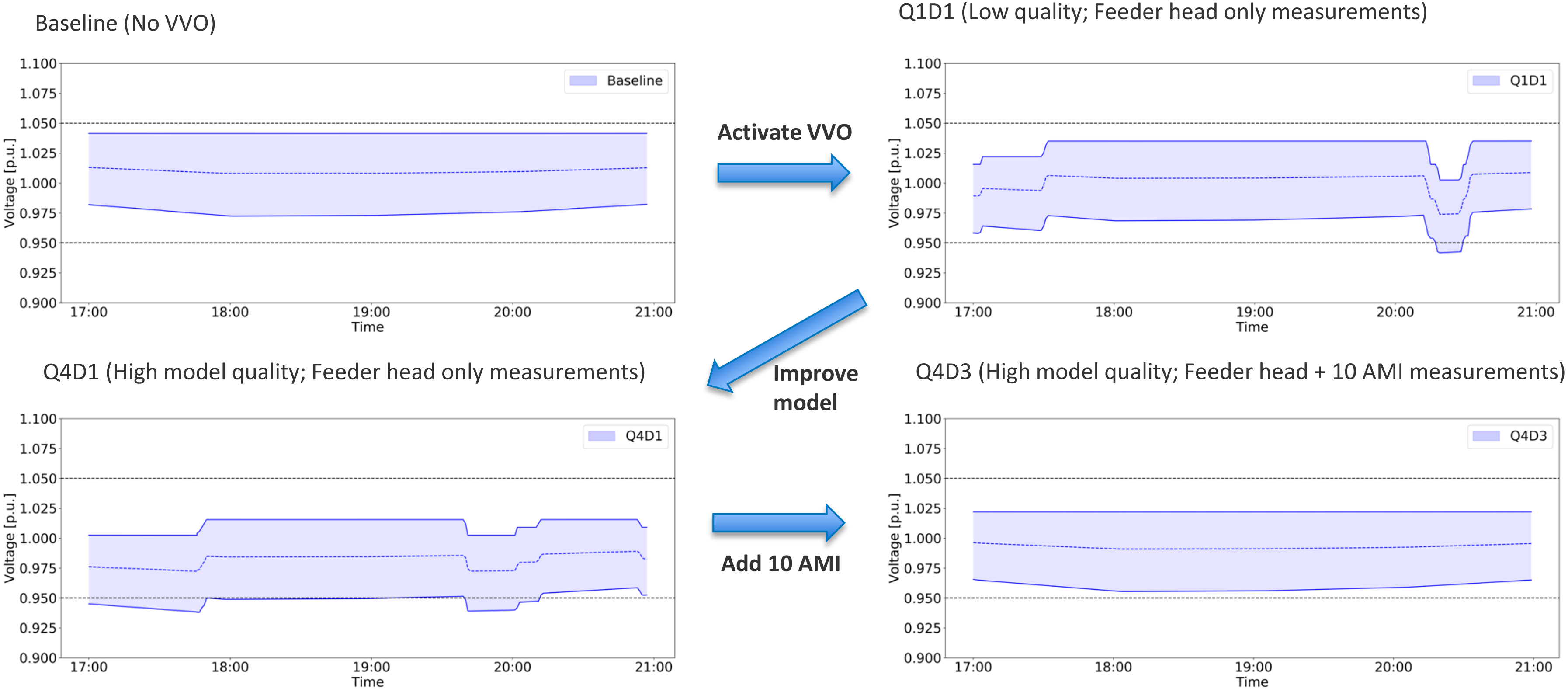


Light Load Results

- VVO drops voltage
- Voltages with higher model quality are lower

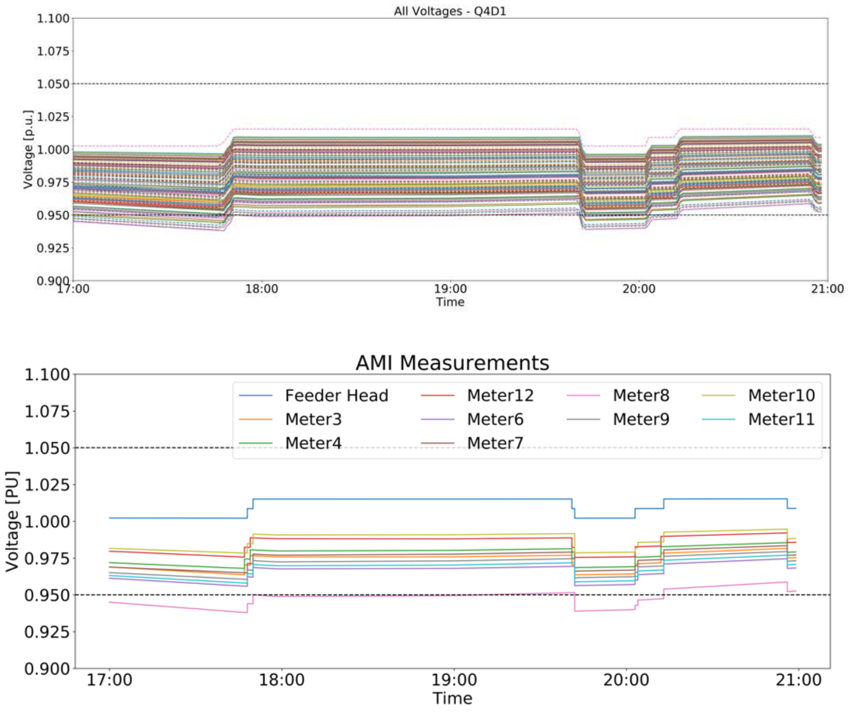


Heavy Load Results

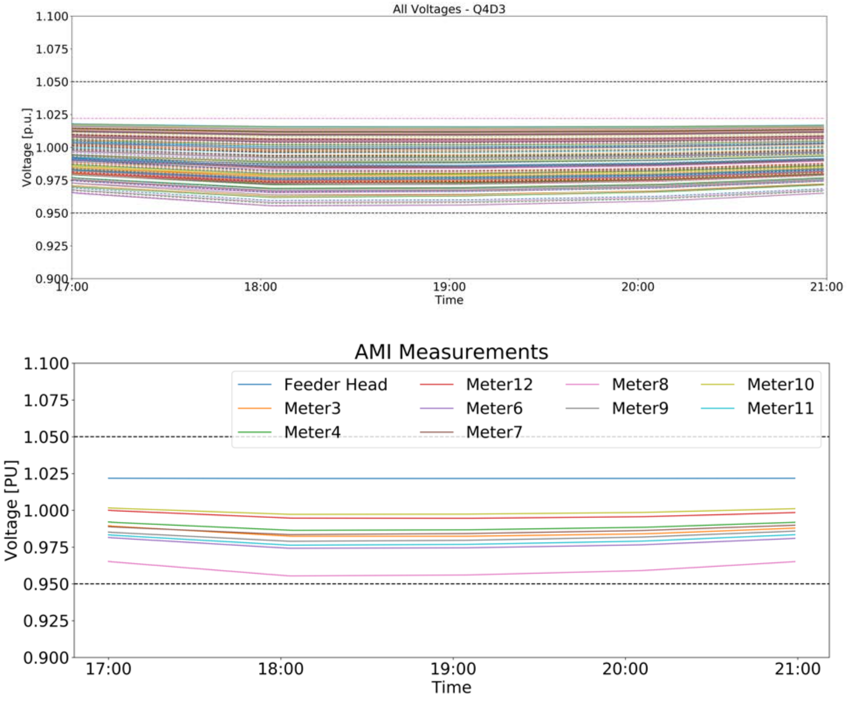


AMI Addition (heavy load)

Q4D1 (High model quality; Feeder head only measurements)



Q4D3 (High model quality; Feeder head + 10 AMI measurements)



Heavy Load - Metrics

	Number of capacitor changes	Number of LTC Tap Changes	Energy Savings (%)	Number of Voltage Exceedances
Baseline	0	0	N/A	0
Q1D1	0	9	0.81	90
Q4D1	0	7	2.9	1014
Q4D3	0	0	1.8	0

The table is calculated based on the data taken between 17:00 – 21:00 (4 hours)

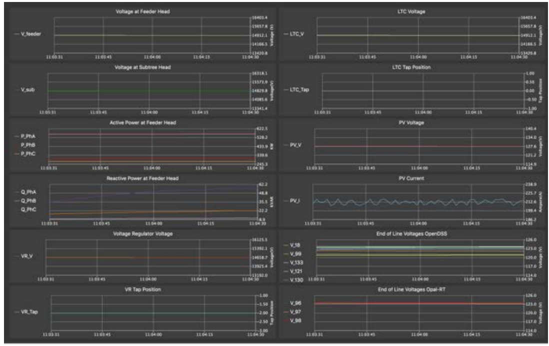
ADMS Test Bed Simulation Outcomes

- For this feeder:
  - higher model quality increased energy savings, and
  - higher measurement density reduced voltage excursions.
- More generally,
  - type of model errors will determine impact on energy savings, and
  - higher measurement density expected to reduce voltage excursions.
- Test bed simulations provided higher-granularity (1-minute time step) of results than data remediation project
- Test bed simulations recorded data from points that ADMS SCADA was not monitoring, so provided more detailed view of feeder performance

ADMS Test Bed Capability Outcomes

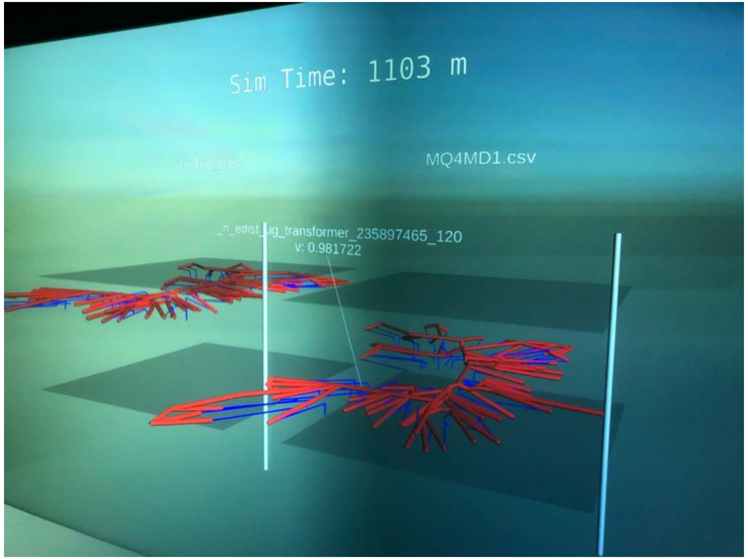
- This use case critical to developing overall test bed capability!
- Multi-timescale simulation of Xcel feeder in test bed:
  - OpenDSS (QSTS) and Opal-RT (phasor domain)
- SE ADMS deployed at NREL:
  - Remote access critical to updates and accessing logs
- Collaborative evaluation of results
- 2D real-time and 3D visualization developed

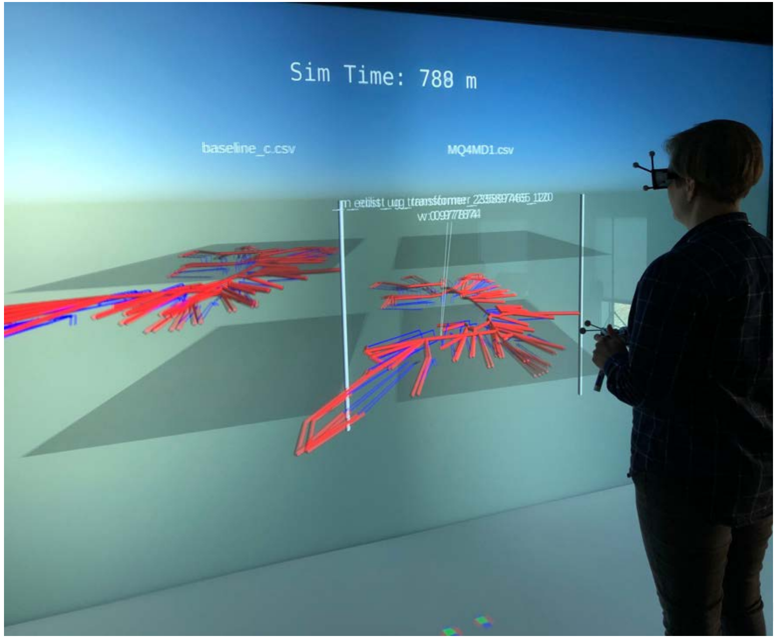
Visualization



- Real-time data streaming for 2-D visualization

- 3-D visualization of results





Publications (related to this use case)

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- IEEE Transactions paper under development
- A. Pratt, I. Mendoza, M. U. Usman, S. Tiwari, H. Padullaparti, M. Baggu, and E. Lightner, “Using an Advanced Distribution Management System Test Bed to Evaluate the Impact of Model Quality on Volt/VAR Optimization,” IEEE T&D, Chicago, Illinois, October 2020.
- A. Pratt, M. Baggu, S. Veda, F. Ding, I. Mendoza, and E. Lightner, “Testbed to Evaluate Advanced Distribution Management Systems for Modern Power Systems,” IEEE Eurocon, July 2019.
- S. Veda, M. Baggu, and A. Pratt, “Defining a Use Case for ADMS Testbed: Data Quality Requirements for ADMS Deployment,” IEEE Conference on Innovative Smart Grid Technologies (ISGT), February 2019.
- S. Veda, H. Wu, M. Martin, and M. Baggu, “Developing Use Cases for the Evaluation of ADMS Applications to Accelerate Technology Adoption,” IEEE Green Technologies Conference (GREENTECH), March 2017.
- K. Prabakar, N. Wunder, N. Brunhart-Lupo, C. Pailing, K. Potter, M. Eash, and K. Munch, “Open-Source Framework for Data Storage and Visualization of Real-Time Experiments,” Kansas Power and Energy Conference, July 2020.

Future Use Cases and Events

Future Use Cases

- Request for information (RFI) on future use cases released June 30, 2021
  - 14 RFI responses

- ARIES User Call released Nov 19; proposals due Jan 14, 2022
  - ARIES = Advanced Research on Integrated Energy Systems
  - Available at https://www.nrel.gov/aries/user-call-for-advanced-distribution-management-system-test-bed.html

Future Events

Webinars:

- GO-SOLAR, Feb 16, 2022
- SOLAR EXPERT, Mar 15, 2022

ADMS Test Bed Workshop:
Apr 19-20, 2022

Planned for in-person at NREL

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. 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.

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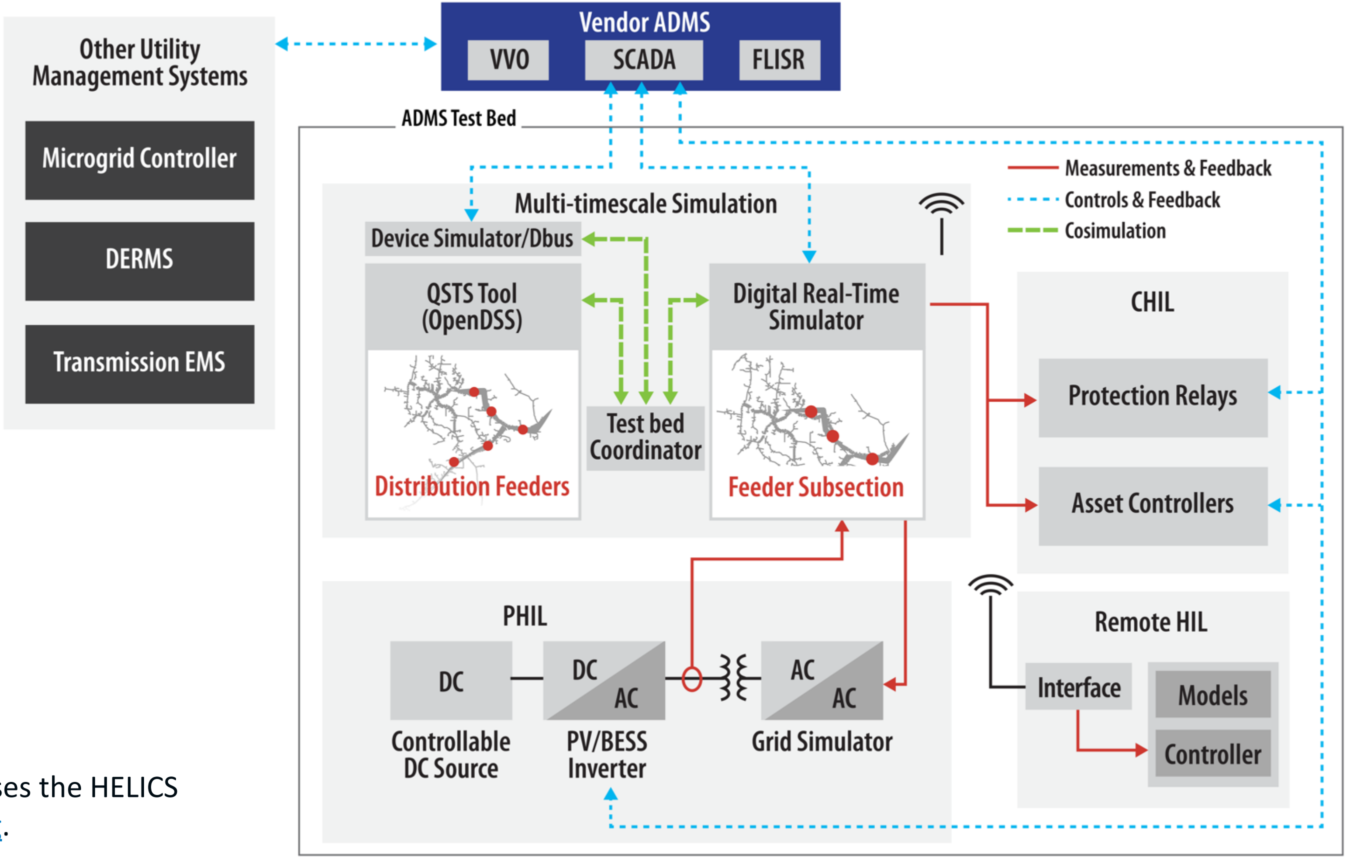
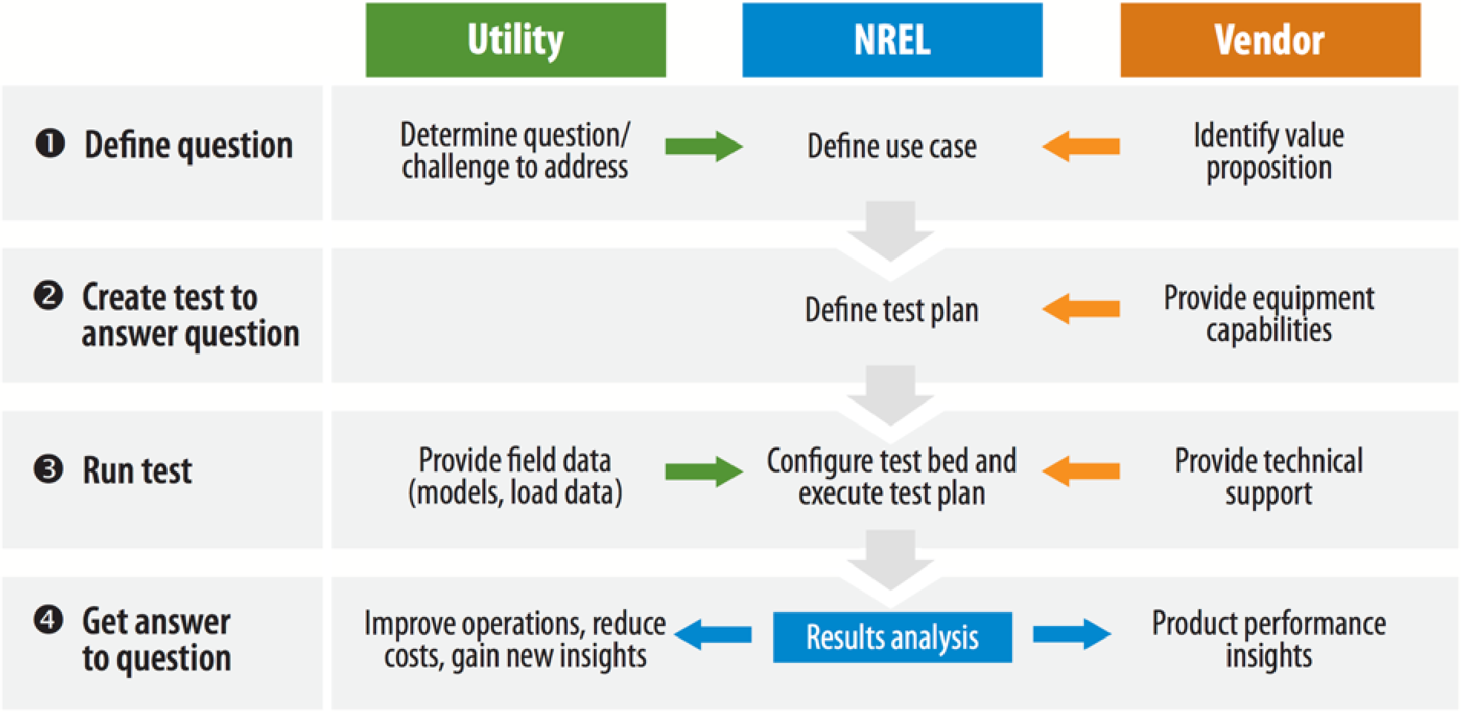


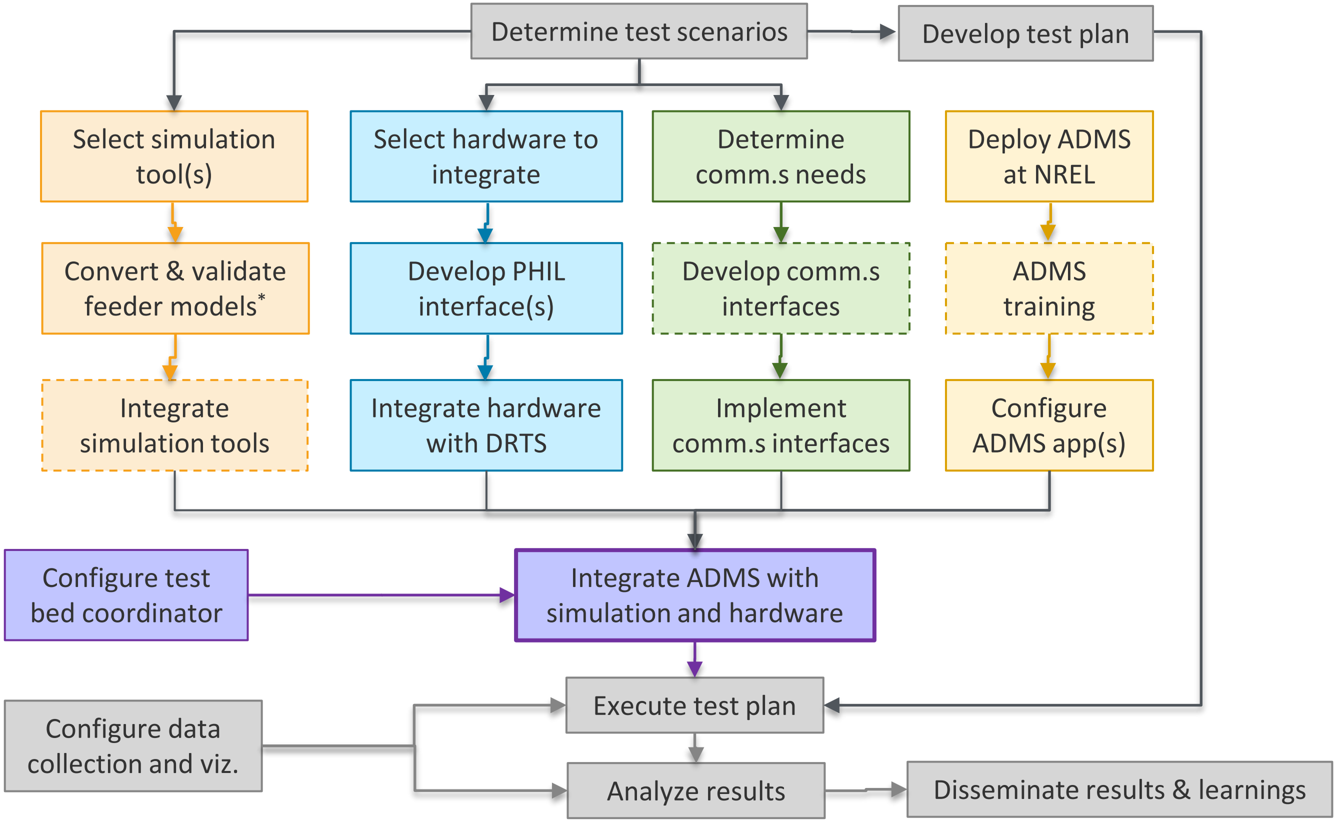
The test bed coordinator uses the HELICS framework: www.helics.org.

Defining an ADMS Test Bed Use Case



A. Pratt, H. Padullaparti, I. Mendoza, M. Baggu, Y. Ngo and H. Arant, “Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources,” ISGT, 2021.

Configuring the Test Bed



* NREL's *Distribution Transformation Tool* (DiTTo): https://github.com/NREL/ditto. Internal

Test Setup: VVO Configuration (data remediation project)

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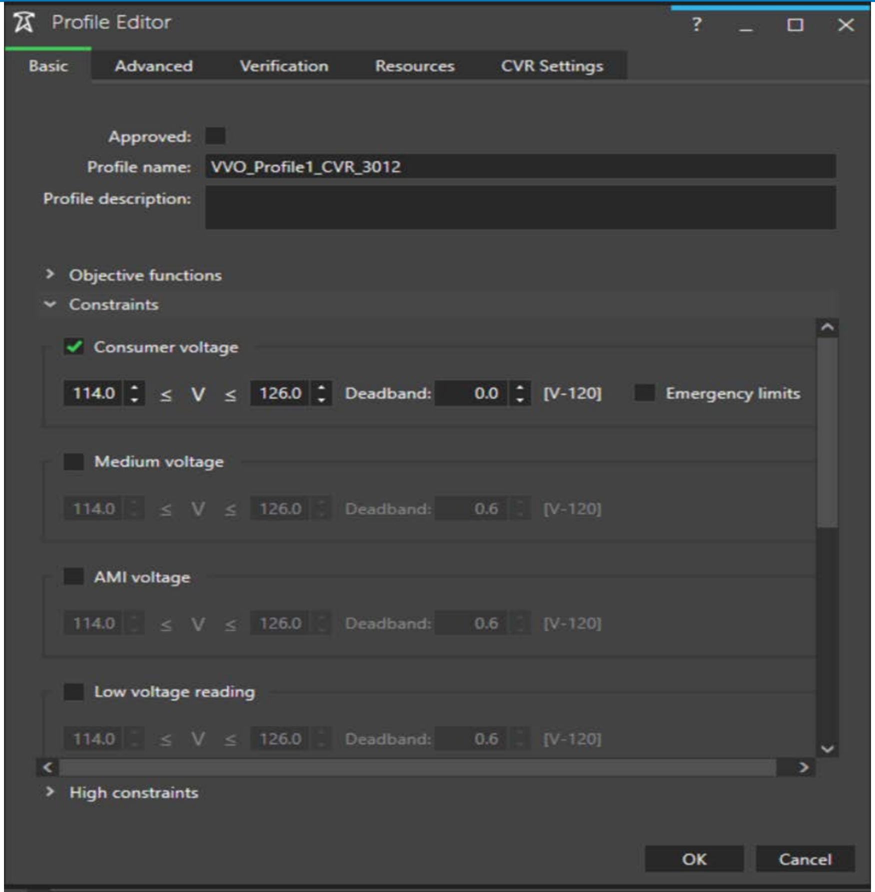

For Further Reading

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- H. Padullaparti, A. Pratt, I. Mendoza, S. Tiwari, M. Baggu, C. Bilby, and Y. Ngo, "Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources," IEEE GreenTech, 2021.
- A. Pratt, H. Padullaparti, I. Mendoza, M. Baggu, Y. Ngo, and H. Arant, "Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources," ISGT, 2021.
- K. Prabakar, N. Wunder, N. Brunhart-Lupo, C. Pailing, K. Potter, M. Eash, and K. Munch, "Open-Source Framework for Data Storage and Visualization of Real-Time Experiments," Kansas Power and Energy Conference, July 2020.
- A. Pratt, I. Mendoza, M. U. Usman, S. Tiwari, H. Padullaparti, M. Baggu, and E. Lightner, "Using an Advanced Distribution Management System Test Bed to Evaluate the Impact of Model Quality on Volt/VAR Optimization," IEEE T&D, Chicago, Illinois, October 2020.
- A. Pratt, M. Baggu, S. Veda, F. Ding, I. Mendoza, and E. Lightner, "Testbed to Evaluate Advanced Distribution Management Systems for Modern Power Systems," IEEE Eurocon, July 2019.
- S. Veda, H. Wu, M. Martin, and M. Baggu, "Developing Use Cases for the Evaluation of ADMS Applications to Accelerate Technology Adoption," IEEE Green Technologies Conference (GREENTECH), March 2017.
- S. Veda, M. Baggu, and A. Pratt, "Defining a Use Case for ADMS Testbed: Data Quality Requirements for ADMS Deployment," IEEE Conference on Innovative Smart Grid Technologies (ISGT), February 2019.
- J. Wang, B. Lundstrom, I. Mendoza, and A. Pratt, "Systematic Characterization of Power Hardware-in-the-Loop Evaluation Platform Stability," IEEE Energy Conversion Conference and Exhibition (ECCE), September 2019.
- K. Prabakar, B. Palmintier, A. Pratt, A. Hariri, I. Mendoza, and M. Baggu, "Improving the Performance of Integrated Power-Hardware-in-the-Loop and Quasi-Static Time-Series Simulations," *IEEE Transactions on Industrial Electronics* (2020), DOI: 10.1109/TIE.2020.3029465.

Other Project Outputs

- PyDBus: https://github.com/NREL/pydbus
- Model conversion tool: https://github.com/NREL/DSS2ePHASOR
- Visualization software: https://github.com/NREL/rts-vis-app and https://github.com/NREL/rts-data

- A video to highlight the ADMS test bed: https://www.youtube.com/watch?v=FBALnednTIE&feature=youtu.b
- A video that provides an overview of the test bed and Use Case1: https://www.youtube.com/playlist?list=PLmIn8Hncs7bGfqrW-G_A9JHVSbQk4BFc0