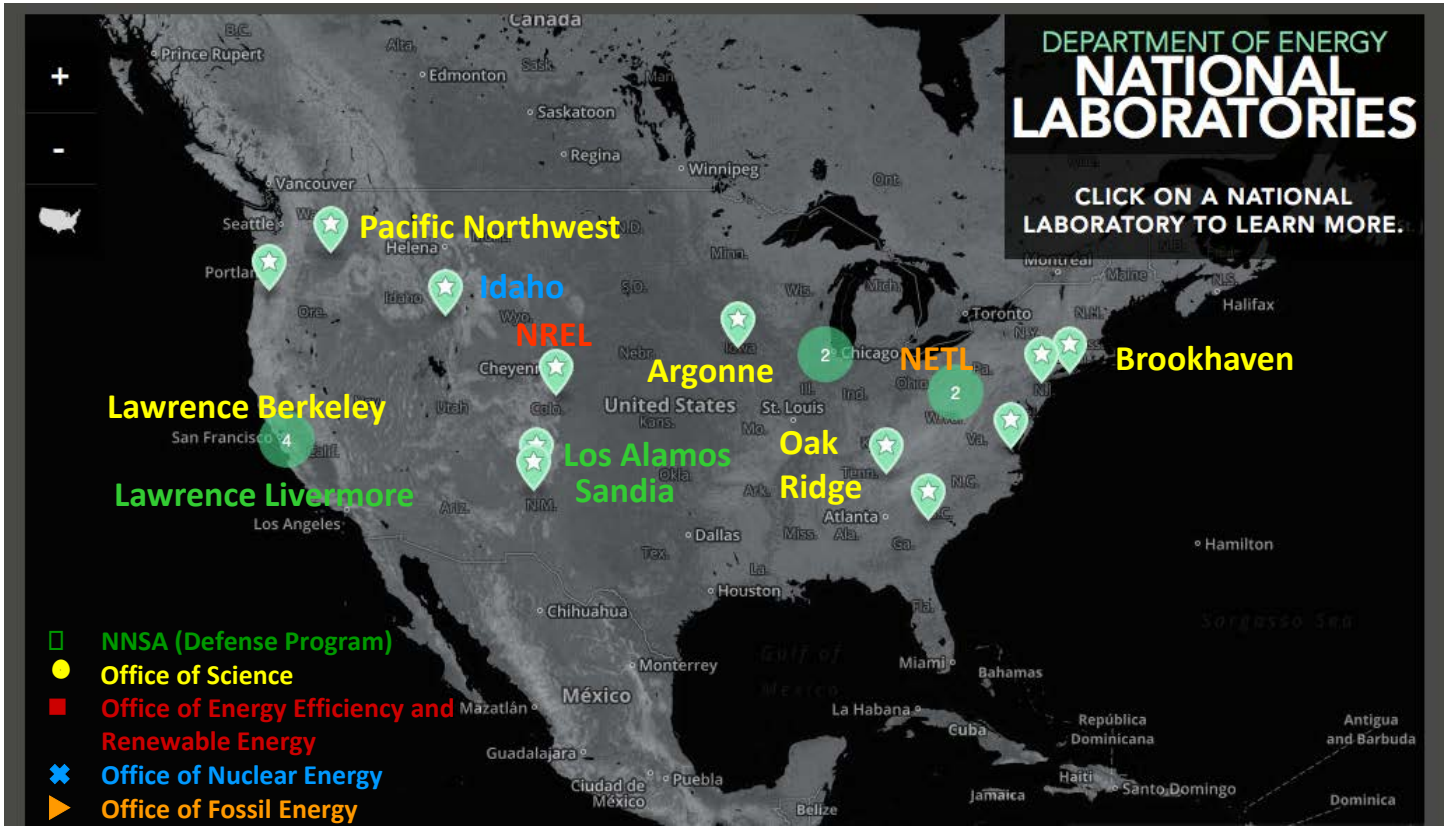
NREL's Advanced Distribution Management System (ADMS) Test Bed

Annabelle Pratt, Chief Engineer, NREL

EUCI: ADMS and DERMS Implementation Lessons and Challenges

September 19–20, 2023

DOE National Laboratories Overview



Source: http://energy.gov/maps/doe-national-laboratories

The National Renewable Energy Laboratory (NREL) is operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE).

NREL at a Glance

2,926

Workforce, including:

219 postdoctoral researchers

60 graduate students

81 undergraduate students

World-class

facilities, renowned technology experts

More than 900

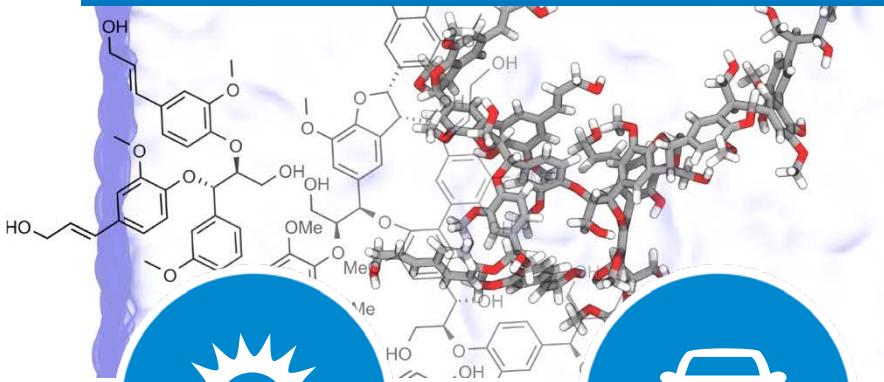
Partnerships

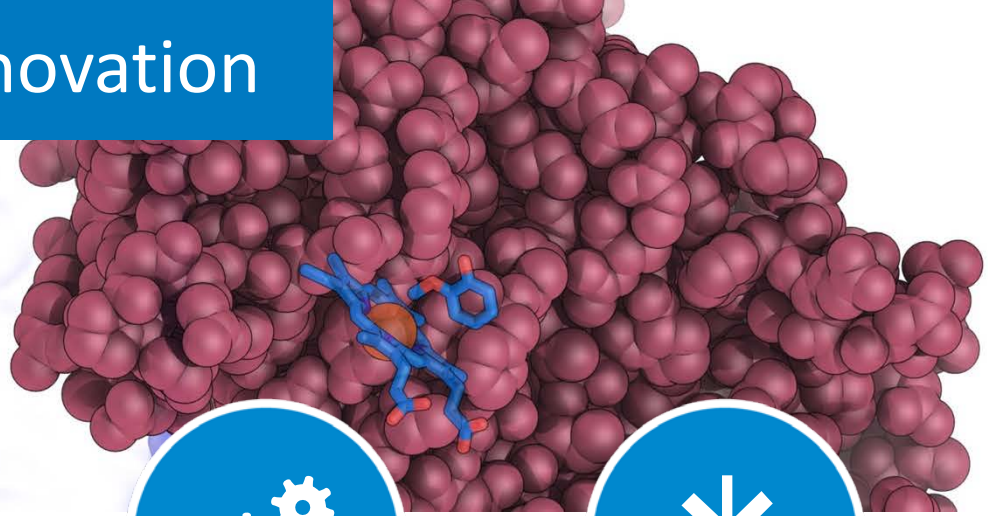
with industry, academia, and government

Campus

operates as a living laboratory

NREL Science Drives Innovation





Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

Grid Integration

Hybrid Systems

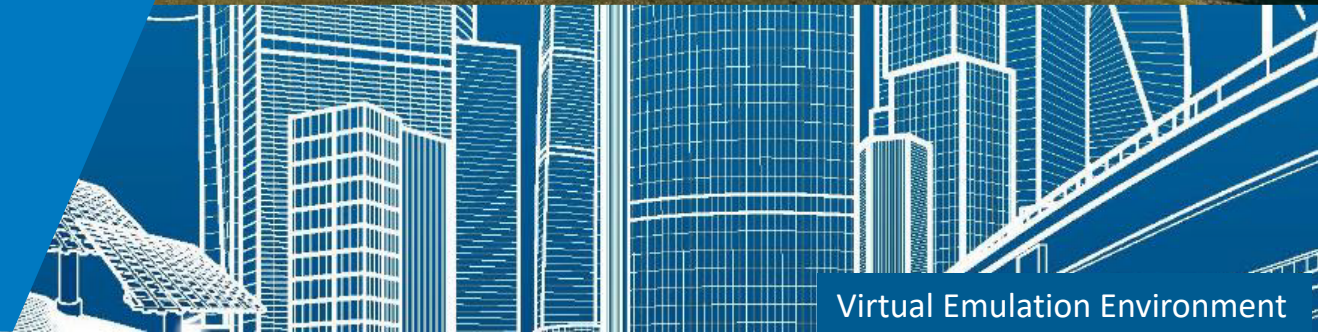
Security and Resilience

ARIES

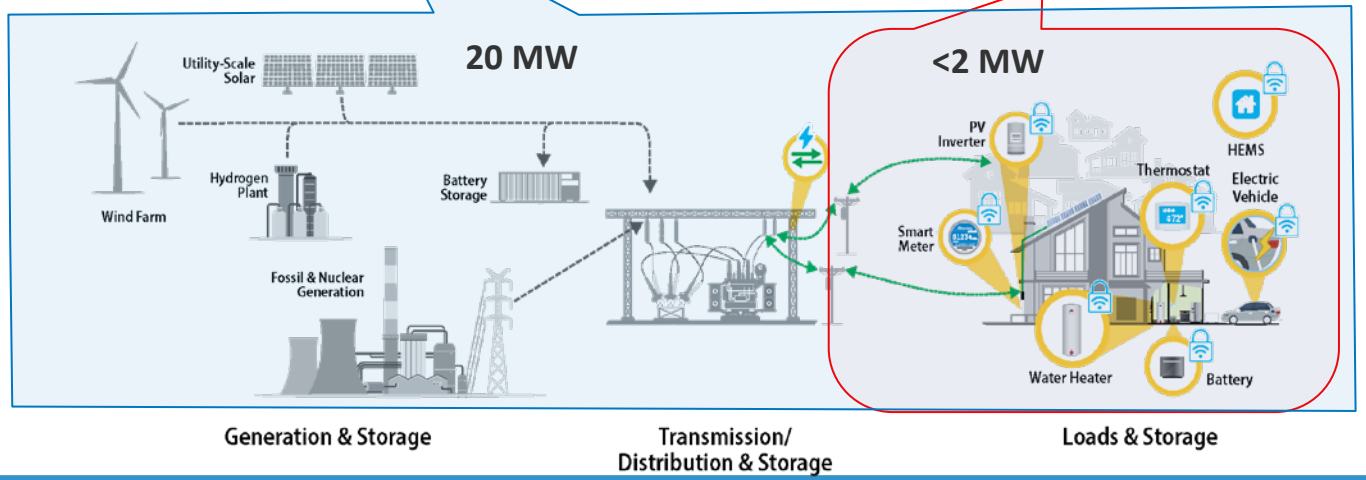
Advanced Research on Integrated Energy Systems (ARIES) is a unique research platform developed by NREL and DOE's Office of Energy Efficiency and Renewable Energy.

Energy Systems Integration Facility

Flatirons Campus


Virtual Emulation Environment

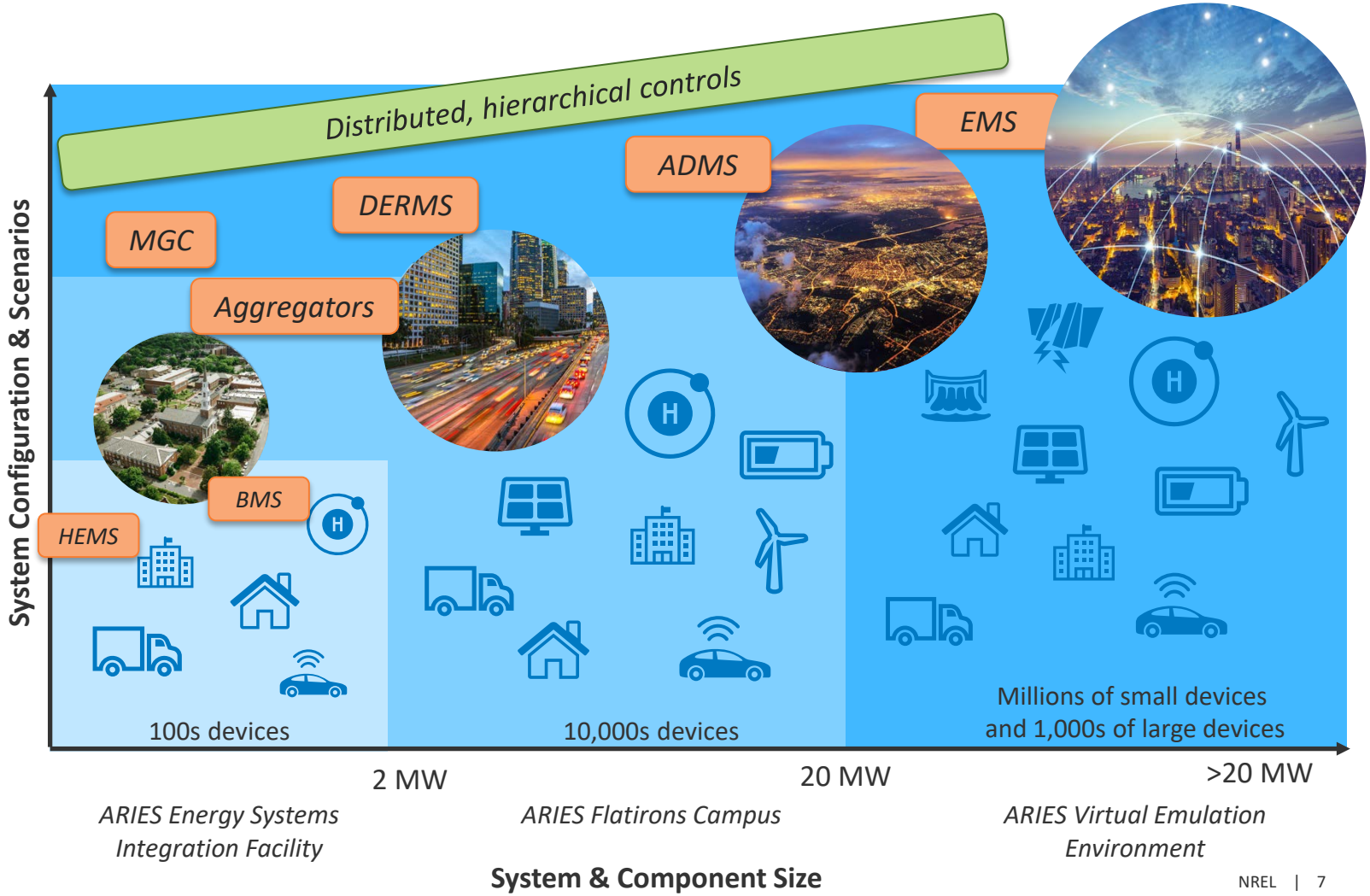
ARIES Research Platform at Scale



ARIES is a **globally unique research capability** that can be used to demonstrate that distributed energy resources (DERs) can operate in real-time energy markets and provide reliable and resilient grid services.

Photos by NREL

ARIES Scale


Distributed, hierarchical controls
EMS
ADMS
DERMS
MGC
Aggregators
BMS
HEMS
System Configuration & Scenarios
100s devices
10,000s devices
Millions of small devices
and 1,000s of large devices
2 MW
20 MW
>20 MW
ARIES Energy Systems Integration Facility
ARIES Flatirons Campus
ARIES Virtual Emulation Environment
System & Component Size

There is a need for “at-scale” testing with real hardware, real data, in real time.

New Ideas on how to make the most of DMS/ADMS

Algorithms get maturity through real-time testing and validation.

DMS in production, at enterprise level—MATURE algorithms

LAB-SCALE

NREL’s core capability

LARGE-SCALE

(DMS is deployed at this level.)

Fixed Data

Changes in ALGORITHMS

Real-Time Simulation Clusters with CHIL, PHIL

Changes in ALGORITHMS

Changes in DATA

Changes in DATA

Fixed Algorithms

Photos by NREL

DOE ADMS and DERMS Core Development

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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.

Four program areas:

Platform:	Develop an 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

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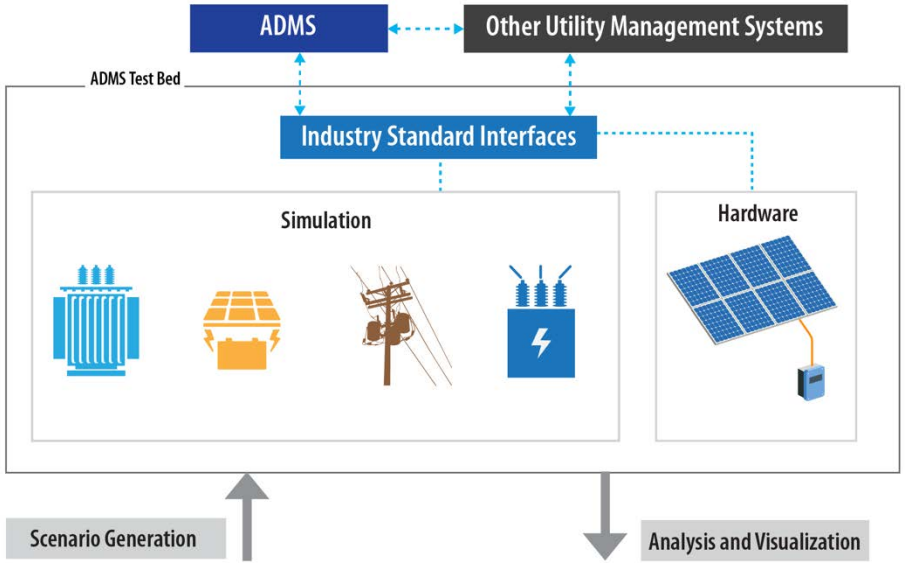
Goal: Accelerate industry adoption of ADMS to:

- Improve normal operations with high levels of 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.



https://www.nrel.gov/grid/advanced-distribution-management.html

ADMS Test Bed

Photo by NREL

ADMS Test Bed

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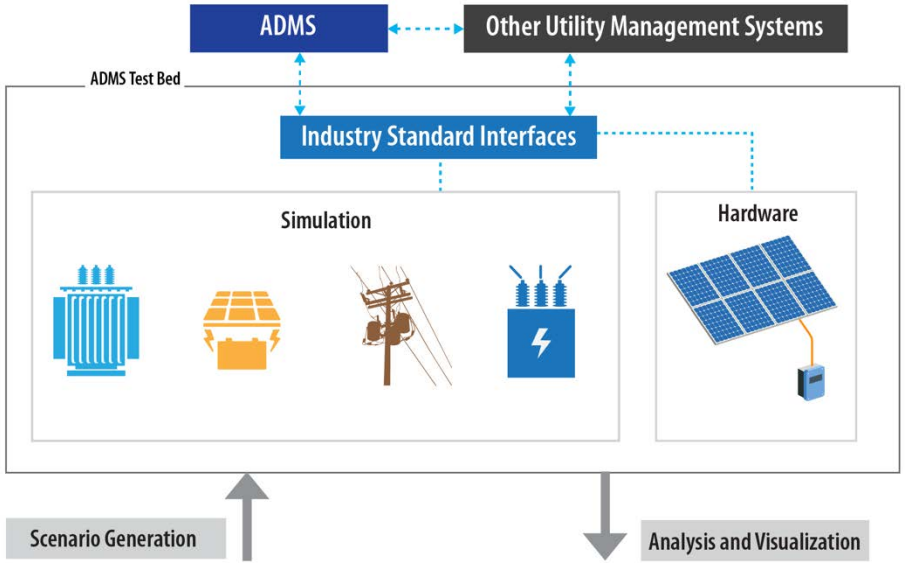
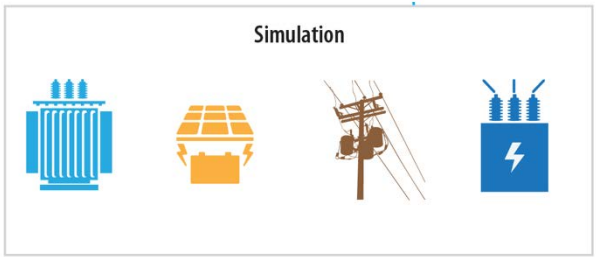
ADMS Test Bed capabilities include:

- Multi-timescale cosimulation
- Hardware integration
- Communication interfaces
- Data collection and visualization.



Multi-Timescale Simulation

- Can select one or more simulators to fit the use case
- We have used/are using:
  - OpenDSS by the 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.
  - eMEGASIM by OPAL-RT:
    - Electromagnetic (EMT) simulation
    - 50- to ~200-µs time step.
  - RSCAD by RTDS:
    - EMT simulation.



Model Conversion

- NREL's open-source Distribution Transformation Tool (DiTTo) can convert between various distribution system modeling formats: https://github.com/NREL/ditto.
  - *Developed a stand-alone OpenDSS to ePHASORSIM conversion tool*, https://github.com/NREL/DSS2ePHASOR.
- Different real-time simulators can import different software formats.
- Model reduction is often required for real-time simulators—we have used NREL and commercial tools.

Multi-Timescale Simulation

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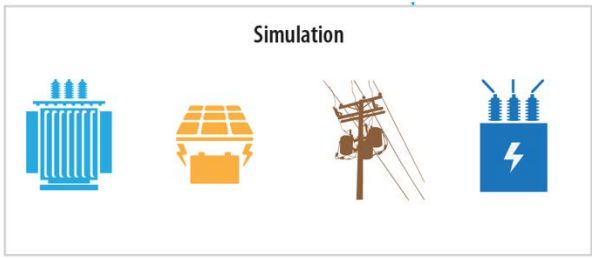
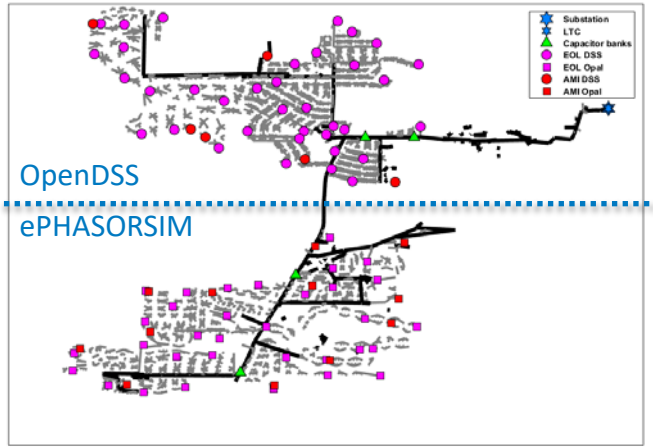
- Can run parts of a feeder in different simulators. Demonstrated:
  - OpenDSS and ePHASORSIM
  - OpenDSS and eMEGASIM.
- Orchestrated by test bed coordinator software:
  - Written in Python.
- Uses the Hierarchical Engine for Large-Scale Infrastructure Co-Simulation (HELICS) framework:
  - DOE investment through the Grid Modernization Initiative
  - www.helics.org.

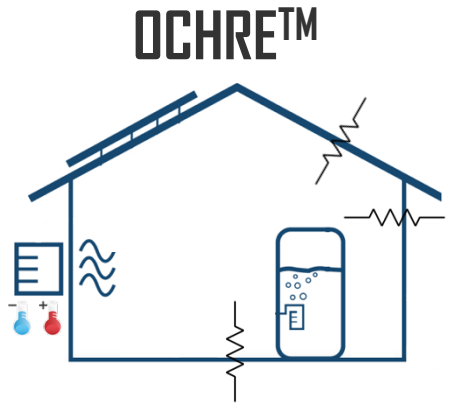




Cosimulation

Cosimulation with other tools:

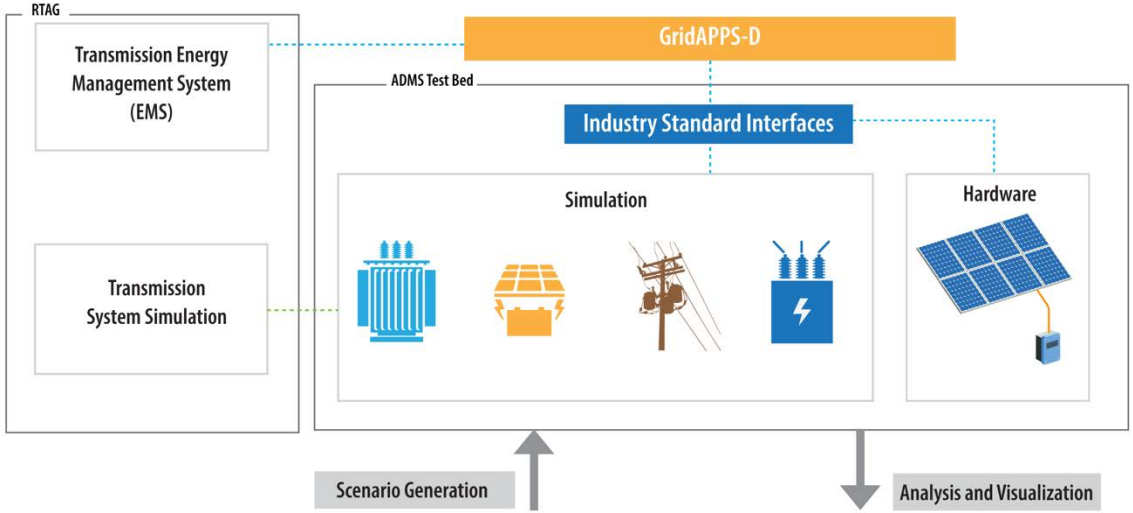
- OCHRE™:
  - Object-Oriented Controllable High-Resolution Residential Energy Model (open source)
  - Residential building simulation suitable for cosimulation with power systems
  - Implementation on high-performance computing for many homes.



Cosimulation

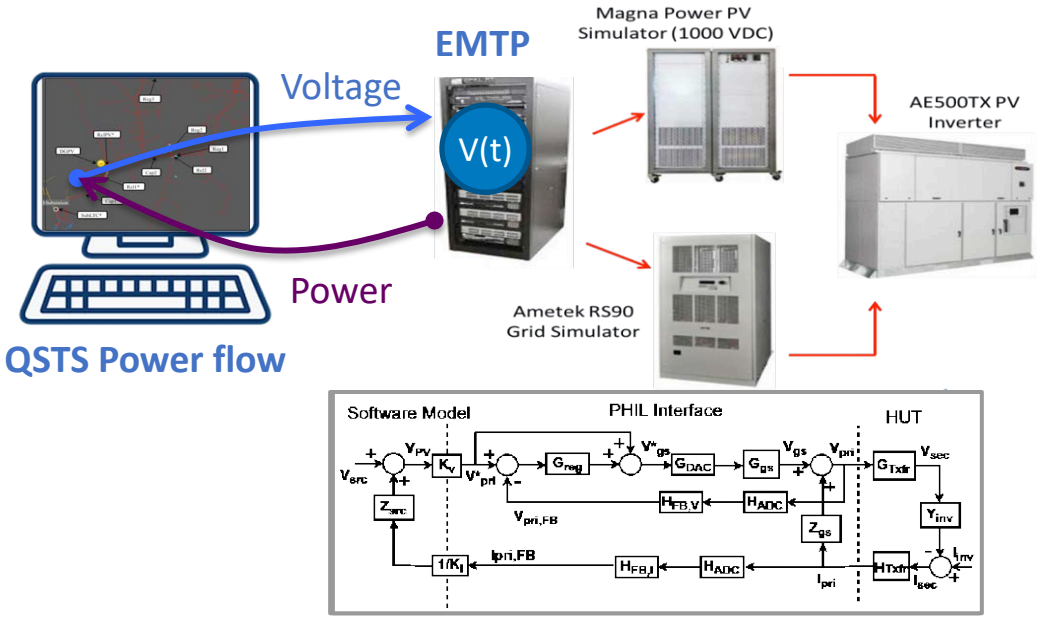
- Real-Time Analytics for Bulk Grid (RTAG):
  - https://www.nrel.gov/grid/control-room.html
  - Transmission power system simulation
  - Transmission energy management system.

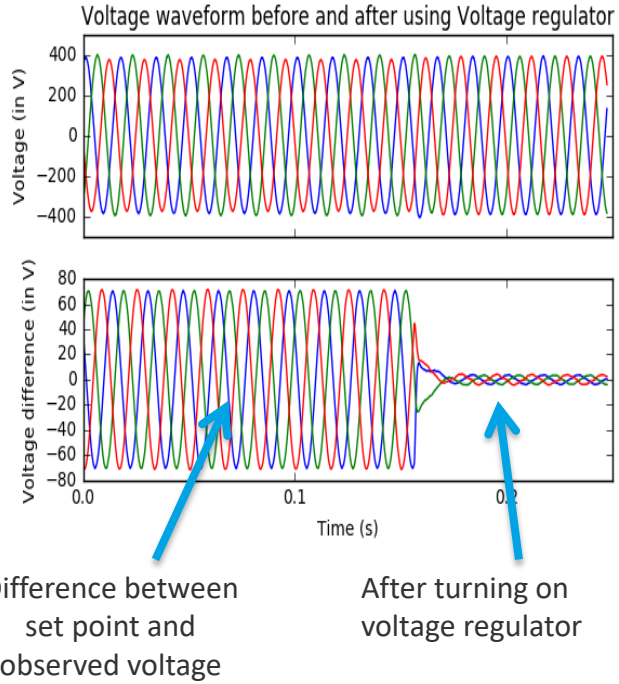
- GridAPPS-D:
  - https://www.gridapps-d.org/
  - Open-source platform for ADMS application evaluation.



Hardware Integration

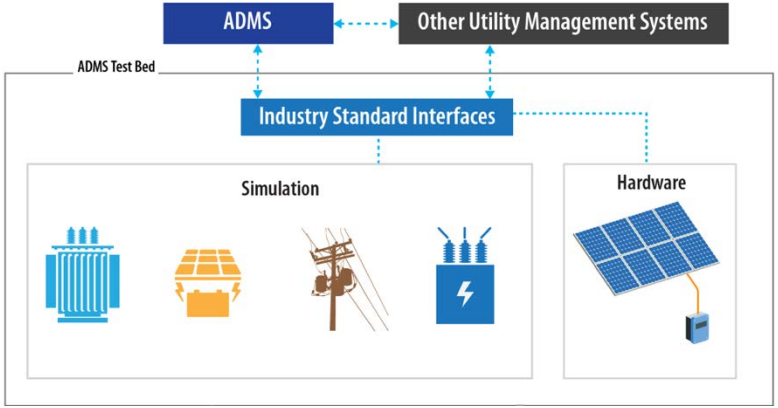
- Hardware-in-the-loop integration of controller and/or power hardware
- NREL-owned equipment is available for use.





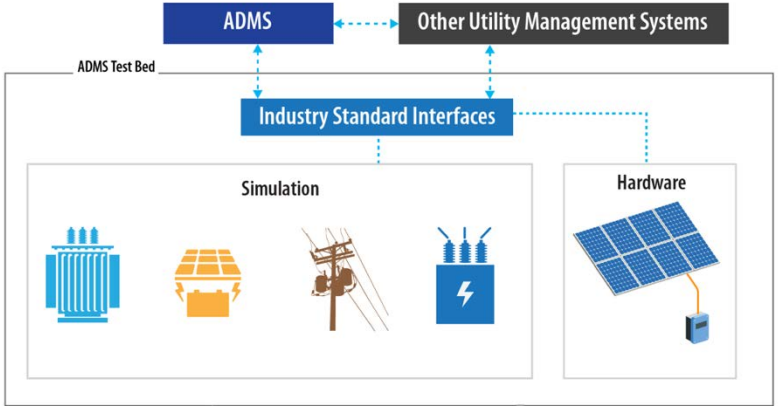
Communication Interfaces

- Uses industry-standard interfaces:
  - Distributed Network Protocol 3 (DNP3):
    - ADMS to OpenDSS:
      - Device simulator developed by EPRI as communication interface to OpenDSS
      - Used SEL RTAC in some use cases.
    - ADMS to OPAL-RT/RTDS:
      - DNP3 drivers available.
  - Currently implementing IEEE 2030.5 clients:
    - Being developed by EPRI.
  - Modbus.
  - MultiSpeak.



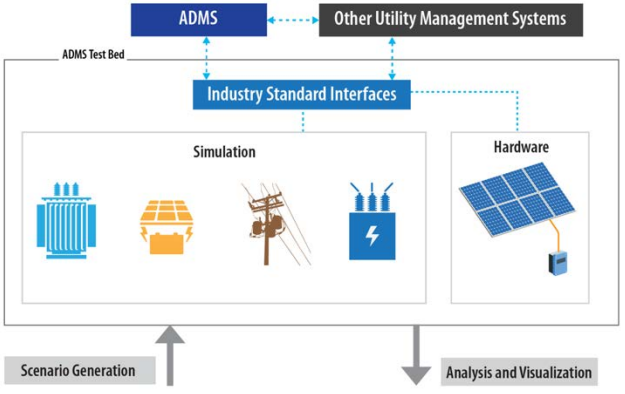
ADMS and Controls Interfaced

- Commercial ADMS by:
  - General Electric
  - Schneider Electric
  - Survalent
  - Oracle
  - OSI.
- Other utility management systems:
  - Varentec GEMS (now Sentient Energy).
- Research control algorithms:
  - Applications on GridAPPS-D
  - Python code.

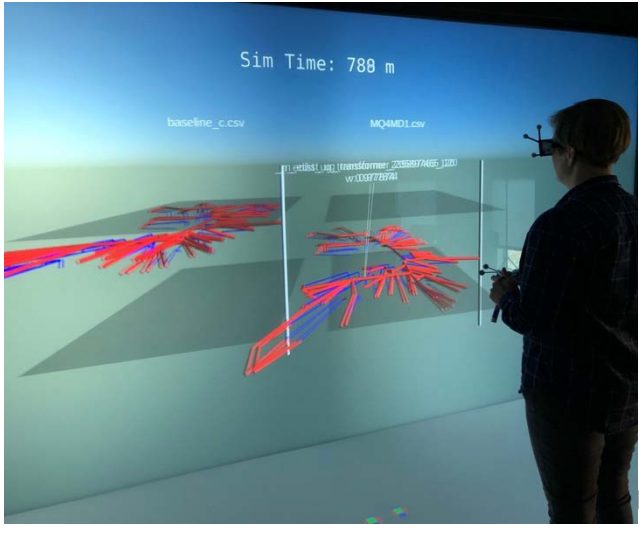


Visualization

- Real-time data streaming for 2D visualization
- 3D visualization of results
- C++ code on GitHub:
  - https://github.com/NREL/rts-vis-app
  - https://github.com/NREL/rts-data.



Photos by NREL



ADMS Test Bed
Use Case Development

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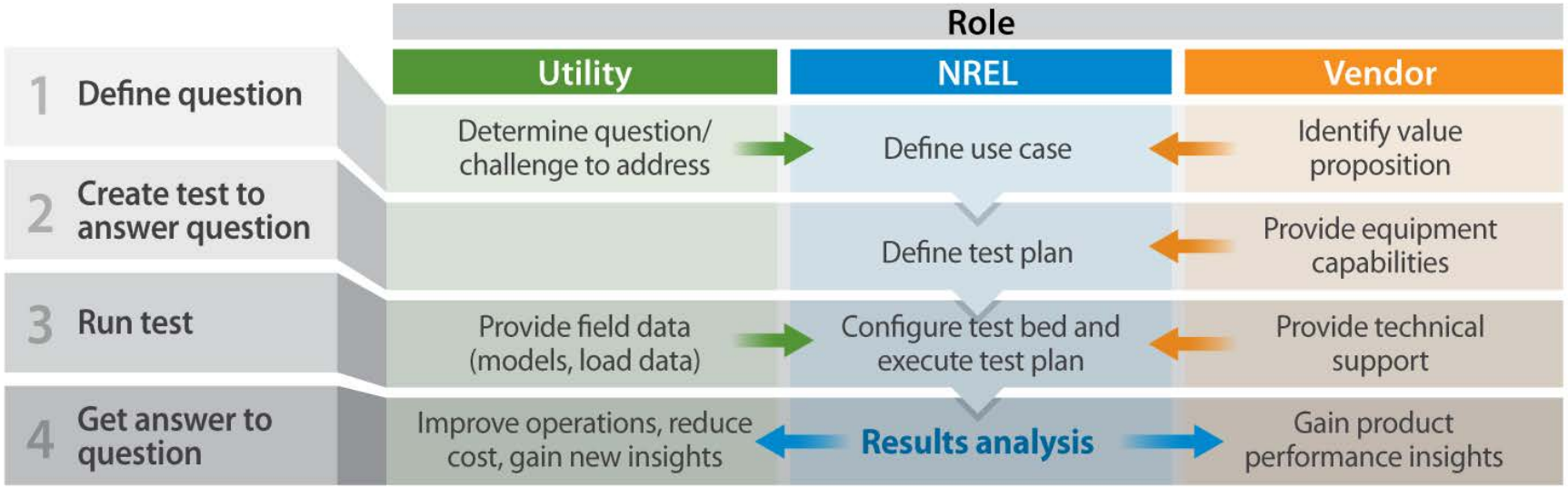
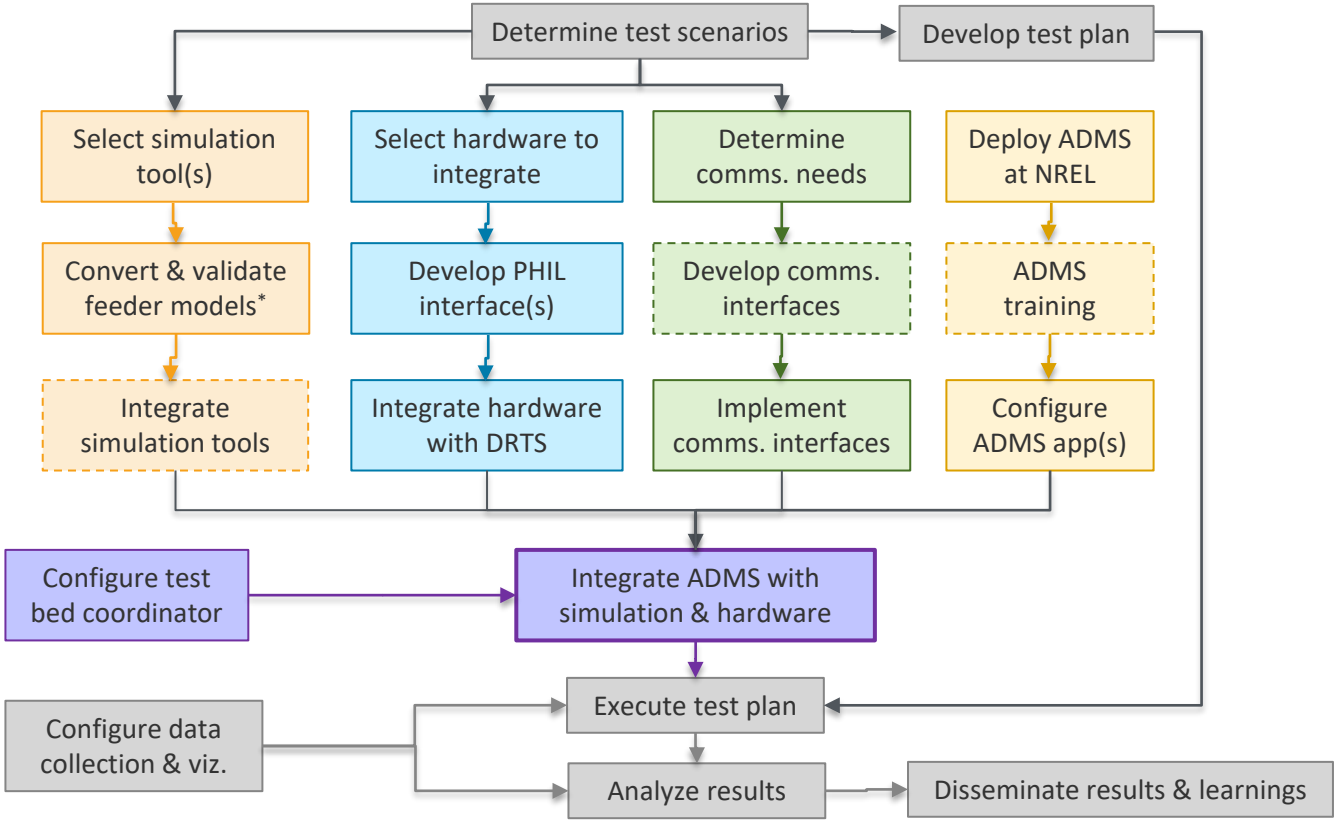


Configuring the Test Bed



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

ADMS Test Bed Use Cases

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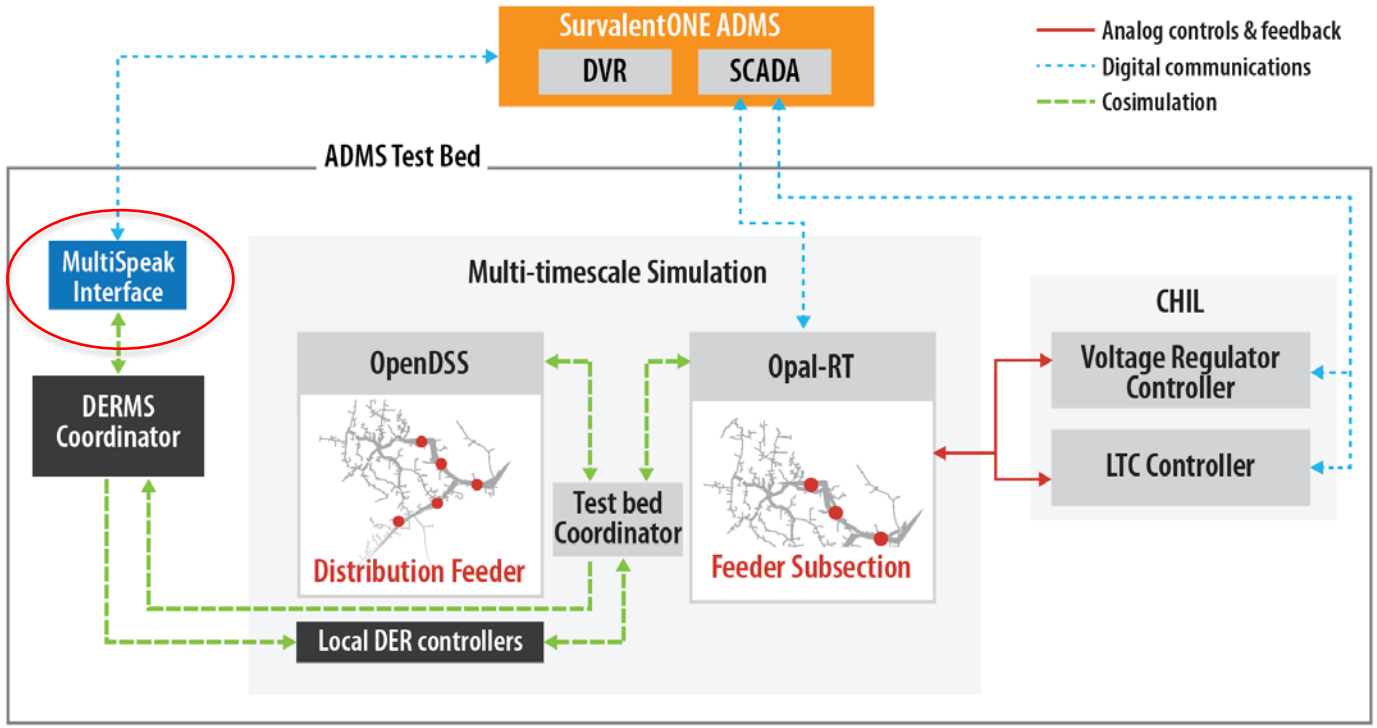
- **ADMS network model quality impact on VVO**
  - Xcel Energy/Schneider Electric
- **Peak load management with ADMS and DERMS**
  - Holy Cross Energy/Survalent
- AMI-based, data-centric grid operations
  - SDG&E + GridAPPS-D
- **FLISR in the presence of DERs**
  - Central Georgia EMC/Survalent
- DER controls strategies for T&D grid services
  - Xcel Energy + GridAPPS-D
- Federated DERMS for high PV system
  - Southern Company/Oracle + GridAPPS-D → Feb. 2024
- Co-optimizing grid and facility operations
  - Shell + Spirae → July 2024
- System restoration with improved fault tracking
  - Israel Electric Company + EGM → June 2024

ADMS test bed capabilities used by:

- Non-wires alternatives
- ECO-IDEA
- GO-SOLAR
- SolarExpert
- Resilient Operation of Networked Microgrids (RONM)
  - SDG&E, Cobb EMC
- **FAST-DERMS**
  - SDG&E, Oracle, EPRI + GridAPPS-D → April 2024
- REORG
  - Holy Cross Energy, Minsait ACS → March 2024
- PV Integration using a Virtual Airgap (PIVA)
  GridBright, SDG&E → Sept. 2023
- **SALMON**
  - Portland General Electric, OSI + TBD DERMS → Aug. 2027

Peak Load Management Use Case



Partners

Holy Cross Energy

Survalent

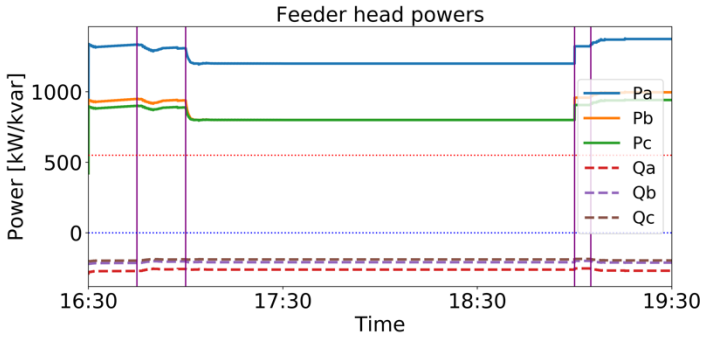
NRECA

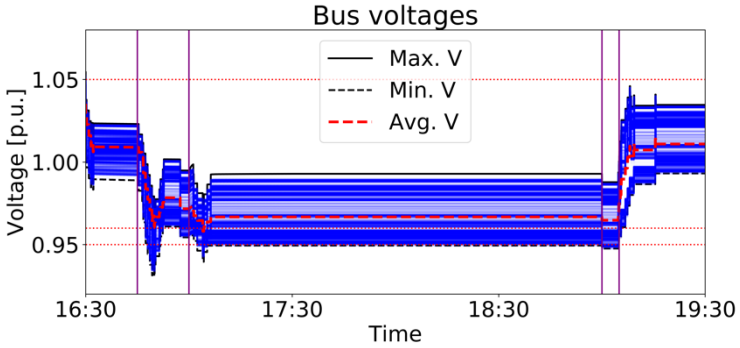
EPRI

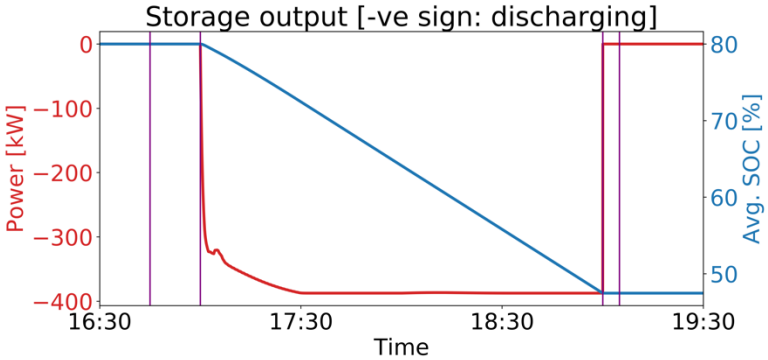
PNNL

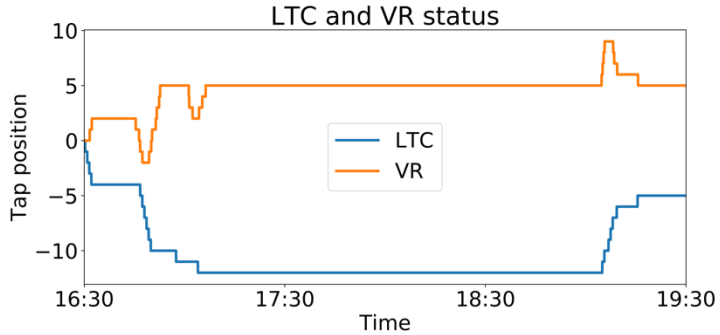
H. Padullaparti, A. Pratt, I. Mendoza, S. Tiwari, M. Baggu, C. Bilby, and Y. Ngo, "Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources," IEEE GreenTech, 2021.

Peak Load Management Use Case: Post-Processed Results









Peak Load Management Use Case: Post-Processed Results Cont.

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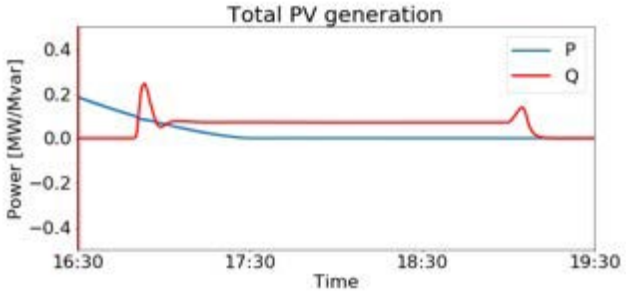
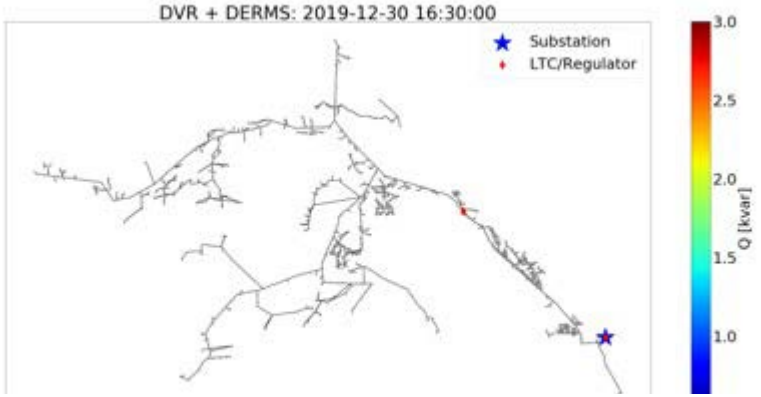
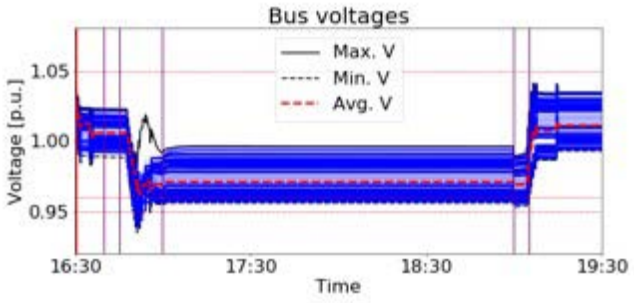
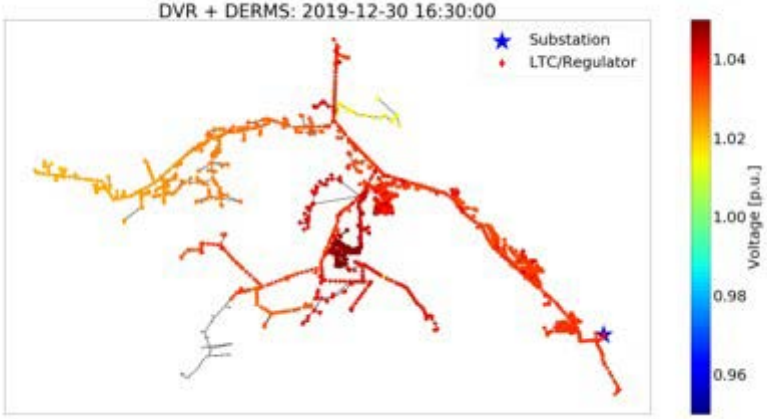
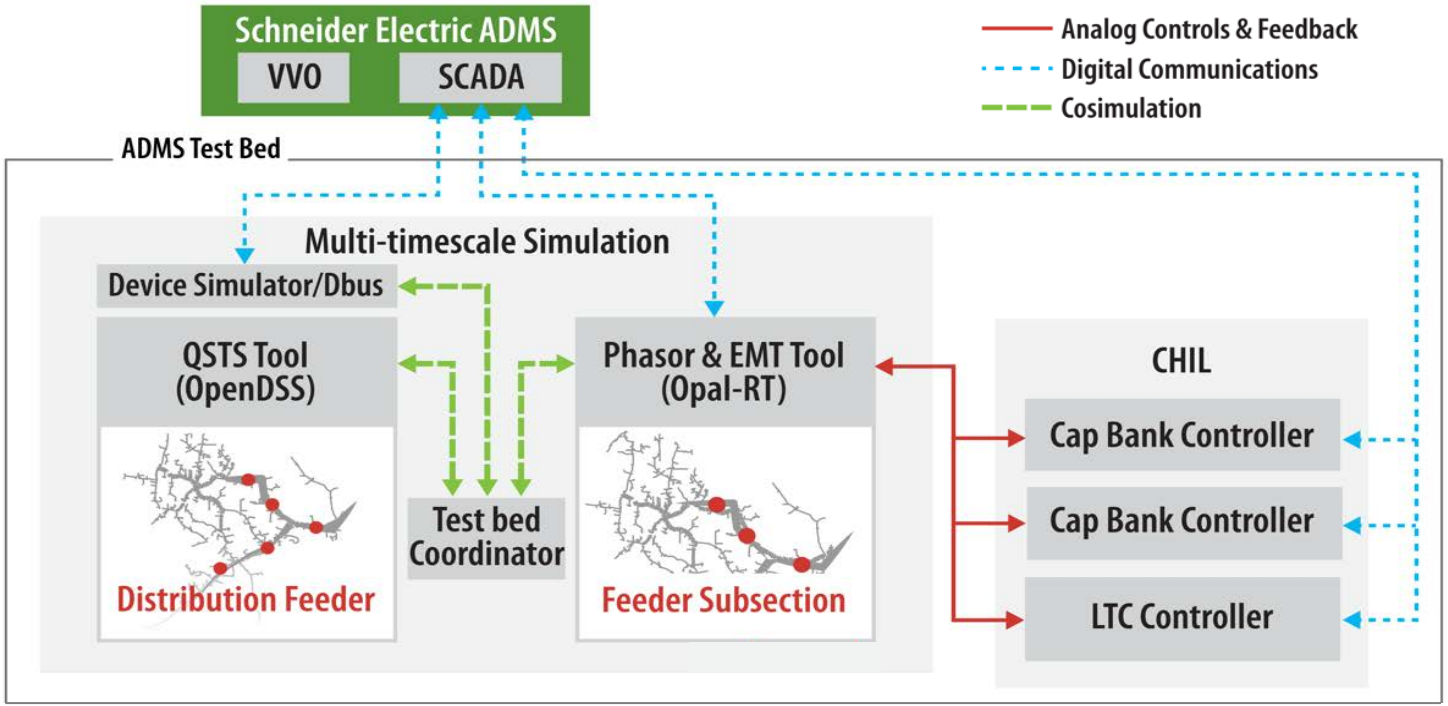








ADMS Network Model Quality Use Case



Partners:
Xcel Energy
Schneider Electric
PNNL
EPRI
Opal-RT

ADMS Network Model Quality Use Case: Post-Processed Results

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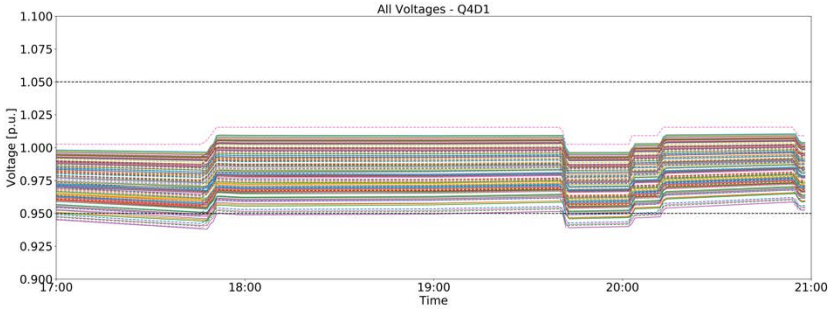
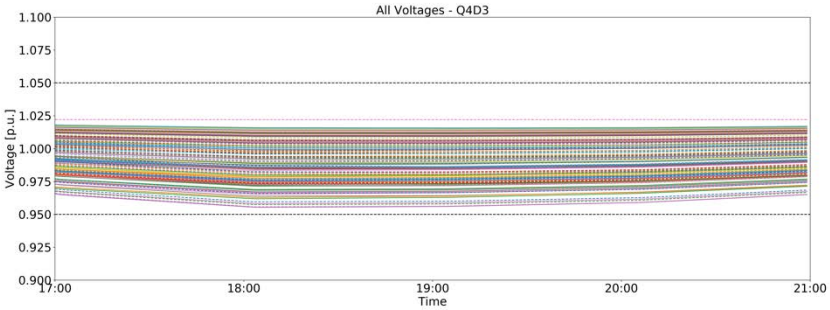
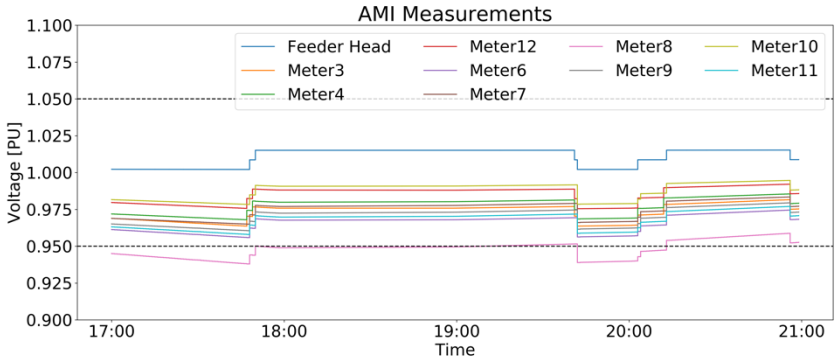
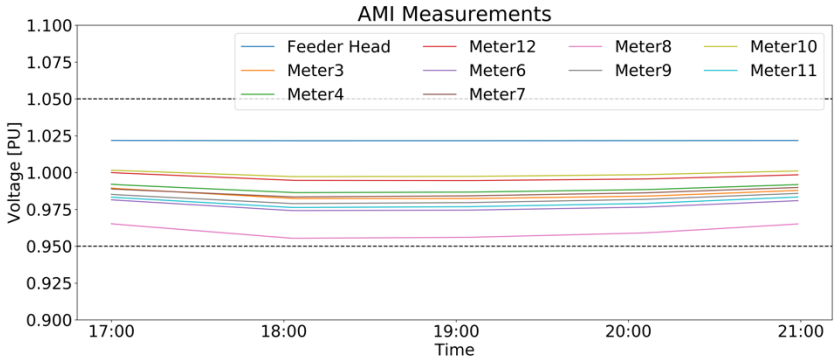
Q4D1 (High model quality; feeder head-only measurements)



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







FLISR in the Presence of DERs

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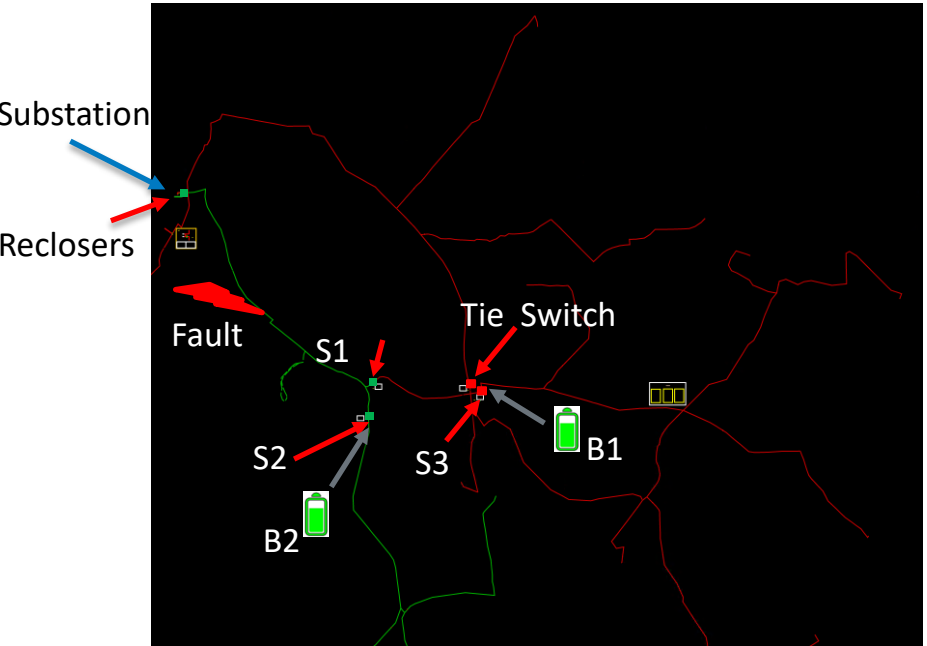
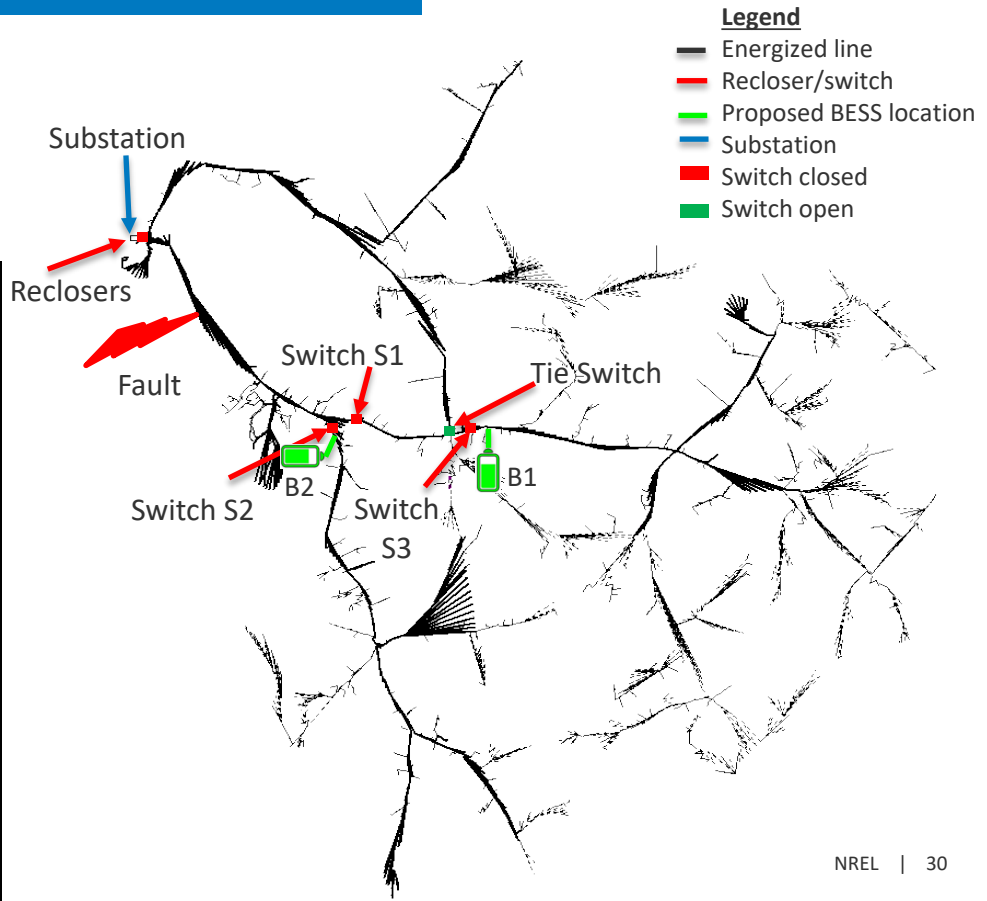
Partners:

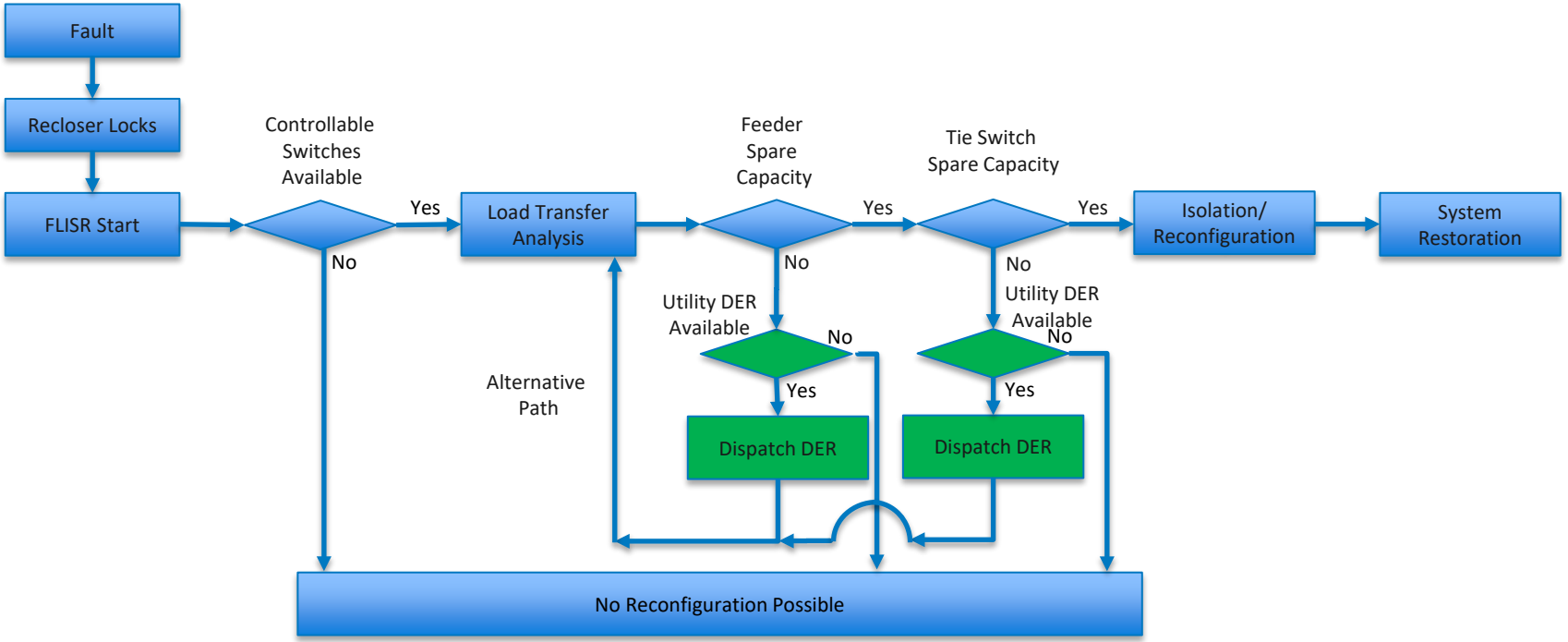
- Utility: Central Georgia EMC
- ADMS: Survalent.





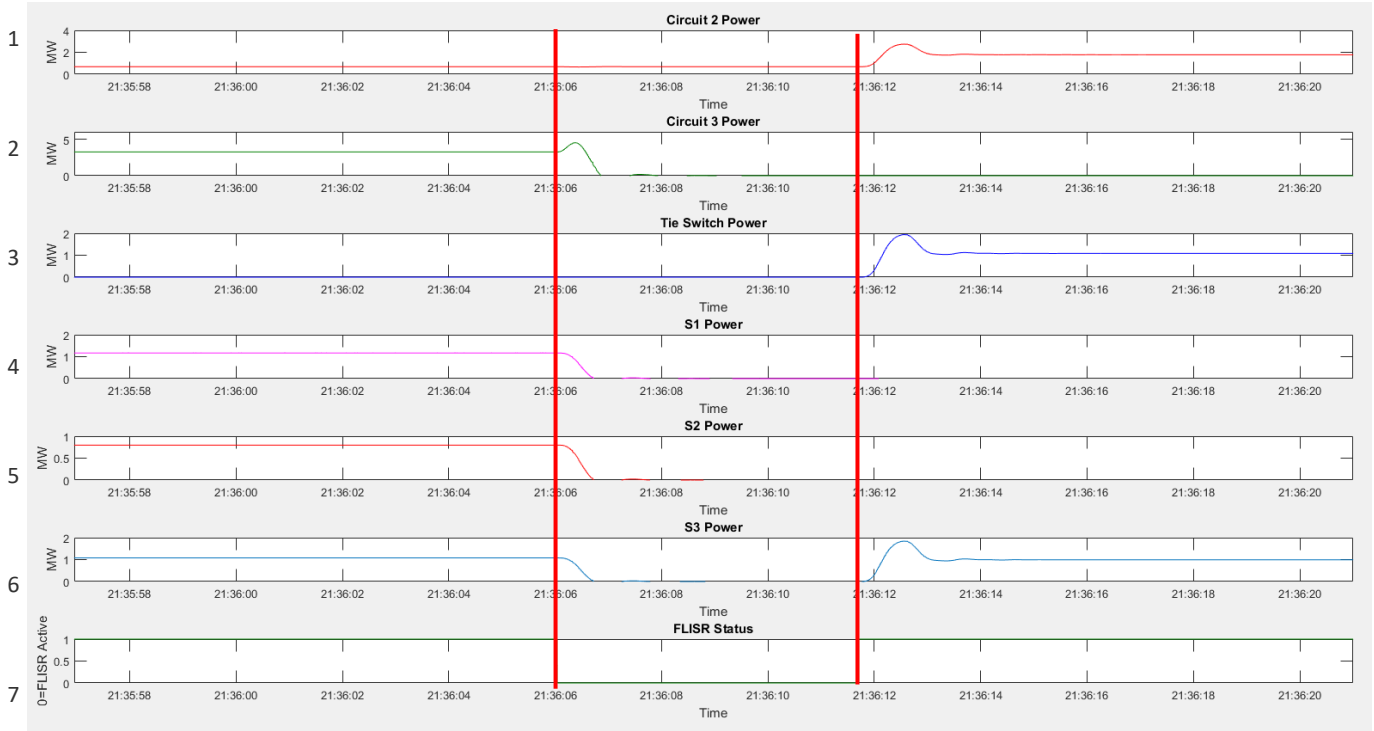
FLISR Flowchart With DER Dispatch

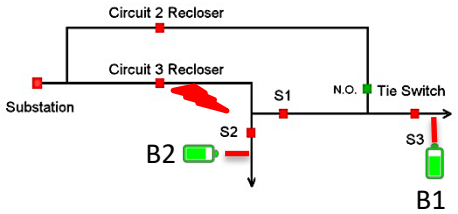
What if FLISR could dispatch DERs?



Simplified, not showing all possible iterations

Power Measurements With B1 & B2 (GFM BESS)





t=21:36:06: Fault occurs, de-energizing Circuit 3; both BESS switch to GFM mode to pick up load during the transition

t=21:36:11.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; BESS 1 switches to GFL

Smart Grid Asset Load Management & Optimized Neighborhood (SALMON)

- Smart Grid Test Bed Collaboration

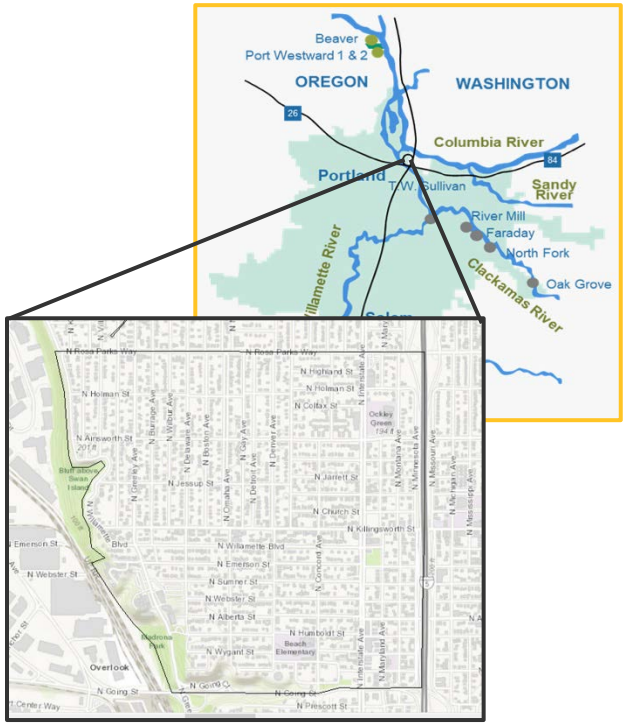
5-year timeline (June 2022–June 2027)

$11.667M budget ($6.65M federal,* $5.017M match)

Retrofit 580 of 2,800 buildings (~21%)

Build 1.4 MW flexible load resource

10% efficiency improvement across treated buildings



* Funded by DOE funded through the Connected Communities program

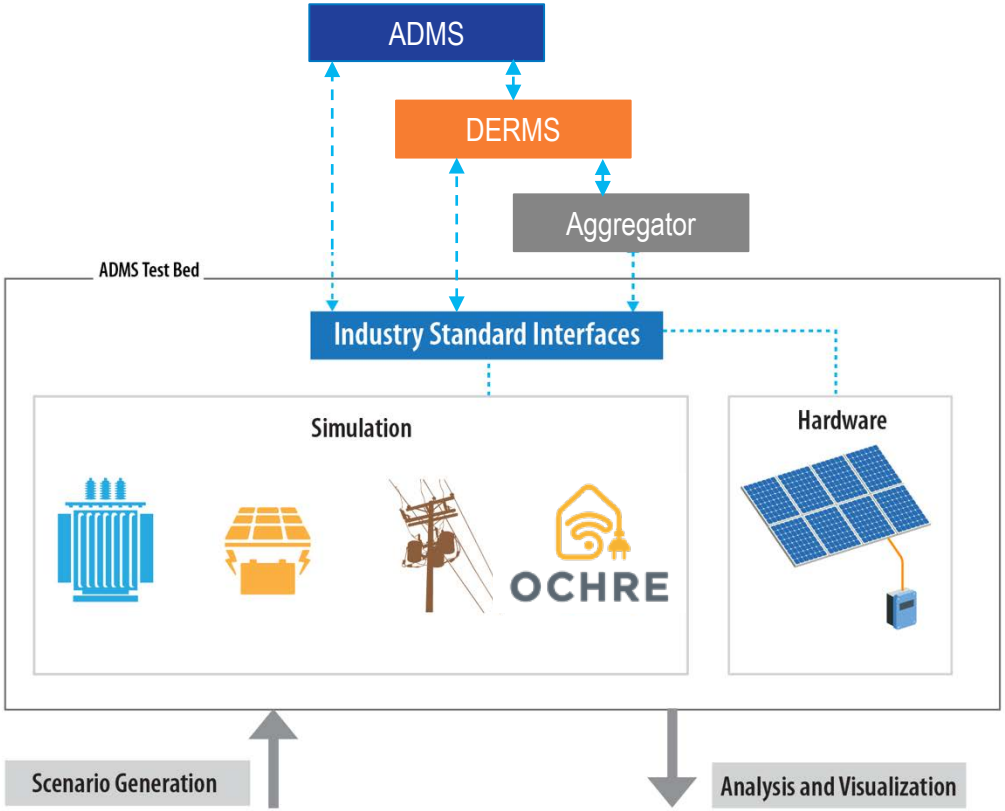
SALMON Test Bed Setup

Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

Partners (on test bed task):

- Utility: Portland General Electric
- ADMS: OSI
- DERMS: TBD.

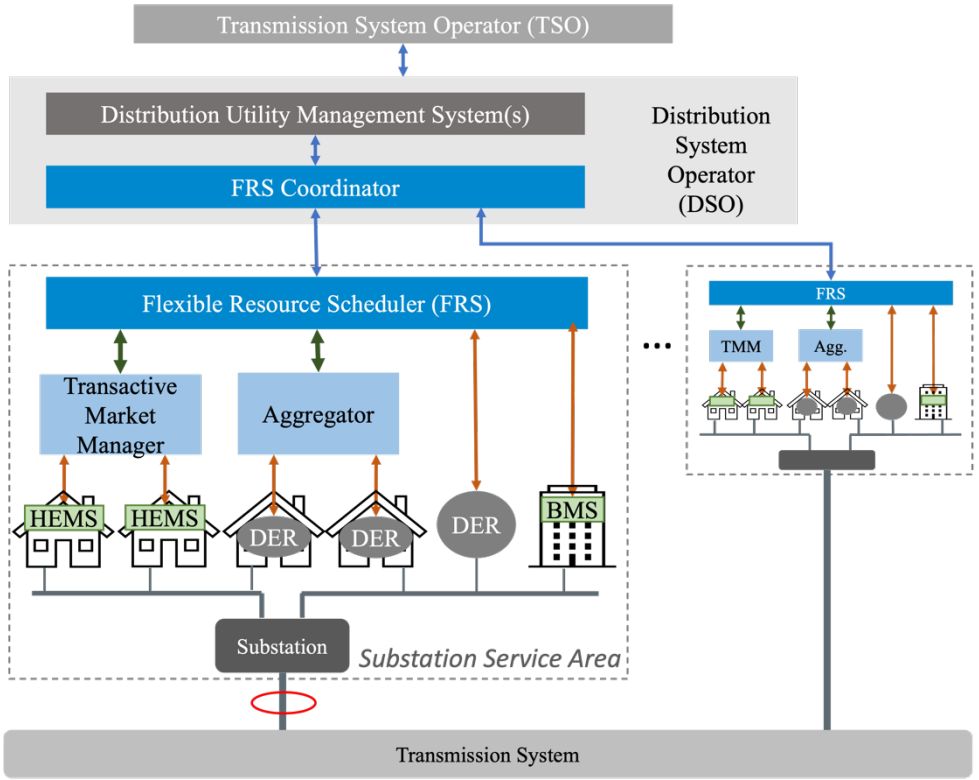
- Developed digital twin of PGE's study area in ADMS Test Bed:
  - Two feeders in OpenDSS
  - ~4,100 homes in OCHRE
  - Run on HPC.
- Integrate with controls:
  1. NREL's research DERMS and aggregator controls
  2. Commercial ADMS and DERMS and NREL's aggregators.



Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

- Employ **"Total DSO" architecture** model such that the DSO represents the aggregated resource response in the bulk transmission system.
- Perform **network-aware optimization** to maintain distribution health while simultaneously providing bulk service.
- Demonstrate **distributed intelligence** by managing aggregations at the distribution substation through our Flexible Resource Scheduler (FRS).
- **Simplify T&D interaction** by defining and measuring transmission services provided at the distribution substation.

The goal is to make multiple substations connected to a transmission load bus (unmanaged load + DER) have the controllability of a conventional generator.



FAST-DERMS Project: Lab Setup

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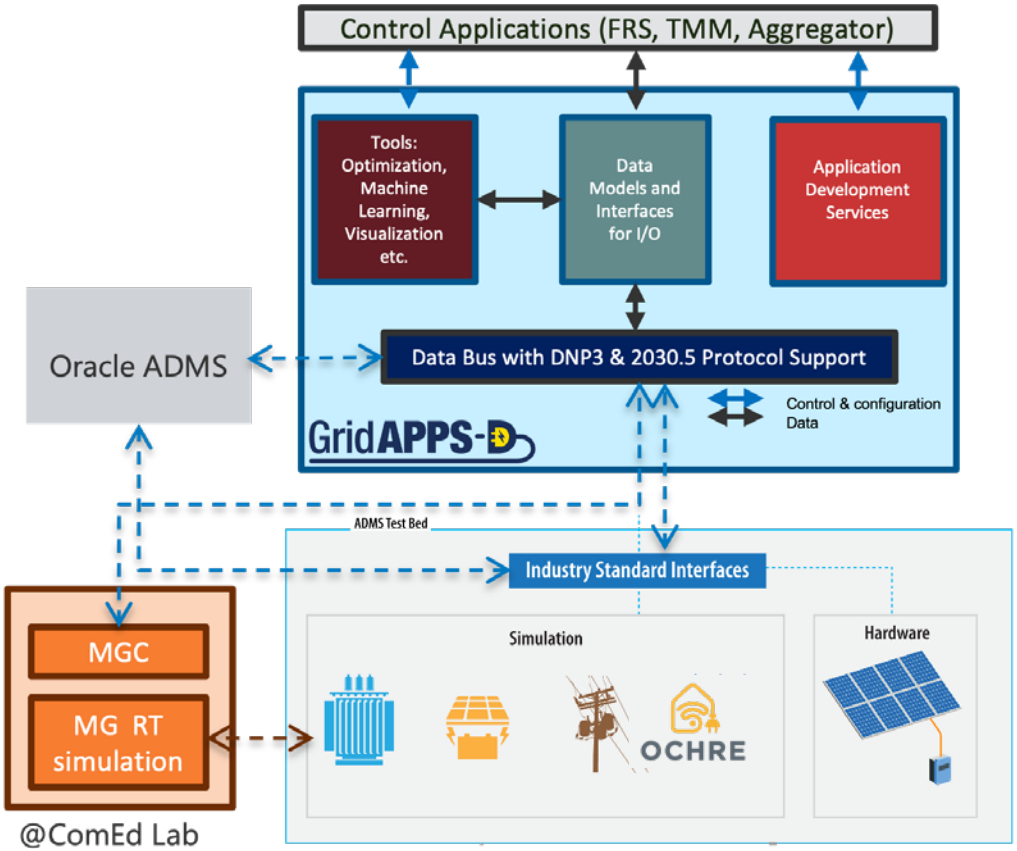
- GridAPPS-D platform: https://www.gridapps-d.org/
  - Research control applications
- Oracle commercial ADMS
- Remote cosimulation with ComEd
  - Siemens microgrid controller
- ADMS Test Bed:
  - NREL's OCHRE residential building simulator
  - High-performance computer
  - 2030.5 communications.

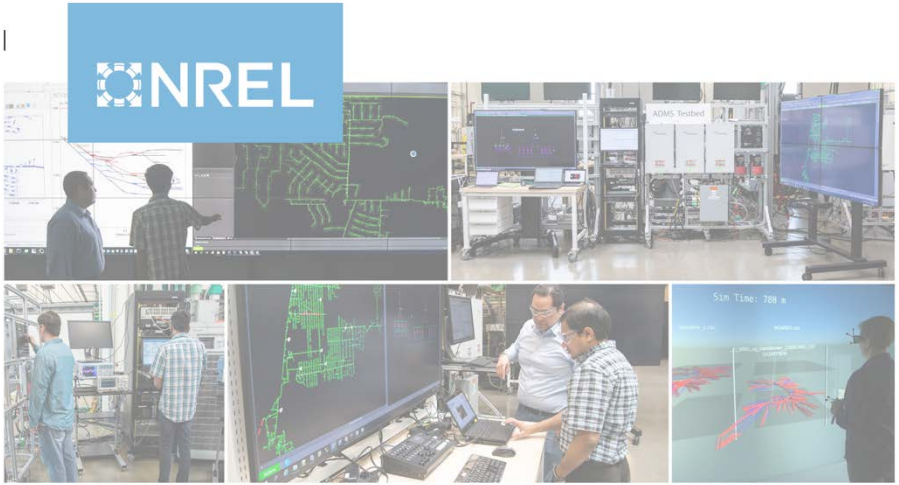
Partners:

- SDG&E, Southern Company, ComEd, New York Power Authority, Oracle, GridBright, EPRI, LBNL, PNNL, ORNL, ISU, UNCC.



ARIES User Call for ADMS Test Bed Future Use Cases

- Issued August 2023



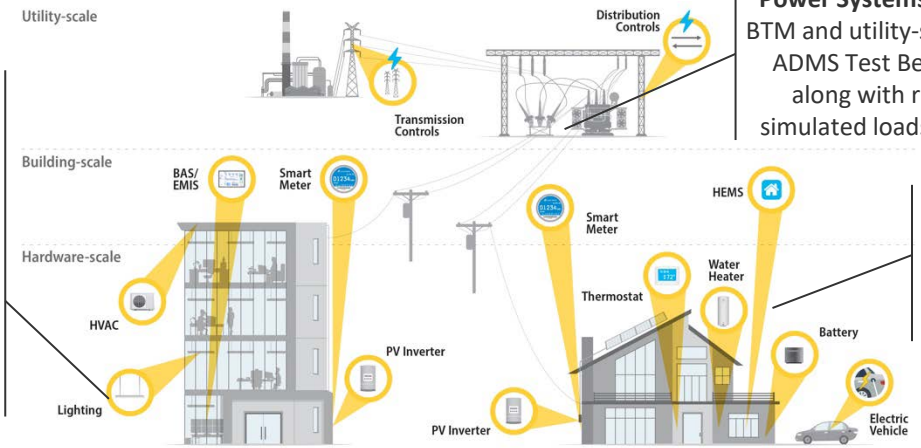
Advanced Research on Integrated Energy Systems (ARIES) User Call for Advanced Distribution Management System (ADMS) Test Bed Vehicle-Grid Integration Use Cases

VGI research areas:

- **Control architectures**—addresses control architectures and/or algorithms for systems with high levels of EVs and other DERs
- **Role of DERMS and aggregators**—addresses ways to coordinate the operation of an ADMS with a DERMS and/or aggregators to manage high levels of EVs and other DERs
- **Integration with buildings**—addresses the evaluation of control and management solutions that specifically include vehicle integration with buildings (residential or commercial)
- **Communication architectures and cyber-secure data**—addresses the evaluation of solutions that specifically include different communication architectures, protocols, and/or cyber-secure solutions
- Proposals due: Oct. 27, 2023:
  - 5-page concept paper + 1 summary slide.

NREL: Integrated, End-to-End Energy Ecosystem

Commercial Building Residential Infrastructure (CBRI) connects commercial DERs, BAS controllers, and thermal energy storage to building simulations and grid simulations.



Power Systems Integration Lab (PSIL) includes BTM and utility-scale DERs, microgrid controllers, ADMS Test Bed, and future DERMS test bed, along with real-time simulators to model simulated loads and simulated power systems.

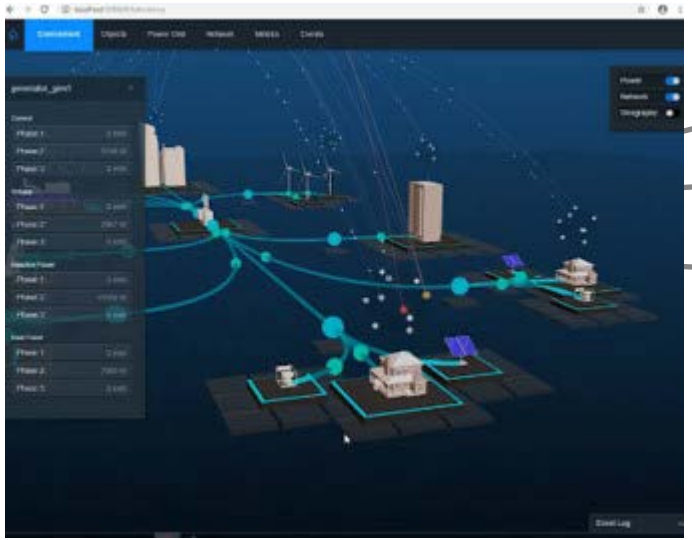
Systems Performance Lab (SPL) contains residential DERs, major appliances, and smart controllers connected to building simulations and grid simulations.

Flexible combination of laboratory hardware, advanced controllers, and simulation tools allows for wide range of experiments:

1. De-risking: Make projects more successful.
2. Proving ground: Evaluate claims.
3. Scaling: Extend results beyond a single project—and from devices, to buildings, to the grid.

The ARIES Cyber Range

A unique capability for cyber-securing distributed, connected energy systems



NREL's Cyber Range is unique:

1. Builds on NREL's best-in-class energy system models and cosimulation
2. Focuses on future energy systems, especially distributed and multi-owner critical infrastructure
3. Engages NREL domain experts
4. Accesses ARIES assets for hardware-in-the-loop.

Photos by NREL

Takeaways

- NREL's ADMS Test Bed provides a realistic laboratory testing environment for grid controls: ADMS, DERMS, etc.
  - Real-time power system and building models
  - Can integrate with bulk system simulation
  - Hardware-in-the-loop capability.
- Opportunity to partner with NREL through ARIES User Call for ADMS Test Bed Vehicle-Grid Integration Use Cases
  - Proposals due Oct. 27.

Thank You

www.nrel.gov

Annabelle.Pratt@nrel.gov

NREL/PR-5D00-87389

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For Further Reading

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ESIF—A National User Facility

- NREL's largest R&D facility (182,500 ft^2/20,000 m^2)
- Space for ~200 NREL staff and research partners.

Photos by NREL

ADMS Test Bed

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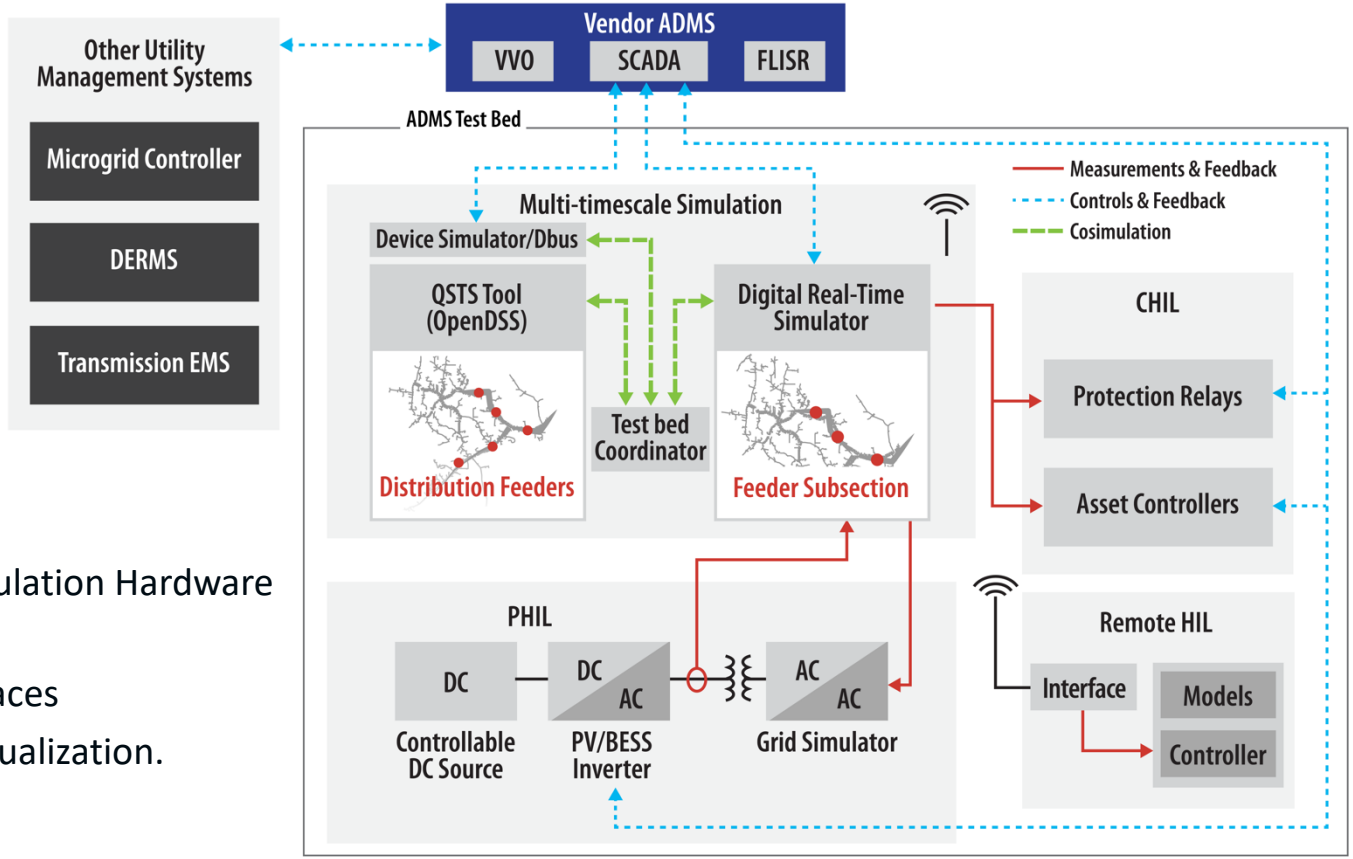
ADMS Test Bed capabilities include:

- Multi-timescale cosimulation Hardware integration
- Communication interfaces
- Data collection and visualization.