Request for Information (RFI)

Advanced Distribution Management System (ADMS) Test Bed Future Use Cases

June 30, 2021

Purpose

The National Renewable Energy Laboratory (NREL) and U.S. Department of Energy (DOE) are issuing a request for information (RFI) from the broader industry to work with a variety of stakeholders to ensure that relevant research is conducted using NREL's *Advanced Distribution Management System (ADMS) Test Bed*. The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on research-and-development (R&D) needs. We are soliciting feedback on the associated capabilities, facilities, and infrastructure needed to ensure the most beneficial outcomes from using the ADMS Test Bed.

The ADMS test bed is a key capability of NREL's Advanced Research on Integrated Energy Systems (ARIES), a new national research capability at NREL that addresses the challenges associated with integrating distributed energy systems (DERs) into the broader power system. The ADMS Test Bed was developed by NREL and the U.S. Department of Energy's (DOE's) Office of Electricity Advanced Grid Research and Development program through DOE's Grid Modernization Laboratory Consortium (GMLC) as a vendor-neutral evaluation platform for advanced grid controls implemented on ADMS platforms. The test bed uses real hardware, large-scale distribution power system models, and advanced visualization to simulate real-world conditions for different use cases.

It has been in used in the past in use cases to study the impact of ADMS network model quality on Volt/VAR optimization (VVO), peak load management using an ADMS and a DER management system (DERMS), and using advanced metering infrastructure (AMI) data for grid operations. It is currently being used to study the effect of DERs on fault location, isolation and system restoration (FLISR); the effectiveness of a federated DERMS approach; and transmission-and-distribution co-optimization.

NREL is requesting responses to this RFI to help define ADMS Test Bed functionalities that are needed to support future use cases. After the responses to the RFI have been evaluated, NREL may issue a request for proposals (RFP) to identify future use cases to be simulated using the ADMS Test Bed. NREL and DOE have identified the following R&D categories as of particular interest for future ADMS Test Bed use cases:

- Control architectures and algorithms for high-levels of DER systems
- Transmission services from distribution grids
- Communications architecture
- Sensor data integration
- Role of DERMS and aggregators
- Role of microgrids
- Market-based (transactive) control
- Distributed storage and generation
- Integration with buildings and smart communities
- Electrification of transportation
- System restoration
- Cybersecure data and information for new control strategies
- Intelligence at the substation

Research and experiments using the ADMS Test Bed will provide data and information to multiple stakeholders involved in the planning and operation of the grid and other energy infrastructure. Examples of some key stakeholders and the benefits to them from using the ADMS Test Bed are listed in Table 1.

Table 1 Stakeholders and Benefits

Entity	**Benefits (Data/Information for:)**
Utility oversight, planning/financing bodies	Investment decisions; system reliability and resilience; identify the cost and benefit of new technologies on the grid.
Grid operators, utilities/energy service providers	Control architectures and strategies; communications architectures and protocols; physical/cybersecurity; data management; integrated performance, reliability, and resilience; capital and operation-and-maintenance cost reductions.
Vendors and industrial equipment providers	Individual component or system performance, reliability, and resilience; interoperability; physical and cybersecurity. *Technologies include (but are not limited to) ADMS, DERMS, microgrid controllers, home and building energy management systems, solar, storage, distributed wind, fuel cells, heavy-duty trucks, EV charging, hydrogen storage, hydropower, sensing and measurement, renewable energy developers, etc.*
Local, state, and federal government	Informing energy infrastructure planning and energy R&D.

NREL is interested in understanding the following from external stakeholders:

1. What key benefits will this capability provide to you and/or your organization?
2. What other R&D challenges should be addressed that will ensure success and impact for industry?
3. Which of the capabilities described here are the most relevant to you?
4. Is there an interest in partnering?
5. What other facilities, equipment, and capabilities might be required?
6. What are facilities are you aware of that has complementary capabilities that NREL could explore partnership with?
7. What capabilities are needed for use cases that involve building integration?
8. What technology innovations and advances can be envisioned with the availability of the ADMS Test Bed?
9. What additional hardware integration would be of most interest to you?
10. What scale of simulation—both time and geographical—are the most relevant to you?
11. What additional simulation tools would be of interest to you to integrate with the test bed?
12. What extensions to the test bed would be required to enable support for international partners?
13. Can you foresee using the test bed for training purposes?
14. What uses do you envision for the test bed beyond evaluation of ADMS applications, such as human interface studies or interoperability testing with other systems?
15. How can the ADMS Test Bed capability be made more relevant to studies beyond ADMS applications?
16. What should be the role of DOE in supporting ADMS adoption by industry?

Introduction

NREL is requesting input on the potential uses of the ADMS test bed at NREL to support industry in evaluating distribution power system management and automation. The ADMS Test Bed is a key capability of NREL's Advanced Research on Integrated Energy Systems (ARIES), an integrated national research capability at NREL that addresses the challenges associated with integrating distributed energy systems (DERs) into the broader power system. The ADMS Test Bed was developed by NREL and the DOE's Office of Electricity Advanced Grid Research and Development program through DOE's Grid Modernization Laboratory Consortium (GMLC) as a vendor-neutral evaluation platform for advanced grid controls implemented on ADMS platforms. The test bed uses real hardware, large-scale distribution power system models, and advanced visualization to simulate real-world conditions for the most accurate ADMS evaluation and experimentation.

This capability brings the evaluation of new grid management and control approaches to a flexible, realistic operating setting. At no risk to customers, utilities can evaluate how their systems will act with new technologies and controls—and ask their biggest "what if" questions about grid innovation. Utilities can simulate just about any modern grid scenario—and achieve real-world results to validate their ADMS before it is deployed.

The ADMS Test Bed is set up in NREL's Energy Systems Integration Facility (ESIF) at NREL's South Table Mountain Campus in Golden, Colorado. The ESIF is a state-of-the-art research facility that provides a unique platform on which partners and users can identify and resolve the technical, operational, and financial risks of integrating emerging energy technologies into today's environment. Hardware testing, real-time and supercomputer simulations, and power systems specialists are all available within one facility at the ESIF. The ADMS Test Bed can also access resources available at NREL's Flatirons Campus located near Boulder, Colorado through a virtual emulation environment between the two campus sites that has been developed through ARIES.

NREL, sponsored by DOE's Office of Energy Efficiency and Renewable Energy (EERE), is dedicated to transforming energy through the research, development, commercialization, and deployment of renewable energy and secure and resilient energy-efficiency technologies. NREL's mission is to advance the science and engineering of energy-efficiency, sustainable transportation, and renewable power technologies and to provide the knowledge to integrate and optimize secure and resilient energy systems.

Background

As the levels of DERs increases—especially intermittent sources such as photovoltaics (PV)—distribution management system capabilities need to be updated to attain effective management of the electric power distribution system. ADMS platforms can provide utilities with greater visibility and controllability of DERs that can be used to increase reliability and power quality, improve resilience and security, reduce costs, and enhance customer participation.

DERs on distribution feeders are not typically controlled directly by operators and have only local controls (such as power factor control). As the level of DERs increases, a coordinated control strategy is likely more appropriate, leading to the need for a distributed energy resource management system (DERMS). Some DERs are colocated in microgrids and managed locally by a microgrid controller, and there is also nascent interest in secure and resilient communities where DERs located within a community are coordinated to benefit the entire community. All these controller types need to be integrated with distribution management systems (DMS) when used by utilities. It is also possible to interface DERs directly with a DMS, but this is more common for a small number of utility-scale DERs. Many DMS vendors now offer products that integrate multiple functions, such as an outage management system (OMS), a geographic information system (GIS), and a supervisory control and data acquisition (SCADA) system. These integrated platforms are commonly referred to as advanced distribution management systems (ADMS). The "advanced" elements of ADMS go beyond traditional DMS by providing next-generation control capabilities, including advanced functions such as Volt/VAR optimization (VVO); fault location, isolation, and service restoration (FLISR); and dynamic voltage regulation (DVR). ADMS capabilities also extend to the management of high levels of DERs; closed-loop interactions with building management systems (BMS); and tighter integration with utility tools for meter data management systems, asset data, and billing.

Despite the potential of an ADMS deployment to increase reliability and power quality, improve resilience and security, reduce costs, and enhance customer participation, adoption rates of ADMS remain low.[1] Part of the reason for this is that ADMS deployment requires a significant investment of time and funds by utilities, which in turn requires the benefits to be well understood and quantified to build a strong business case for such an investment. This is especially critical for utilities that operate under the oversight of public utility commissions; however, it can be hard to determine the impact of new management systems on a specific utility's distribution system ahead of time.

The Advanced Grid Research and Development Program of DOE's Office of Electricity has invested in the development of a vendor-neutral ADMS Test Bed to address this challenge. The test bed provides utilities and vendors the opportunity to understand the benefits of specific applications for a specific distribution system under a wide range of conditions that can be simulated and emulated in a laboratory environment. Additionally, evaluation in a laboratory can be done at a much lower cost than a field pilot.

As power systems with high levels of DERs become increasingly common, ADMS applications need to function effectively. This requires, at a minimum, visibility of the DERs and, ideally, some level (direct or indirect) of controllability. The ADMS Test Bed can be used to evaluate the effectiveness of ADMS applications on a futuristic model of a utility feeder. For example, a feeder that currently has low PV level can be modeled with the level of PVlevel that is forecasted in 5, 10, or 20 years. Similarly, increased levels of electric vehicles (EVs) or more efficient and flexible heating and cooling systems can be modeled.

Description

The ADMS Test Bed is an evaluation platform consisting of software and hardware elements that realistically represent a power distribution system to a commercial or precommercial ADMS. Its main elements are simulation; controller and power hardware that can be interfaced with the software simulation through the use of hardware-in-the-loop (HIL) techniques; and industry-standard communications interfaces, as shown in Figure 1.

[1] Voices of Experience: Insights into Advanced Distribution Management Systems, U.S. DOE, February 2015. https://www.smartgrid.gov/voices_of_experience.html

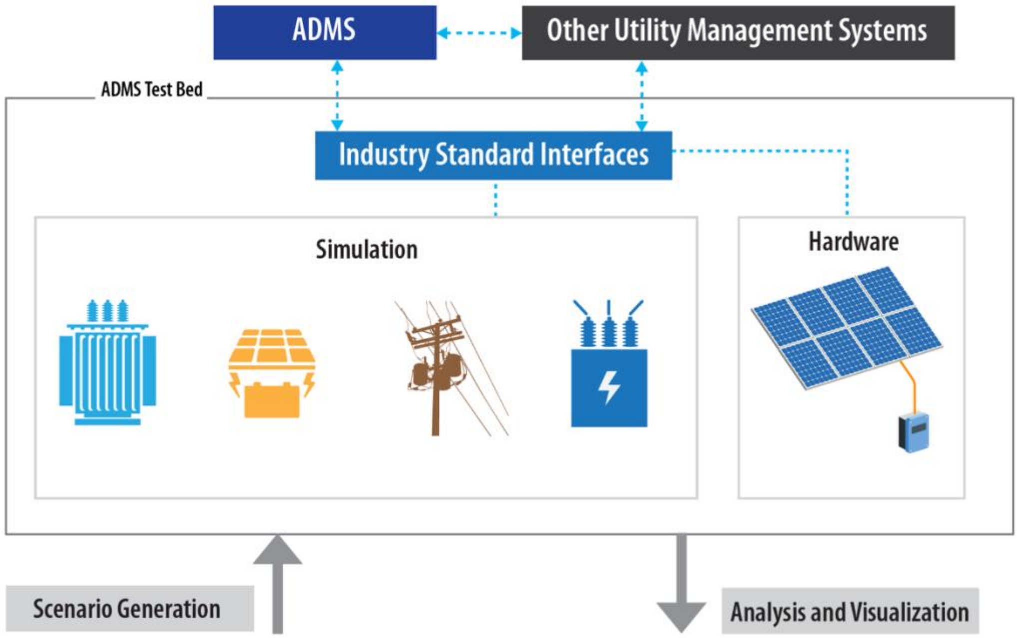

Figure 1. Overview diagram of the ADMS Test Bed

The software simulation environment acts as the real distribution system on which the ADMS operates. The simulation environment can combine quasi-steady-state simulations, phasor-domain simulations, and electromagnetic transient (EMT) simulation studies. The Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS)[2] platform, developed by a consortium of DOE national laboratories, interconnects these simulation tools and integrates physical hardware.

Controller hardware and power hardware such as PV and battery energy storage system (BESS) inverters, grid-edge devices, and legacy utility control and automation equipment can be linked to the simulated utility environment. Through integrating power hardware, researchers can test how equipment interacts with the ADMS at scale and validate software models.

Another essential element of the test bed is the ability for all simulated devices that interface with the ADMS to communicate using an industry-standard communications protocol. Other utility management systems—such as a transmission energy management system, DERMS, microgrid controller, or building automation system—can also be incorporated into the test bed, as needed, for specific use cases.

For each use case, a set of scenarios is generated that includes loading and solar insolation conditions, DER levels, and/or faults. These scenarios are then simulated and can be observed using real-time visualization tools developed for the test bed, and the data are also stored to enable analysis.

ADMS Test Bed Use Cases

Use cases for the ADMS Test Bed are defined to reflect how and under what conditions ADMS applications are used by a utility. An ADMS offers many functions to distribution utilities, so there is a wide range of

[2] https://helics.org/

possible use cases.[3] We use a collaborative approach in which we involve utility and vendor partners as stakeholders, as illustrated in Figure 1. The definition of a use case could start with a utility that defines an operational challenge that they want to address through an ADMS deployment. It could also start with a vendor that wishes to demonstrate the value of one of their applications under certain conditions. It could also be a combination of the two, i.e., a utility might be interested in evaluating whether a proposed vendor solution will address their operational challenge.

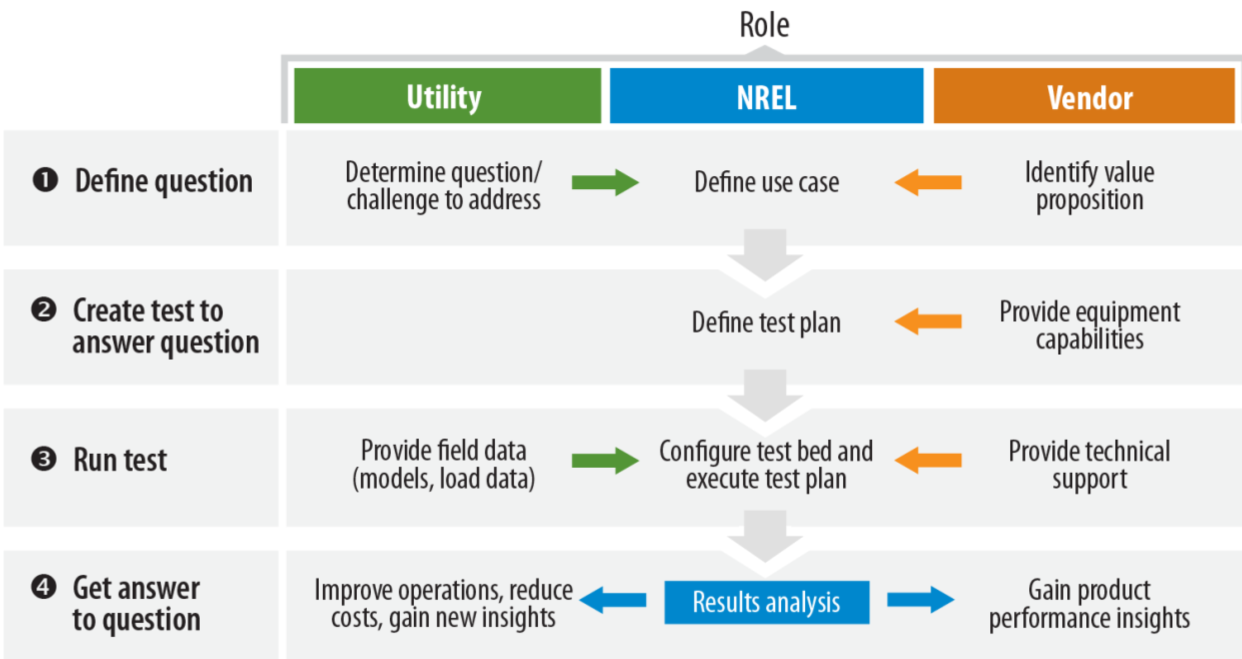

Figure 2. Use case selection process.

Once the use case is defined, we define a test plan and configure the test bed for the specific use case with inputs from the utility and vendor. These inputs typically include the ADMS platform, training on the use of the platform, and information on the equipment capabilities from the vendor; and distribution network models and historical field data from the utility. For a vendor-driven use case with the intent of showing the value of a new application, for example, we might choose to use synthetic feeders, i.e., anonymized, realistic feeders, such as those made available through the Advanced Research Projects Agency-Energy GRID DATA program[4] or representative feeders provided by the Electric Power Research Institute (EPRI). Upon execution of the test plan, we analyze the results and disseminate them to our partners and, to the extent possible, with proper anonymization in place, with the broader utility industry and academic power research community.

NREL has partnered with different utilities, vendors, and other organizations to perform several use case studies, including the impact of ADMS network model quality on VVO, ADMS-DERMS coordinated peak load management, and using advanced metering infrastructure (AMI) data for grid operations. These are described briefly in Table 1, along with descriptions of an ongoing study on the effect of DERs on FLISR

[3] Veda, S., 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)*, Denver, Colorado, March 29–31, 2017.

[4] https://www.bettergrids.org/portfolio_category/griddata

and newly launched studies on a federated DERMS approach and transmission-and-distribution co-optimization. More details on each use case are provided in the Appendix.

Table 1. ADMS Test Bed use case summaries

Use Case	**Partners**	
Impact of ADMS Network Model Quality *Funded by DOE's Office of Electricity and Xcel Energy.*	Utility: Xcel Energy Vendor: Schneider Electric	NREL's ADMS Test Bed was used to help Xcel Energy learn the necessary amount of data cleansing in the ADMS model to make the most of its ADMS investment. The test bed was set up to simulate an Xcel feeder and was integrated with an ADMS from their vendor, Schneider Electric.
Peak Load Management with ADMS and DERMS *Funded by DOE's Office of Electricity, Holy Cross Energy, DOE's EERE, and ARPA-E.*	Utility: Holy Cross Energy Vendor: Survalent	Holy Cross Energy partnered with NREL to use the ADMS Test Bed to test NREL's real-time optimal power flow (RTOPF) control algorithms that manage DERs to regulate distribution voltages, reduce peak demand, and provide more cost-efficient energy use for DER owners in a laboratory setting. Following these experiments, the ADMS Test Bed was used to demonstrated the operation of NREL's RTOPF algorithms controlling DERs along with Holy Cross Energy's ADMS, provided by Survalent, controlling legacy equipment, to reduce peak demand.
Data-Centric Grid Operations *Funded by DOE's Office of Electricity and the California Energy Commission's Electric Program Investment Charge (EPIC) of San Diego Gas & Electric Company (SDG&E).*	Utility: SDG&E	NREL collaborated with SDG&E to demonstrate AMI-based data-driven grid operations with NREL-developed algorithms implemented on DOE's GridAPPS-D[5] open-source platform. The ADMS Test Bed was configured to model SDG&E's feeder and provide realistic real-time AMI-data from across the distribution feeder to the controls deployed on GridAPPS-D. NREL's Online Data-Enabled Predictive Control (ODeePC) algorithm uses AMI data alone to control LTCs and capacitor banks along with PV inverters to maintain the voltage profile on the primary and secondary networks.
Data-Enhanced Hierarchical Control Optimizes System Performance *Funded by DOE's Solar Energy Technologies Office through the Enabling Extreme Real-Time Grid Integration of Solar Energy*	Utility: Xcel Energy Vendors: Schneider Electric Varentec Research organizations: EPRI	The Enhanced Control and Optimization of Integrated Distributed Energy Applications (ECO-IDEA) project used the ADMS Test Bed to validate a new data-enhanced hierarchical control architecture. The ADMS test bed was configured to model an Xcel Energy substation and the associated feeders, and was then interfaced with the DEHC architecture. NREL demonstrated that this architecture can seamlessly coordinate multiple systems, including the ADMS, the grid-edge management system (for controlling grid-edge dynamic reactive power devices), and NREL's RTOPF for dispatching PV inverter set points. The project team

[5] https://ieeexplore.ieee.org/document/8397161

(ENERGISE) program.		demonstrated a part of the architecture on the field and quantified the techno-economic benefits.
<u>FLISR in the Presence of DERs</u> *Funded by DOE's Office of Electricity and Central Georgia EMC.*	Utility: Central Georgia EMC Vendor: Survalent	This use case uses the ADMS Test Bed to evaluate the performance of a commercially available FLISR application on a feeder of an electric cooperative, Central Georgia EMC, for future scenarios with high levels of DERs. The ADMS Test Bed is being set up to emulate an existing distribution feeder with increased levels of DERs to represent a future version of the feeder.
<u>Federated DER Management to Provide Bulk Grid Services</u> *Funded by DOE's Office of Electricity and DOE's Building Technologies Office through the GMLC.*	Utilities: SDG&E Southern Company Commonwealth Edison NYPA Vendors: Oracle Research organizations: LBNL, PNNL, ORNL, EPRI, UNCC, Iowa State University	A Federated Architecture for Secure and Transactive DER Management Solutions (FAST-DERMS) has been developed to enable the provision of reliable, resilient, and secure distribution and transmission grid services through scalable aggregation and near-real-time management of utility-scale and small-scale DERs. A controller at the substation level performs reliability-constrained economic dispatch of DERs, either directly or through a transactive market or DER aggregator, in coordination with an ADMS. The FAST-DERMS project is being led by NREL and is supported by multiple partners. This project will implement the federated controls on GridAPPS-D and use the test bed to evaluate the controls in a competitive wholesale market scenario on an SDG&E feeder with an Oracle ADMS.
<u>Federated DER Management for High-PV Feeder</u> *Funded by DOE's Office of Electricity and Southern Company*	Utility: Southern Company Vendors: Oracle	NREL is also partnering with Southern Company to evaluate the federated controls being developed through the FAST-DERMS project in a use case focused on the use of utility-owned and behind-the-meter batteries in distribution systems with high PV levels, which can result in reverse power flow and voltage management challenges. The controls will be evaluated on a Southern Company feeder using NREL's ADMS Test Bed integrated with an Oracle ADMS.
<u>Transmission-and-Distribution Co-Optimization to Support the Bulk Grid</u> *Funded by DOE's Office of Electricity.*	Utility: Xcel Energy HECO	In partnership with Xcel Energy and Hawaiian Electric Company (HECO), we will use the ADMS Test Bed to demonstrate the participation of an active distribution network comprising distribution utility assets and flexible loads as an aggregated resource at the bulk grid level. This use case addresses the emerging need for DERs to provide bulk services without endangering distribution system reliability.

Request for Information

The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on research-and-development (R&D) needs. We are soliciting feedback on the associated capabilities, facilities, and infrastructure needed to ensure the most beneficial outcomes from using the ADMS Test Bed for accelerating ADMS deployment. NREL and DOE have identified the following R&D categories as of particular interest for future ADMS Test Bed use cases.

- **Control architectures and algorithms for high-levels of DER systems:** Distribution operators need to prepare for a future electric grid with increased levels of renewables and DERs, prosumers and microgrids, as well as new business models and services, some of which could be provided by third-party aggregators. This complex operating environment will require enhanced operating systems, platforms, and applications for the management of electricity. As the level of DERs increases—especially intermittent sources such as PV—DMS capabilities, including ADMS applications, need to be updated to attain effective management of the electric power distribution system. This requires at a minimum visibility of the DERs and ideally some level (direct or indirect) of controllability. There is growing consensus that a more distributed framework with hierarchical control and communications structure would provide more benefits toward the scalability of monitoring, control, and communications and the underlying computations for grid operation. The ADMS Test Bed could be used to implement different control architectures and/or algorithms and address questions such as: How do the proposed distribution system control architectures and/or algorithms perform on systems with high levels of DER?
- **Transmission services from distribution grids:** Increasing adoption of DERs represent a systemic risk and opportunity as recent incidents such as the Blue Cut fire[6] and Texas outages[7] have shown. Given the trends of increasing electrification of end-use loads such as electric vehicles (EVs), adoption of DERs such as solar PV and energy storage and enhanced controls at the grid-edge, the distribution system with appropriate controls and visibility can reliably provide system resource adequacy and other grid services for the bulk grid. The recent FERC Order 2222[8] provides the regulatory framework for DER aggregations at the distribution system level to participate in different bulk grid services. Distribution grid flexibility provides an opportunity for improving reliability, resiliency and affordability of bulk grid operations. The ADMS Test Bed can be used to perform real-time cosimulation of transmission and distribution system to address questions such as: What is the impact of future DER penetrations and increased load flexibility on bulk grid operations? How can the bulk grid operators leverage the flexibility offered by the distribution system?
- **Communications architectures:** There is a complex industry-standard landscape for communications. Various standards have been used in this space, including Distributed Network Protocol 3 (DNP3) (IEEE 1815) and the Institute of Electrical and Electronics Engineers (IEEE) Standard 2030.5. Communications standards can support different information models, such as the International Electrotechnical Commission (IEC) Standard 61850 and SunSpec Modbus. The communications landscape gets even more complex if considering the various types of current and evolving communications network technologies and topologies, and the associated protocols that could be used in a specific or new deployment such as supervisory control and data acquisition (SCADA), advanced metering infrastructure (AMI) and third-party networks. Interoperability is needed at all levels, and communications architecture advancements are needed to manage complexity and to encourage interoperability while preserving data privacy. The ADMS Test Bed could be used to implement different communications architectures and/or protocols and address questions such as: How do the proposed communications perform for different types of control and under different adverse system conditions? What is the impact of communications latency?

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[6] https://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf

[7] https://energyinnovation.org/wp-content/uploads/2021/05/Lessons-from-the-Texas-Big-Freeze.pdf

[8] https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet

- **Sensor data integration:** More types of sensors are available at lower cost, and this presents an opportunity to enhance power system operations. For example, AMI provides end-point sensors that give utilities granular information about system operations and customer energy usage and can enable utilities to operate more efficiently, improve customer service, automate processes, protect revenue, improve power quality, verify outages, increase reliability, evaluate asset health, and more.[9] These data can help utilities gain insights and make data-driven decisions, but there are still challenges with integrating the increased amount of data meaningfully into grid operations, as well as in validating and securing the data. How many new telemetry points should be added to ensure adequate observability for the ADMS online power flow application for feeders with high levels of PV?
- **Role of DERMS and aggregators:** DERs on distribution feeders are typically not controlled or they have only local controls (such as power factor control). As the level of DERs increases, a coordinated control strategy might be more appropriate, leading to the development of DERMS and the emergence of third-party aggregators, some of which provide virtual power plant (VPP) services. Both controller types need to be integrated with DMS when used by utilities. It is also possible to interface DERs directly with a DMS, but this is more common for a small number of utility-scale DERs. The ADMS Test Bed could be integrated with both an ADMS and a DERMS and used to address questions such as: What is the best way to coordinate the operation of an ADMS with a DERMS, and what level of visibility does the ADMS require into DERMS operations? Systems with high levels of DERs also provide opportunities to use DERs to provide grid services, and the test bed can be used to evaluate the management of DERs for the provision of bulk grid services.
- **Role of microgrids:** Some DERs are deployed in microgrids and managed locally by a microgrid controller. Microgrids currently make up a very small portion of the electricity generation of the U.S., but there is broad expectations of acceleration in microgrid adoption. An increased penetration of microgrids will require increased attention to optimal coordination among networked microgrids, requiring research into hierarchical, distributed, and hybrid control strategies for that will allow microgrids to become building blocks of our future grid. What level of visibility does an ADMS need into the operation of the microgrid, and what is the best way to make use of the advanced functionalities of microgrid controllers to complement system operations?
- **Market-based (transactive) control:** Many forms of market (or value)-based controls, including transactive controls, have been proposed and studied, and some pilot studies have been completed. As this form of control becomes more prevalent, ADMS will need to be able to manage the grid reliably while local markets drive power profiles. What level of visibility and management is required to ensure adequate reliability?
- **Distributed storage and generation:** In traditional centralized generation, flexible generators ramp up or down in response to changing demand and use their inertia to manage grid stability; however, variable power sources such as wind and solar are not readily dispatchable and predictable, so supply and demand profiles do not always align, causing curtailments or negative pricing. These sources are also increasingly interfaced to the grid through power electronics, which lacks the inertia that traditional sources provide to the grid. As increasing amounts of low-cost wind and solar energy are added, both behind the meter and utility-owned, the relative level of variable generation increases. This, plus the addition of more low-cost storage and the offset of electricity growth due to progress in energy efficiency, could change the balance of energy, capacity, and ancillary services required in many grid operating regions and thus affect affordability, reliability, and resilience. What is the best approach to maximizing performance when the ADMS needs to interact with legacy voltage control equipment, smart inverters, storage assets, grid-edge devices, DERMS, and microgrids?
- **Integration with buildings and smart communities:** Households and businesses are constantly installing new devices (EV chargers, rooftop solar, energy storage, smart appliances, etc.) onto the grid. As the number increases to the millions, new solutions and capabilities are needed to optimize distribution power

[9] Voices of Experience: Leveraging AMI Networks and Data, U.S. DOE, March 2019. https://www.smartgrid.gov/voices_of_experience.html

management. The ability to handle the sheer number of communications and the massive amount of data also becomes a challenge in managing power. In an optimal system, there would be sufficient communications and visibility between the bulk power and distribution sides to keep the overall grid in equilibrium and to maximize asset utilization; thus, seamless power flow, communications, and data management between the distribution and bulk power systems would create more real-time options for operating decisions that can benefit both customers and grid operations. There are also some disadvantaged communities that lag in their deployment of smart devices; thus, use cases that address the benefits of ADMS technology for future power systems in such communities are of high interest.

- **Electrification of transportation:** As more of the transportation fleet is electrified, the impact on distribution systems will become significant. In addition to increased load and potentially generation, EVs are mobile and will move between different nodes within the distribution power system. Some commercial or industrial customers might also deploy fleets of EVs at the distribution level. Managing the impact of transportation electrification on the grid will require optimization of EV charging that considers grid operations. What level of visibility and management of EVs is required to ensure adequate reliability?
- **System restoration:** FLISR is a critical application offered in commercial ADMS platforms being deployed in utility distribution systems. It operates groups of switches on distribution feeders to improve the reliability of power delivery after localizing outages. FLISR is an essential function for enabling a self-healing grid, and it directly affects grid reliability and resilience. The presence of DERs brings both new opportunities and challenges for FLISR applications. Specifically, some DERs can help service restoration by acting as backup generation sources through appropriate switching actions and efficient algorithms are available to utilize the DERs for service restoration. However, the bidirectional power flow resulting from DERs might require dynamic changes to protective devices' fault current settings, and thus the FLISR application will need to dynamically adjust its operations in coordination with the dynamic protection settings. Also, some FLISR applications make their service restoration decisions and close tie-switches based on predefined rules. that might no longer be appropriate in the presence of DERs because of their impact on net loads on the feeder network. What is the impact of DER on the performance of FLISR? How can DERs, especially those with black-start and grid-forming capabilities, be used to improve system restoration performance?
- **Cybersecure data and information for new control strategies**: As home, commercial building, and industrial energy management systems control energy consumption by managing DERs (e.g., rooftop PV, local storage) and by shaving, shifting, and modulating loads, customer participation will increase through reliance on networked sensors and controls. These management systems also need to interface with distribution and bulk power system service providers to optimize asset utilization for lower cost while maintaining reliability and resilience; therefore, with this increased access, cybersecure solutions to new control strategies are critical to maintaining overall grid infrastructure reliability and resilience.
- **Intelligence at the substation:** Currently, there is poor visibility upstream and downstream of the substation and little integrated controls of bidirectional power flows. Improved visibility and controls could improve situational awareness and grid operations, thus improving the affordability of services (energy, capacity, ancillary). Can we demonstrate new ways for modern substations with control and automation equipment to enable DER market participation, microgrids, black starts, and other new capabilities?

Capabilities

NREL has decades of experience with the grid integration of DERs and has world-class teams of experts dedicated to grid integration and DER technologies, including solar, buildings, vehicles, storage, and fuel cells. NREL has deep expertise across the value chain for DER integration—from device design, to nationwide impact analysis and hardware testing, to deployment assistance. This section describes the NREL capabilities pertinent to this RFI.

Advanced Research on Integrated Energy Systems

The ADMS Test Bed is a key capability of NREL's Advanced Research on Integrated Energy Systems (ARIES) Research Platform, a new national research capability at NREL that addresses the challenges associated with integrating large-scale energy systems into the broader power system. ARIES encompasses capabilities at both the ESIF and the Integrated Energy Systems at Scale capabilities at NREL's Flatirons Campus.[10] Research at the ESIF can go up to 2 MW, which covers distribution-level testing. NREL is developing its Flatirons Campus to allow for research at the 20-MW scale and beyond, representing the interface between the distribution and bulk power levels. A virtual emulation environment between the two campus sites enables a virtual connection between the ADMS Test Bed at ESIF and the resources available at the Flatirons Campus, expanding the scope of the research that can be performed using the ADMS Test Bed.

The Energy Systems Integration Facility (ESIF)[11] provides integrated energy research capabilities across six indoor high-bay laboratories, three outdoor test areas, and associated control and visualization rooms. ESIF research is propelled by a novel electrical bus for controlled experimentation with both AC and DC lab assets and real devices. Covering power systems, grid controls, thermal systems, residential and commercial buildings application, advanced vehicles interfaces, hydrogen storage and use, power electronics and grid technologies, the ESIF offers one of the world's most diverse concerted energy technology integration portfolios. Electrical power systems and devices up to 2 MW (AC and DC) are supported, including 13.2kV distribution research connections, 1 MW electrolysis, 600+kg hydrogen storage, hydrogen vehicle fueling, combined heat and power (CHP) turbines, and more. Communications and cyber technologies at ESIF leverage expertise and advanced emulation tools for true system operation scenarios, helping move technology toward the secure, efficient and affordable energy system of the future. Further discussion of NREL capabilities can be found in the *ESIF Annual Reports*[12]:

The Flatirons Campus includes individual technologies at the megawatt scale, a full medium-voltage (13.8-kV) distribution system that allows for the experimentation and integration of numerous diverse technologies at the 20-MW aggregate scale, reconfigurable microgrids and the coordination of adjacent microgrids to provide improved resilience, and two independently configurable multimegawatt grids and emulation capabilities at ARIES for bulk power systems engineering studies. The Flatirons Campus currently has 9.9 MW of installed generation capacity, including large-scale wind turbines, PV systems, and energy storage systems that can be configured for experiments involving large-scale, variable generation on the grid. The interconnection capacity to the utility grid is rated at 19.9 MW with the necessary transformers, transmission-level infrastructure, including a 1-mile 115-kV power line, and protective equipment. A 3-MW programmable RLC load bank supports microgrid research, wherein devices are connected on a grid to simulate a variety of loads. Grid integration research pads enable quick installation and interconnection of power devices to the grid infrastructure at the site, including energy generation, storage devices, power conditioning equipment, and loads. There are currently three existing research pads, and three additional research pads will be built to accommodate increasing demand. In addition, infrastructure required for hydrogen storage will be included to support future electrolyzer investments. The existing 6.3-MW controllable grid interface (CGI) links megawatt-scale electrical power devices to

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[10] NREL's recently renamed Flatirons Campus is located near Boulder, Colorado. The campus is also home to the National Wind Technology Center, which provides unique capabilities that support experiments, innovation, and technology validation that advances U.S. leadership in wind energy technology.

[11] https://www.nrel.gov/esif/integrated-energy.html

[12] *ESIF Annual Report 2020, ESIF Annual Report 2019, ESIF Annual Report 2018, ESIF Annual Report 2017*

precisely created grid anomalies (e.g., grid faults, transients, and frequency fluctuations) under safe conditions isolated from the utility grid. A second CGI will support larger and more complex wind grid integration experiments involving even greater than 20 MW for full hybrid system and microgrid research.

Advanced Distribution Management System Test Bed

The ADMS Test Bed is a national, vendor-neutral evaluation platform funded by DOE's Office of Electricity Advanced Grid Research and Development Program to accelerate industry development and the adoption of ADMS capabilities. The test bed enables utility partners, vendors, and researchers to evaluate existing and future ADMS, DERMS, and other utility management system applications in a realistic laboratory environment.

The ADMS Test Bed consists of software simulations of distribution systems and field equipment integrated through HIL techniques that realistically represent a power distribution system to a commercial or precommercial ADMS, as shown in Figure 3.

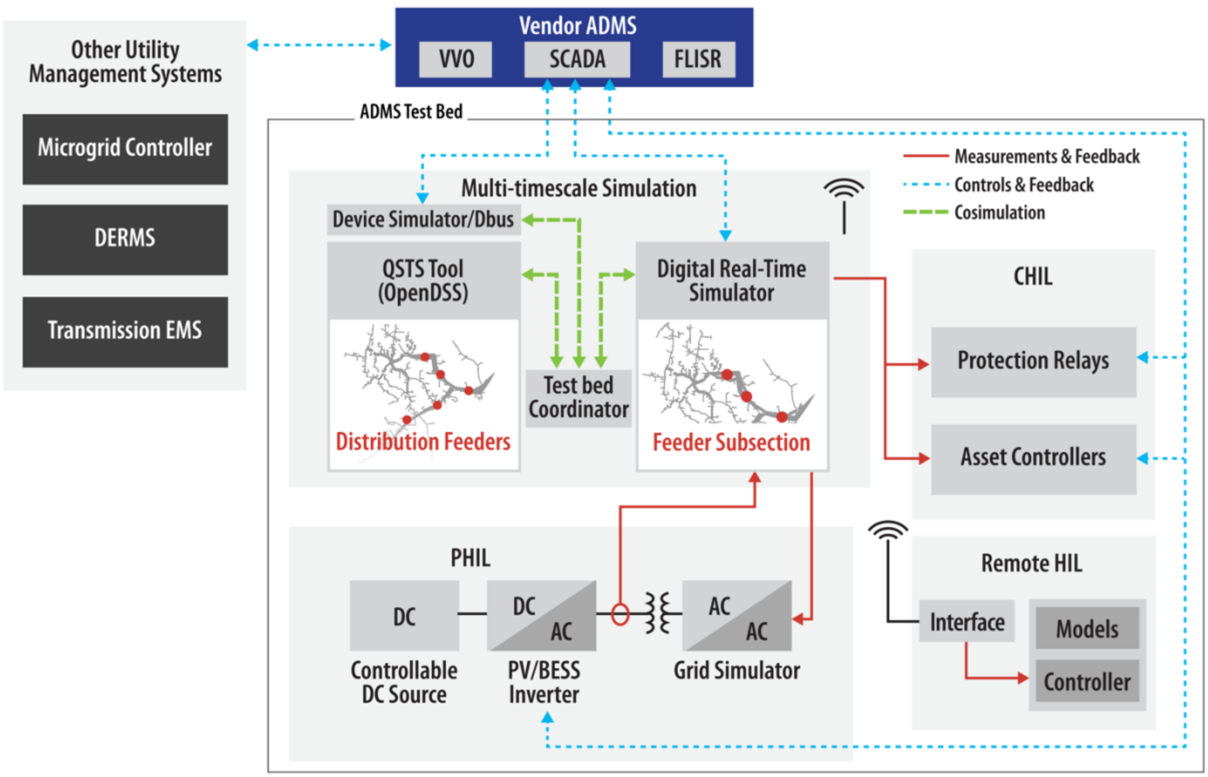

Figure 3. ADMS Test Bed capability

An ADMS is interfaced to the test bed using industry standard communications protocols—such as DNP3 and IEEE 2030.5—so it can be deployed as it would be in a utility environment. Other utility management systems—such as a microgrid controller, DERMS or transmission energy management system (EMS)—can also be integrated through protocols such as MultiSpeak and Inter-Control Center Communications Protocol (ICCP).

The multi-timescale simulation environment will act as the real distribution system on which the ADMS operates. The simulation environment is capable of performing quasi-steady-state time-series (QSTS) simulations, phasor-domain simulations, and/or EMT simulation studies. We use OpenDSS for quasi-steady-state time-series simulations of systems with tens of thousands of nodes and several substations, and we can use either RTDS or OPAL-RT digital real-time simulators for phasor or EMT simulations of hundreds to several thousand nodes. Different simulation tools are coordinated through a test bed coordinator using HELICS, an open-source, cyber-physical-energy cosimulation framework for electric power systems. The test bed can also integrate simulations of end-use loads in buildings using NREL's OCHRE[13] tool as well as home energy management system (HEMS) controllers with the distribution system simulation.

Controller-hardware-in-the-loop makes it possible to evaluate controller hardware—including legacy equipment such as capacitor bank, LTC and line voltage regulator controllers, and newer devices such as smart meters—when testing at actual scale or power levels is not required or possible. Power-hardware-in-the-loop (PHIL) links actual power system equipment such as PV and BESS inverters, grid-edge devices, and legacy utility control and automation equipment to a lab-simulated utility environment. With PHIL, researchers can test how equipment interacts with the ADMS at scale and validate software models. The megawatt-scale PHIL capability at the ESIF allows NREL researchers and partners to integrate multiple hardware devices, each with a separate simulated point of common coupling using multiple bidirectional AC grid emulators. Each point of common coupling has independent phase control that enables the recreation of a variety of grid scenarios, such as voltage sags/surges and the complete loss of a single phase or multiple phases. The AC grid emulators can be interfaced with either OPAL-RT/RT-Lab or RTDS/RSCAD real-time simulation platforms. NREL has also developed approaches to conduct HIL experiments in real time with commercially available power systems simulation software such as OpenDSS. The picture of the ADMS Test Bed in Figure 4 shows a couple of different ADMS user interfaces, a digital real-time simulator, and controller and power hardware.

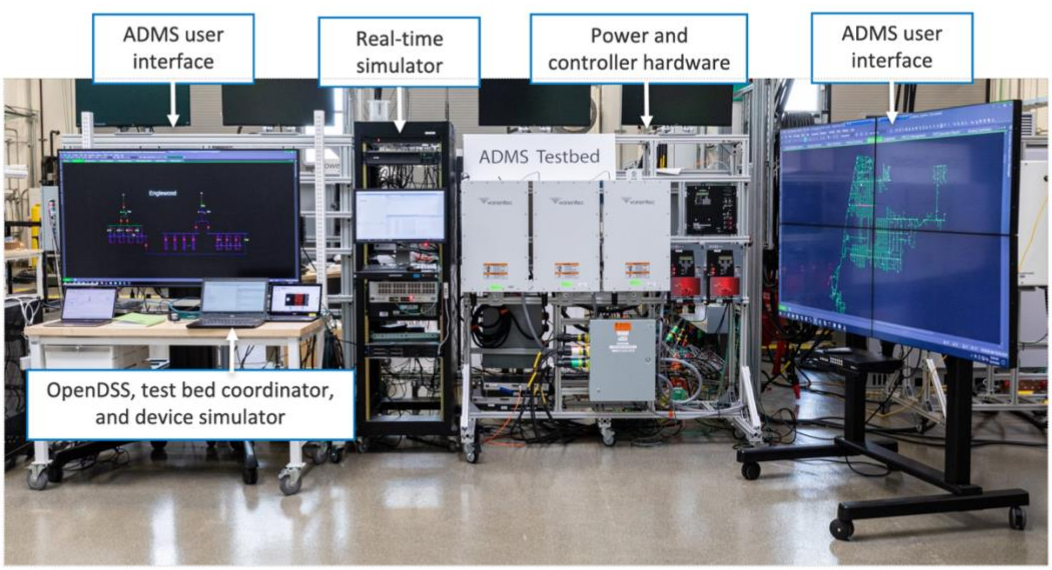

Figure 4. Photograph of ADMS Test Bed setup

Researchers and partners can make use of NREL's advanced visualization capabilities,[14] including 3D visualization, to analyze and present results from the test bed.

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[13] https://doi.org/10.1016/j.apenergy.2021.116732

[14] https://www.nrel.gov/computational-science/visualization-analysis-data.html

Publications that provide more information on the ADMS Test Bed are listed in the Appendix.

Open-Source Platform and Applications for Advanced Distribution Management Systems

NREL is partnering with Pacific Northwest National Laboratory to build an open-source ADMS platform, GridAPPS-D,[15] that will accelerate the deployment of ADMS technologies to address the operational challenges faced by distribution utilities. GridAPPS-D has been designed to provide a services-based platform that supports the development of applications. GridAPPS-D provides a reference architecture and implementation that can be used by others to implement similar application development tools or to adapt existing systems or create new ones for the operational deployment of applications that comply with standards. Researchers, utilities, and vendors can use this open-source platform to develop, test, and adopt functionalities tailored to their needs without the burden of implementing full-scale ADMS systems.

GridAPPS-D has been integrated with the ADMS Test Bed to evaluate the performance of a novel ADMS voltage regulation application, as described earlier. The GridAPPS-D platform and some of its open-source advanced distribution applications are available for future use cases. Existing applications include real-time DER dispatch, short-term grid forecasting, and intra-hour solar forecasting.

High-Performance Computing (HPC)

The ADMS Test Bed can also take advantage of the HPC capability at the ESIF[16] to emulate larger systems. One example is the federated DERMS for high-PV systems use case, where the HPC will be used to enable real-time cosimulation of the power system with many homes that have HEMS. Eagle is the newest HPC system at NREL, and it is configured to run compute-intensive and parallel computing jobs. It is a cluster comprising 2,186 nodes (servers) that run the Linux operating system (Red Hat Enterprise Linux or the derivative CentOS distribution), with a peak performance of 8 PetaFLOPS. The nodes are connected to each other and to storage by a high-speed 100-Gb/s EDR InfiniBand network. All nodes and storage are connected using an enhanced 8-dimensional hypercube topology that provides a bisection bandwidth of 26.4 terabytes/s.

Communications Network Emulation

The ADMS Test Bed can be interfaced with a communications network emulation, originally developed for NREL's Cyber-Energy Emulation Platform (CEEP), to allow researchers to model the telecommunications network and to visualize and evaluate the interdependencies of power systems and network communications flows.

NREL is also developing a research-focused network communications capability, Grid Research End-to-End Network Communications (GREEN-C), within the ESIF that aims to facilitate the interconnectivity and accessibility of virtual and physical assets at the communications layer. GREEN-C will serve as a management plane (fabric/underlay) for asset administration as well as a user plane (experiment/overlay) for user-defined networks. The goal is to commission an isolated research network that provides architectural freedom, enables full data visibility, and reduces "time to experiment." GREEN-C leverages cyber network emulation capabilities that include virtual machine environments, protocol translation, cloud interfaces, and remote connectivity. This capability will be available for integration with the ADMS Test Bed for selected use cases.

[15] https://www.gridapps-d.org/

[16] https://www.nrel.gov/hpc/

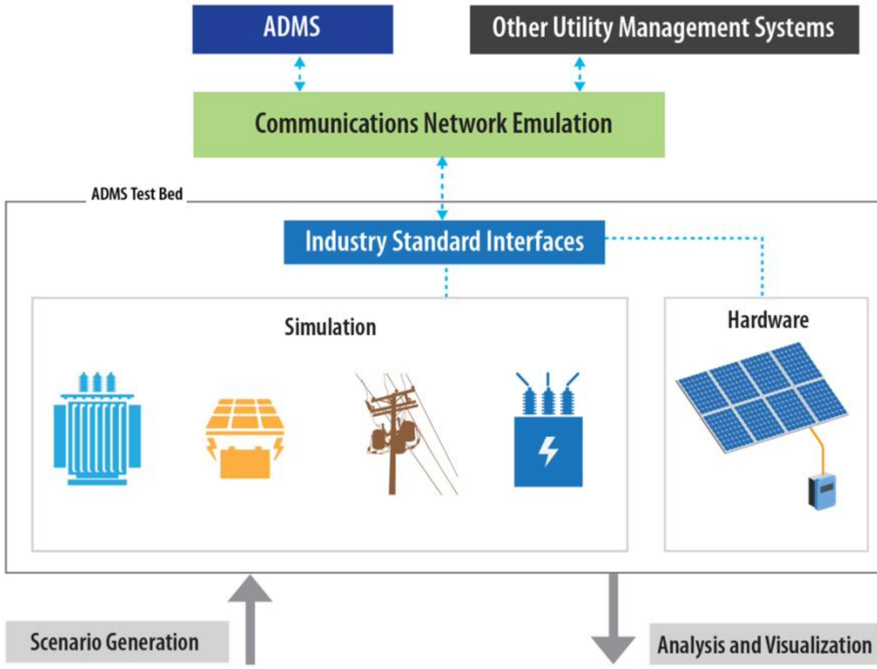

Figure 5. ADMS Test Bed interfaced with NREL's communications network emulation

Cyberattack Simulation

Analysts can perform threat and consequence attack scenarios for distribution-level cybersecurity evaluations to safely explore cyber vulnerabilities and mitigation effectiveness. Researchers can launch attacks in the virtual world on both emulated and actual physical devices, such as a remote terminal unit that is linked to a residential solar system inverter, and evaluate how they would respond to an attack in the real world. Researchers defending the virtual world can then try to identify the cyberattack and implement mitigations, both manual and autonomous, to keep the system running. From there, researchers can assess the large-scale implications of an attack on an emulated electric grid. Some use cases might also benefit from NREL application developers that work to continually improve the security, analysis, and detection tools needed to better analyze and respond to attack scenarios on our current and future energy systems.

Real-time Analytics for Bulk Grid (RTAG)

RTAG is a high-fidelity control room operation simulator based on the entire Western Interconnect bulk energy system models previously run by Peak Reliability/WECC Reliability Coordinator for reliability monitoring. It is able to provide realistic simulation of steady state bulk grid EMS applications, system dynamics and transient events in a Dispatch Training Simulator (DTS) mode for the entire Western Electricity Coordinating Council (WECC) footprint. RTAG is able to import predicted natural gas unit curtailments and real-time solar and wind 24-hour forecasts to perform contingency scenario simulation and reliability & resilience risk assessment. RTAG uses the EMS-Planning model mapping to automatically adjust WECC basecase power flow from historical EMS state estimation or DTS-simulated SE cases, and will be able to provide hourly or 5-minute interval EMS state estimation snapshot-based chronological WECC basecases for cosimulation of transmission and distribution grids. RTAG is able to simulate various cybersecurity events and their impact on SCADA, state estimation, real-time contigency analysis, automatic generation control (AGC) and others, including loss of communication links. The RTAG capability can be used in conjunction with the ADMS Test Bed to cosimulate transmission and distribution systems and study, for example, the provision of bulk grid services by DER.

Key Questions

NREL is interested in the following information to ensure the optimal use of the ADMS Test Bed to support translating our stakeholders' ambitions to implementable actions that will achieve secure and resilient communities of the future. Research and experiments using the ADMS Test Bed will provide data and information to multiple stakeholders involved in the planning and operations of the grid and other energy infrastructure. Based on the R&D areas and capabilities described here, NREL is interested in understanding the following from external stakeholders:

1. What key benefits will this capability provide to you and/or your organization?
2. What other R&D challenges should be addressed that will ensure success and impact for industry?
3. Which of the capabilities described here are the most relevant to you?
4. Is there an interest in partnering?
5. What other facilities, equipment, and capabilities might be required?
6. What are facilities are you aware of that has complementary capabilities that NREL could explore partnership with?
7. What capabilities are needed for use cases that involve building integration?
8. What technology innovations and advances can be envisioned with the availability of the ADMS Test Bed?
9. What additional hardware integration would be of most interest to you?
10. What scale of simulation—both time and geographical—are the most relevant to you?
11. What additional simulation tools would be of interest to you to integrate with the test bed?
12. What extensions to the test bed would be required to enable support for international partners?
13. Can you foresee using the test bed for training purposes?
14. What uses do you envision for the test bed beyond evaluation of ADMS applications, such as human interface studies or interoperability testing with other systems?
15. How can the ADMS Test Bed capability be made more relevant to studies beyond ADMS applications?
16. What should be the role of DOE in supporting ADMS adoption by industry?

Response Requirements:

The response to this RFI posting is limited to five (5) pages of single-spaced text of 11-point Times New Roman font, with a minimum of 1-inch margins all around. Brevity is encouraged and responders do not need to respond to all the questions but can respond to only the ones that they are interested in.

All responses shall be submitted in writing via email to NREL.ADMS@nrel.gov. Electronic format shall be in Microsoft Word or converted to .pdf. Telephone calls will not be accepted.

The email subject line must be "Request for Information (RFI) / Advanced Distribution Management System (ADMS) Test Bed"

Responses to this notice must be received on or before **5 p.m. MST August 6, 2021**. Responding to this notice identifies your organization as an interested party only.

****Disclaimer and Important Notes ****

This RFI is NOT a funding opportunity announcement; therefore, NREL is not accepting applications.

Your response to this notice will be treated as information only. NREL will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. NREL will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that NREL is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

Proprietary Information

Because information received in response to this RFI might be used to structure future programs and/or otherwise be made available to the public, **respondents are strongly advised to NOT include any information in their responses that might be considered business sensitive, proprietary, or otherwise confidential.** If, however, a respondent chooses to submit business sensitive, proprietary, or otherwise confidential information, it must be clearly and conspicuously marked as such in the response.

If your response contains confidential, proprietary, or privileged information, you must include a cover sheet marked as follows identifying the specific pages containing confidential, proprietary, or privileged information. Failure to comply with these marking requirements might result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise.

1. Mark the title page with the following legend:

   "This response includes proprietary data that shall not be disclosed outside the government or NREL and shall not be used or disclosed—in whole or in part—for any purpose other than to evaluate this response. This restriction does not limit the government or NREL's right to use this proprietary data if obtained from another source without restriction. The proprietary data subject to this restriction are contained on pages [insert page and line numbers or other identification of pages] of this response"; and

2. Highlight (in yellow) the proprietary data on each page it wishes to restrict and add the following footer:

   "Use or disclosure of proprietary data contained on this page is subject to the restriction on the title page of this offer."

Questions:
During the RFI process, respondents may ask for clarifications concerning the request itself. Each inquiry will be documented, and the answer will be provided to each respondent if in the opinion of NREL the response will enhance the information requested. NREL will endeavor to provide these responses within three (3) to five (5) business days of the inquiry. To facilitate respondents' questions before the scheduled RFI deadline, please submit any clarifying questions by July 16, 2020.

Any clarification or question deemed proprietary by a respondent should be so noted and, if properly marked and determined so by NREL, shall not be shared with other respondents.

All communications regarding this RFI must be submitted in writing via email to: NREL.ADMS@nrel.gov. Telephone calls will not be accepted.

Do not submit questions or any offerings to any NREL contacts other than the representatives listed here.

SCHEDULE:

RFI issue:	June 30, 2021
Clarification questions due:	July 16, 2021 / 5:00 p.m. Mountain Time
Responses to clarification questions:	July 23, 2021
RFI due date:	August 6, 2021 / 5:00 p.m. Mountain Time

Appendix A

This Appendix includes information on past and present ADMS Test Bed use cases and a list of publications related to the ADMS Test Bed.

Use Cases

Impact of ADMS Network Model Quality
Funded by DOE's Office of Electricity and Xcel Energy.

Like many utilities, Xcel Energy is looking to reduce energy use and monthly bills for its customers, specifically with an ADMS application for more precise voltage control. In doing so, the utility faces a trade-off that depends on its confidence in the ADMS network model. If Xcel Energy is less confident in the ADMS model, it can keep voltage levels higher to avoid undervoltage events. Alternatively, the utility can invest in data cleansing to gain more confidence and increase energy savings with less conservative voltage settings. Because data cleansing is expensive and time-consuming, NREL's ADMS Test Bed was used to help Xcel Energy learn the necessary amount of cleansing to make the most of its ADMS investment. The test bed was set up to simulate an Xcel feeder and was integrated with an ADMS from their vendor, Schneider Electric. Preliminary simulation results showed that a low-quality ADMS model resulted in numerous voltage exceedances and multiple utility equipment operations, while the highest quality model resulted in significant reductions in both and showed an increase in energy savings.[17]

Peak Load Management with ADMS and DERMS
Funded by DOE's Office of Electricity, Holy Cross Energy, DOE's EERE, and ARPA-E.

Residents of a rural Colorado community are quickly adopting new energy technologies at the grid edge, challenging utility cooperative Holy Cross Energy to modernize its system and continue to offer resilient and affordable power. Holy Cross sought to test NREL's real-time optimal power flow (RTOPF) control algorithms, developed under a project funded by DOE's Advanced Research Projects Agency-Energy (ARPA-E) Networked Optimized Distributed Energy Systems (NODES) program, which manage DERs to regulate distribution voltages, reduce peak demand, and provide more cost-efficient energy use for DER owners. Holy Cross partnered with NREL to use the ADMS Test Bed to evaluate the control algorithms in a laboratory setting,[18] after which Holy Cross successfully deployed the control techniques in a net-zero emissions, affordable housing community. NREL's RTOPF algorithms were programmed onto controllers located within the homes.[19]

Following these experiments, the ADMS Test Bed was used to evaluate the coordinated operation of NREL's RTOPF algorithms controlling DERs with Holy Cross Energy's ADMS, provided by Survalent, controlling legacy equipment, including a load tap changer (LTC) at the substation and line voltage regulators. Peak load management is a critical application for utilities that enables distribution utilities to

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[17] .116732t, 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 IEEE PES Transmission & Distribution Conference & Exposition (T&D) 2020*, Chicago, Illinois, October 12–15, 2020.

[18] J. Wang, M. Blonsky, F. Ding, S. Drew, H. Padullaparti, S. Ghosh, et al., "Performance Evaluation of Distributed Energy Resource Management via Advanced Hardware-in-the-Loop Simulation," *IEEE Innovative Smart Grid Technologies (ISGT)*, Washington, D.C., February 17–20, 2020.

[19] https://spectrum.ieee.org/energy/the-smarter-grid/tomorrows-power-grid-will-be-autonomous

avoid high costs during peak demand by reducing demand when the system peak is anticipated. This is typically achieved by reducing the voltages across the distribution network by changing the LTC, voltage regulator, and capacitor bank settings. These changes can be made automatically by an ADMS. With increasing levels of DERs, distribution system operators have the opportunity to leverage these DERs to reduce load directly. We demonstrated how the DERs can be controlled at an aggregate level by using NREL's DER control algorithms, enabling the ADMS to use the DER assets without having to exert direct control, thereby simplifying DER integration challenges. We demonstrated coordinated actions taken by the ADMS and the DERMS to reduce demand[20] and how DERs can be used to provide localized voltage support through reactive power.

Data-Centric Grid Operations

Funded by DOE's Office of Electricity and the California Energy Commission's Electric Program Investment Charge (EPIC) of San Diego Gas & Electric Company.

NREL is collaborating with San Diego Gas & Electric Company (SDG&E) to demonstrate AMI-based data-driven grid operations with NREL-developed algorithms implemented on DOE's GridAPPS-D[21] open-source platform. The ADMS Test Bed is configured to model SDG&E's feeder, interface smart meter, PV inverter and capacitor bank controllers as HIL and provide realistic real-time AMI-data from across the distribution feeder to the controls deployed on GridAPPS-D. The AMI is leveraged as a pervasive secondary voltage monitoring platform for next-generation planning and operations, especially for feeders with high levels of PV. The project team generated weather-dependent load profiles using NREL's Object-oriented, Controllable, High-resolution Residential Energy (OCHRE) tool and integrated them with the ADMS Test Bed to model real-time building energy use. The AMI data from these simulated customers are collected in real time and made available to the GridAPPS-D platform. NREL's Online Data-Enabled Predictive Control (ODeePC) algorithm, integrated within GridAPPS-D, is used as the advanced voltage control application. ODeePC is analogous to a model-free equivalent of model predictive control (MPC), where MPC is a class of algorithms used widely for model-based integrated volt/VAR control in ADMS platforms. The ODeePC algorithm uses AMI data alone (without feeder impedance models) to control LTCs and capacitor banks along with PV inverters (if included as a control lever) to maintain the voltage profile on the primary and secondary networks.

Data-Enhanced Hierarchical Control Optimizes System Performance

Funded by DOE's Solar Energy Technologies Office through the Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE) program.

The Enhanced Control and Optimization of Integrated Distributed Energy Applications (ECO-IDEA) project used the ADMS Test Bed to validate a new data-enhanced hierarchical control architecture. The project aimed to help utilities optimize systems with high levels of distributed generation using both legacy assets and new grid-edge devices. Partnering with Xcel Energy, Schneider Electric, the Electric Power Research Institute (EPRI), and Varentec, NREL demonstrated that this architecture can seamlessly coordinate multiple enterprise bus systems, including the ADMS, the grid-edge management system (for controlling grid-edge dynamic reactive power devices), and NREL's RTOPF (for dispatching PV inverter

[20] 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*, April 7–9, 2021.

[21] https://ieeexplore.ieee.org/document/8397161

set points). On a simulated Xcel Energy feeder, the architecture achieved reliable and efficient system-wide operations at multiple spatiotemporal scales in the face of volatile ambient conditions. Results showed that by coordinating the control of legacy assets and new devices, such as PV systems and grid-edge dynamic reactive power devices, utilities can achieve significant improvements to voltage conditions under high levels of distributed PV. The ADMS test bed was configured to model an Xcel Energy substation in the Denver metro area and the associated feeders, interfaced a PV inverter and grid-edge devices as HIL, and deployed PV inverter controls. The ADMS test bed was then interfaced with the DEHC architecture consisting of multiple enterprise-level control systems. The project team demonstrated a part of the architecture on the field and quantified the techno-economic benefits.

FLISR in the Presence of DERs
Funded by DOE's Office of Electricity and Central Georgia EMC.

This use case evaluates the performance of a commercially available FLISR application on a feeder of an electric cooperative, Central Georgia EMC, for application with highlevels of DERs. FLISR is a key ADMS application being deployed in utility distribution systems, and there has been a lot of research and development of FLISR algorithms in recent years. In this use case, the operation of Survalent's commercially available ADMS platform's FLISR application in the presence of DERs is being evaluated through laboratory experiments using the ADMS Test Bed, which is being set up to emulate an existing distribution feeder with increased levels of DERs to represent a future version of the feeder.[22]

Federated DER Management to Provide Bulk Grid Services
Funded by DOE's Office of Electricity and DOE's Building Technologies Office through the GMLC.

The increased deployment of distribution-connected DERs will require the participation of those DERs in providing grid services to the bulk grid. A Federated Architecture for Secure and Transactive DER Management Solutions (FAST-DERMS) has been developed to enable the provision of reliable, resilient, and secure distribution and transmission grid services through scalable aggregation and near-real-time management of utility-scale and small-scale DERs. A key control component of this architecture is a flexible resource scheduler (FRS) at the substation level that performs reliability-constrained economic dispatch of DERs, either directly or through a transactive market or DER aggregator, in coordination with an ADMS. The FRS, aggregators, and transactive market will be implemented on GridAPPS-D, building on the test bed integration with GridAPPS-D completed in the data-centric operations use case. The FAST-DERMS project is being led by NREL and is supported by multiple partners, including Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Oak Ridge National Laboratory, SDG&E, Southern Company, EPRI, Commonwealth Edison, and Oracle. This project will evaluate the federated controls being developed in a competitive wholesale market scenario on an SDG&E feeder using NREL's ADMS Test Bed integrated with an Oracle ADMS.

Federated DER Management for High-PV Feeder
Funded by DOE's Office of Electricity and Southern Company.

NREL is also partnering with Southern Company to evaluate the federated controls being developed through the FAST-DERMS project in a use case focused on the use of utility-owned and behind-the-meter batteries in distribution systems with high PV levels, which can result in reverse power flow and voltage

[22] 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," *IEEE Conference on Innovative Smart Grid Technologies (ISGT) 2021,* September 15–17, 2021.

management challenges. The controls will be evaluated on a Southern Company feeder using NREL's ADMS Test Bed integrated with an Oracle ADMS. This use case will also take advantage of the high-performance computing (HPC) capability at the ESIF to simulate real-time building energy use with NREL's OCHRE tool.

<u>Transmission-and-Distribution Co-Optimization to Support the Bulk Grid</u>
Funded by DOE's Office of Electricity.

In partnership with Xcel Energy and Hawaiian Electric Company, we will use the ADMS Test Bed to demonstrate the participation of an active distribution network comprising distribution utility assets and flexible loads as an aggregated resource at the bulk grid level. This use case addresses the emerging need for DERs to provide bulk services without endangering distribution system reliability. The increasing level of DERs presents a systemic risk and an opportunity to provide flexibility to bulk grid operations. Recent industry changes, such as Federal Energy Regulatory Commission (FERC) Order 2222, provide the regulatory framework for enabling these advanced operational paradigms in the near future. The co-optimization controls will be deployed on GridAPPS-D, and interfaces for integrating with distribution-level ADMS and bulk-level energy management system will be developed. The test bed will be extended to include bulk system simulation using the HELICS cosimulation framework.

Publications

More details on the ADMS Test Bed are available on NREL's website[23] and in the following publications:

- 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*, Novi Sab, Serbia, July 1–4, 2019.
- 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*, April 7–9, 2021.
- 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 PES Transmission & Distribution Conference & Exposition (T&D) 2020*, Chicago, Illinois, October 12–15, 2020.
- 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) 2019*, Washington, D.C., February 17–20, 2019.
- 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," *IEEE Conference on Innovative Smart Grid Technologies (ISGT) 2021*, September 15–17, 2021.
- Veda, S., 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)*, Denver, Colorado, March 29–31, 2017.

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