GRIDWISE ALLIANCE

TECHNOLOGY PORTFOLIO

A summary and explanation of technologies used in electric grid infrastructure and how they support grid modernization today and for the future.

DECEMBER 2021

ABOUT GRIDWISE ALLIANCE

The GridWise Alliance (GridWise) and our members believe that the electric grid and its supporting infrastructure is the critical component of a decarbonized advanced economy. Our goal is to champion the principal concepts, policies, and investments needed to transform the electricity grid and accelerate the prudent changes required to maintain the grid's essential role in a robust economy.

GridWise uniquely serves the electricity industry by leveraging diverse stakeholder perspectives to articulate the numerous benefits of grid modernization. GridWise helps create a common understanding of the numerous and transformational operations-focused and policy-related changes taking place across the electricity industry. Our work ensures that emerging policy is aligned with industry best practices to facilitate effective and widespread change.

For more information, please visit www.gridwise.org.

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INTRODUCTION

The American economy is becoming increasingly reliant on the electric grid. Across all levels and sectors, a variety of stakeholders see the opportunity and value in electrification. The cost of renewable energy generation continues to fall, outcompeting traditional fossil-fuel generation plants. Extreme weather events are becoming more frequent and intense, spurring amplified action to reduce greenhouse gas emissions. Technology baselines and product offerings are shifting, resulting in more electric vehicle models on the market, smart energy interfaces like thermostats facilitating greater home control over energy use, and building developers including solar and EV charging into new builds as a default. Figure 1 highlights some of the actions occurring across stakeholder groups.

Figure 1. Stakeholder interests driving electrification

Federal, State, and Local Policymakers

OBJECTIVES

- Reduce emissions by decarbonizing the grid and electrifying transportation and building loads.
- Competitive advantage to attract businesses where grid is clean, reliable, secure, resilient, and affordable.

EXAMPLES

- **Federal:** Infrastructure Investment and Jobs Act
- **States:** CO Together We Build; MA 2050 Roadmap
- **Local:** Pepco DC's Climate Solutions Plan; San Luis Obispo Climate Action Plan

Corporate and Business Interests

OBJECTIVES

- Business case for markets producing sustainably-manufactured, clean products.
- Decreasing costs and technology improvements in EVs, charging technology, solar panels, and storage driving action and commitments.

EXAMPLES

- Corporate renewable energy procurement goals – RE100
- Auto manufacturer commitments to go all-electric and combustion engine phase outs.

Consumer Demands

OBJECTIVES

- Cost savings and both local and global environmental benefits.
- Greater control and visibility into energy use enabled by digital technologies.

EXAMPLES

- EV and residential solar demand
- Load management and interactive utility programs, rate incentives
- Participation in CCA programs

Academic and Industry Research

OBJECTIVES

- New use cases and sector demands require more research and development.
- Opportunity to gain academic or competitive edge in knowledge development and sharing.

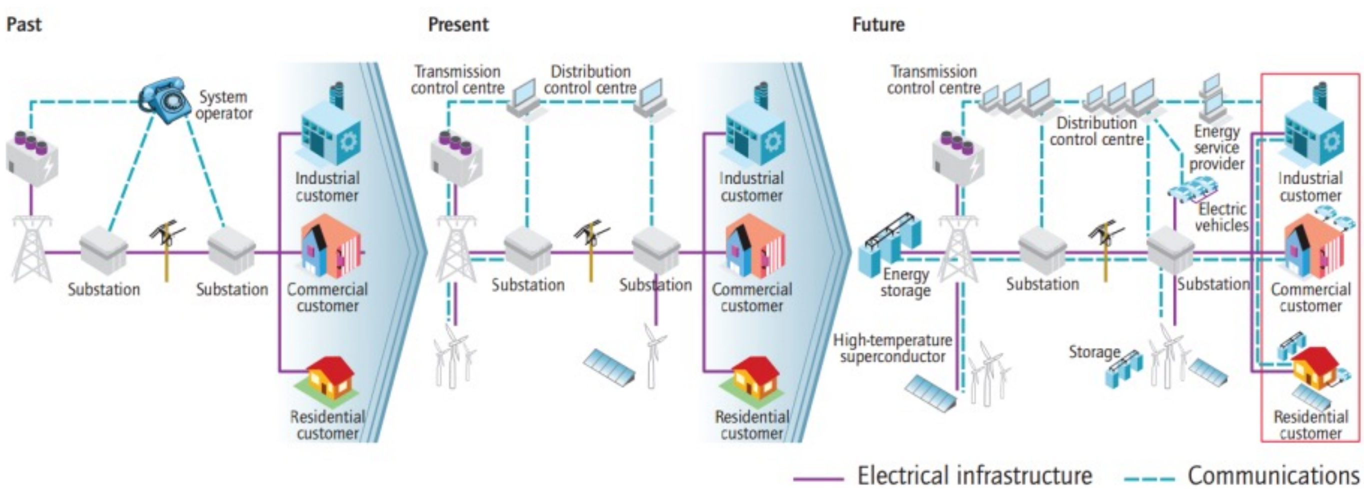
EXAMPLES

- Princeton's Net Zero America Study
- Regional Roadmaps: Decarbonizing the Northeast; Decarbonizing the Northwest
- EPRI's Powering Decarbonization: Strategies for Net-Zero CO2 Emissions

With these ongoing trends, the grid is becoming a foundational backbone for the American economy. Underlying this transformation is the need for the grid to be safe, secure, reliable, and affordable. In 2009, the American Recovery and Reinvestment Act (ARRA) provided a significant source of funding for securing and updating components of the grid. In the decade since then, however, much has impacted the grid that calls for renewed investment sources, as well as dedicated examination of the components and systems that make up and govern the grid.

The age and size of the grid calls for continual replacement and hardening of critical assets. At the same time, new technologies like distributed energy resources (DERs) are changing its traditional operation. Historically, the system operated in one direction, from generation to customers, and was centrally controlled. Today it's clear to the electricity industry, policymakers, and customers alike that a new paradigm of two-way electricity flow and decentralized operation is either here today or approaching rapidly (Figure 2).

Figure 2. Evolution of the electric power grid. Credit: OECD/IEA 2011 Technology Roadmap: Smart Grids, IEA Publishing. License: http://www.iea.org/t&c/termsandconditions/



While critical to the American economy, grid infrastructure, and the technologies and systems that are critical to its operation, can be confusing to understand. This Technology Portfolio seeks to demystify it and provide a resource to anyone interested in a modernized grid and the components necessary to get there. The next chapter in this paper provides further perspective on grid infrastructure and an overview to the framework used here and how it can be applied to illustrate grid modernization needs. Next, five functional areas, each representing a fundamental capability a modern grid must deliver, are defined and described in terms of current and future grid operation. Finally, this paper concludes with a series of one-pagers each summarizing a different technology critical for operating the grid.

OVERVIEW

The electric grid is an immense connected machine, an ultra-large-scale system unlike no other. Over the last hundred years the infrastructure comprising the grid - the wires, poles, and myriad of substation and transformers laying its foundation - has been built, hardened, and extended to meet the needs of the American economy. Unquestionably, the electric grid is a complex system with a specialized and extensive workforce. For anyone not deep in the weeds of the electricity industry, however, the technical terms and acronyms makes the electric grid difficult to understand. In this Technology Portfolio, we seek to provide a resource for stakeholders interested in the grid and who want to understand what specific types of technologies are needed when it is said that the grid must be modernized.

In a simplistic sense, the grid can be thought of as the bottleneck in the center of an hourglass (Figure 3). On one end of the hourglass (the top side as illustrated in Figure 3) you have electricity generation. On the other side, you have customers using electricity. The goal at hand is to make sure electricity flows as smoothly from one end of the hourglass to the other, that generation is connected with customers in the most efficent way possible. Ultimately, this is what grid modernization is all about, installing new technologies and replacing grid infrastructure to serve this end. Grid regulators and operators have key terms they think about when deciding what investments and upgrades to make: investments must support the grid being safe, secure, reliable, and affordable.

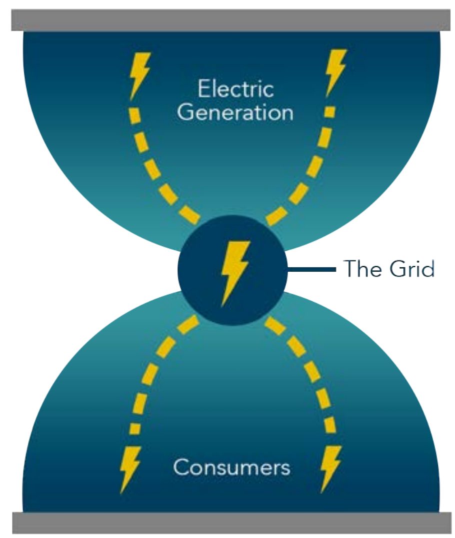


Figure 3. The grid is the connection between electric generation and customer demand.

There are certain **outcomes** that policymakers, regulators, and energy service providers (ESPs) are striving towards when modernizing the grid. In addition to the stakeholder interests driving electrification (see Figure 1), outcomes are big picture goals that can be met through grid modernization. They include decarbonized power supply, reliable delivery, affordable energy, a resilient system, beneficial electrification, and customer choice.

In order to better understand how specific technologies support meeting desired outcomes, this Portfolio presents a set of **functional areas**, or areas that encapsulate the fundamental capabilities that a modernized grid must deliver. The five functional areas are:

- Integrated planning
- System visibility
- Real-time operation
- Consumer and energy services engagement
- Emerging grid architecture

There are many **technologies**, both legacy and new, available to be installed and used on the grid. Indeed, all of the technologies needed to meet desired outcomes are available today. Featured here in a series of one-pager summaries are 10 technologies, spanning both software and hardware. This is not meant to be a complete list of technologies, but illustrative. Note that while some of the technologies fit under one functional area, many of the technologies cross functional areas. This shows how single technologies serve multiple use cases and that grid modernization investments serve multiple purposes.

A final element is the role of **enabling technologies**. Here, enabling technologies are defined as processes, computation methods, or systems that enhance system operation, improve business value, and accelerate technology adoption. They are not solutions to grid challenges or directly used to support desired outcomes, but indirectly support technology operation and enable functional area solutions. Examples of enabling technologies include:

- Internet of Things
- Machine learning
- Data science
- Blockchain
- Open source and data standards
- Physical & cybersecurity protocols
- Cloud services

Figure 4 illustrates how these pieces fit together: how technologies can be linked to functional areas, how functional areas can be mapped back to desired outcomes, and how enabling technologies support technology operation, all of which come together as a toolkit to show how a modern grid can be pieced together to achieve desired outcomes.

Figure 4. Overview of Technology Portfolio components

One application of the Technology Portfolio is to trace how specific technologies, enabling technologies, and functional areas link together to serve a specific desired outcome. For example, if a policymaker or regulator is interested in the desired outcome of beneficial electrification, electrified transportation specifically, the technology portfolio can help illustrate the links and components that support the outcome.

Figure 5 show the components and links in this example. At the top, electrified transportation is highlighted as the outcome of interest. All five functional areas are necessary to reach this goal:

- **Integrated planning** helps with forecasting electric load growth and how grid infrastructure may need to be upgraded to support new loads;
- **System visibility** and advanced sensors send data on where electric vehicles are plugging into the grid for situational awareness;
- **Real-time operation** provides the link between the electric vehicles and grid conditions, sending signals to potential storage systems co-located with chargers or with customers to optimize conditions on the grid for when a vehicle will charge;
- **Consumer and energy services engagement** is critical to ensuring a smooth interface to interact with customers or aggregation services; and
- **Emerging grid architecture** models, such as a networked microgrid, will likely benefit from sending dynamic pricing signals to electric vehicles to support operation when the system isolates from the grid, either using the vehicle as an energy source or sink as needed.

Two technologies that can support electrifying transportation in a modern grid and two enabling technologies are included to illustrate how they work together to provide greater system efficiency. Also included in Figure 5 is a discrete function of a modernizied grid critical to facilitating vehicle electrification: dynamic pricing. Not quite a technology or an enabling technology itself, dynamic pricing (sometimes called dynamic tariffs or time-variable pricing) is a function of a modern grid itself, and refers to price signals sent to customers that reflect system conditions. Today, most customers have a flat, or static, price for electricity throughout the year. Dynamic pricing offers cost saving opportunities for customers (to reduce their power use when rates are higher), power system flexibility for the grid (to respond to congested power lines), and reduce peak load and overall investment needs in large-scale grid infrastructure. Depending on customer preferences, electricity use can be adjusted manually or automatically, but advanced metering infrastructure and advanced distribution management systems are examples of technologies that make use of dynamic pricing signals to enable demand-side flexibility and many of the functional areas that support the outcome of electrified transportation.

Note that the components included in Figure 5 are illustrative and not exhaustive; there are other technologies, functions, and enabling technologies that also play a role in electrifying transportation.

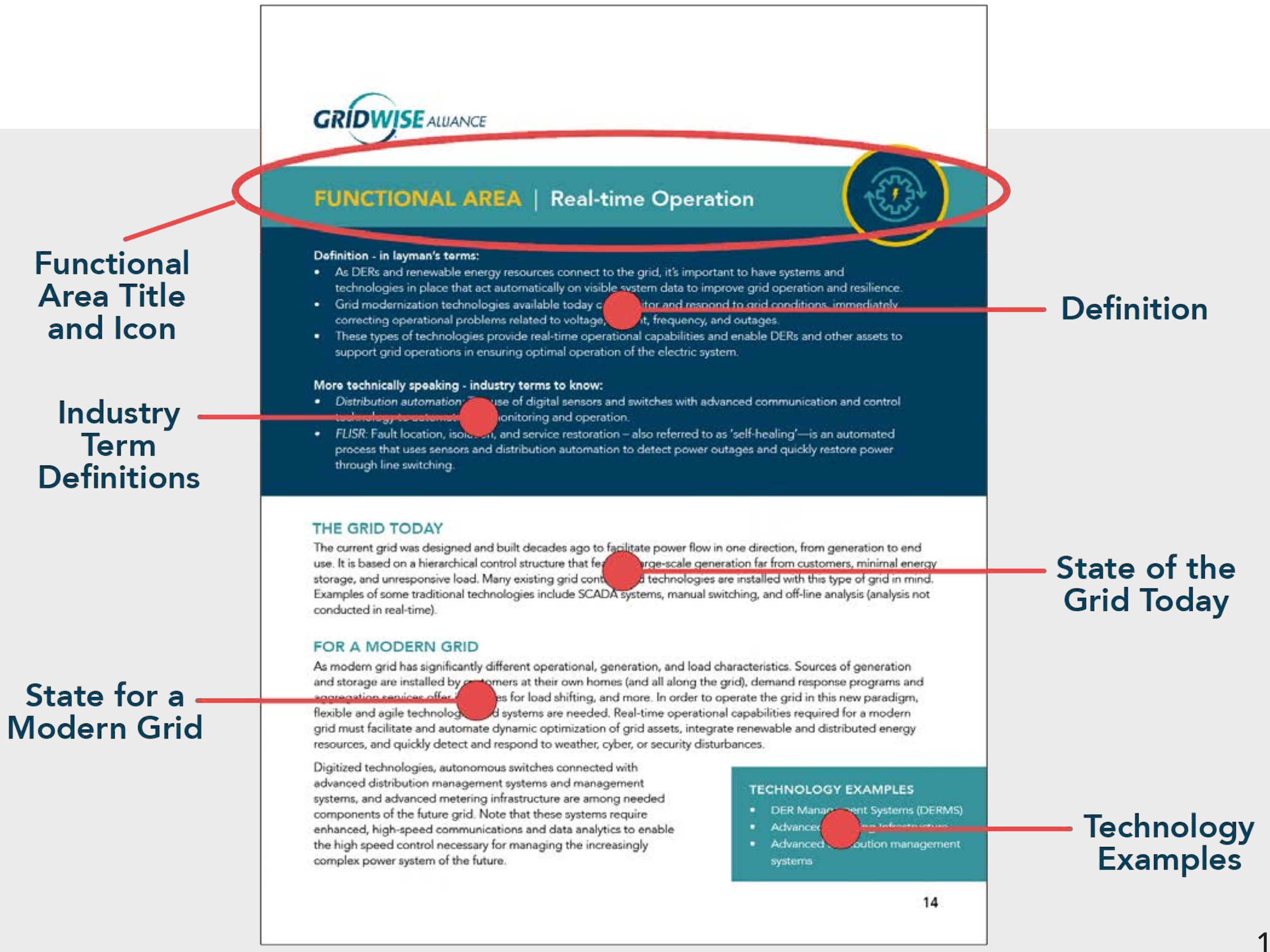
Figure 5. Technology Portfolio illustratively applied to an electrified transportation outcome

FUNCTIONAL AREAS

To better understand specific technologies and how they serve a modern grid, Gridwise has determined five functional areas, or areas that encapsulate the fundamental capabilities that a modernized grid must deliver. The five areas include:

- Integrated planning
- System visibility
- Real-time operation
- Consumer and energy services engagement
- Emerging grid architecture

In this section, each functional area is further detailed in a one-pager. Each page is laid out similarly and includes the following components:



FUNCTIONAL AREA | Integrated Planning

Definition - in layman's terms:

- Every state and utility has planning processes in place to determine operational and capital expenditures required to meet near- and long-term strategic and implementation needs.
- Increasing DER and renewable resources deployment, along with electrification increasing electric loads across the system and modifying traditional load profiles, call for improved planning processes.
- Integrated planning processes include modeling that considers variables like resource & transmission planning, earth system models, technology adoption curves, and critical infrastructure needs.
- It includes forecasting with more sophisticated models that handle uncertainty better and more powerful algorithms that improve the capacity and productivity of planning tools.

More technically speaking - industry terms to know:

- *Hosting capacity:* Refers to a maximum amount of DER the distribution grid can accommodate in specific locations without new infrastructure buildout.
- *Deterministic forecasts:* Refers to a modeled forecast of future grid needs where many variables are assumed to be unchanging. Better forecasting methods use multiple scenario forecasts instead which test a variety of variables under different conditions.
- *Integrated resource planning*: A public, legally required plan that sets the long-term vision for resource development in a utility's territory. Utilities use IRPs to evaluate and communicate potential strategies for delivering reliable supply at the lowest system-wide cost over 10 to 20 years.

THE GRID TODAY

Planning processes today differ significantly from state to state based on market type, generation ownership, state targets, and more. Generally, typical grid planning processes, including distribution planning, integrated resource planning, and transmission planning, are conducted independently.

Modeling and forecasting used for planning makes use of deterministic forecasts and future projections are based on historic data. Systems external to the grid (like gas networks) are not included in planning processes and traditional planning requirements including reliability, safety, security, congestion, and voltage constraints are considered.

FOR A MODERN GRID

New and emerging planning requirements include considering the integration of renewables, cybersecurity, climate change adaptation, equity, and electrification demands. This calls for integrated planning, where distribution planning, integrated resource planning, and transmission planning are coordinated with consistent assumptions, and incorporated into a modeling environment. Multiple scenario forecasts can then be conducted during the planning process, featuring models of identified system interdependencies, earth systems (weather, flooding, etc.) to account for climate change, financial and supply chain constraints, and more.

TECHNOLOGY EXAMPLES

- Integrated distribution and transmission planning
- Interdependency coplanning tools
- Automatic DER interconnections

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FUNCTIONAL AREA | System Visibility

Definition - in layman's terms:

- To operate and plan for a modernized grid, system operators need to 'see' as much of the system as possible.
- This includes understanding where electricity is entering and leaving the system, when it is being used and generated, and how the power is flowing through the distribution and transmission lines. Communication and data sharing systems are integral components here.
- This situational awareness is particularly important as more devices connect to the grid, and can be improved by maximizing the use of various sensors, meters, and power flow analysis to have better information about the status of numerous components on the grid.

More technically speaking - industry terms to know:

- *SCADA:* Supervisory control and data acquisition – the traditional software systems used to monitor and control the grid.
- *Telemetry:* The process of collecting data at a remote location and then sending it to a central location for processing and analysis.

THE GRID TODAY

The current grid was designed and built decades ago to facilitate power flow in one direction, from generation to end use. Grid operators have placed sensors and monitors along the system to monitor this one-way flow of power through bulk power system generation, transmission, and distribution. Traditional SCADA systems are primarily used to monitor and control the grid and utility-owned and operated private communications networks transfer critical data.

FOR A MODERN GRID

As DERs connect at all points along the grid, large-scale renewable resources inject increased variable power into the system, and storage and demand response solutions offer greater flexibility, grid operators require enhanced visibility into the more complex real-time grid conditions and power flow. This is needed to respond to quickly changing conditions as assets charge, store, and discharge power. It's also needed to respond to reliability events which may be caused by a storm knocking down part of the grid or more dynamic behavior from renewables, increasing the need for advanced sensing, measurement, and ultimately, real-time predictive grid operational tools.

Dynamic monitoring and sensing technologies with greater resolution and reliability are now available to grid operators, providing improved situational awareness and facilitating faster response times. Advanced metering infrastructure and power flow analysis software tools are also available and will be critical to unlocking the full visibility into the grid, and subsequent control and communication with DERs. Upgrading communication systems to state of the art systems is also an integral component of modernizing system visibility.

TECHNOLOGY EXAMPLES

- Syncrophasors
- Dynamic monitoring
- Advanced metering infrastructure
- Power flow analysis software

FUNCTIONAL AREA | Real-time Operation

Definition - in layman's terms:

- As DERs and renewable energy resources connect to the grid, it's important to have systems and technologies in place that act automatically on visible system data to improve grid operation and resilience.
- Grid modernization technologies available today can monitor and respond to grid conditions, immediately correcting operational problems related to voltage, current, frequency, and outages.
- These types of technologies provide real-time operational capabilities and enable DERs and other assets to support grid operations in ensuring optimal operation of the electric system.

More technically speaking - industry terms to know:

- *Distribution automation:* The use of digital sensors and switches with advanced communication and control technology to automate grid monitoring and operation.
- *FLISR*: Fault location, isolation, and service restoration – also referred to as 'self-healing'—is an automated process that uses sensors and distribution automation to detect power outages and quickly restore power through line switching.

THE GRID TODAY

The current grid was designed and built decades ago to facilitate power flow in one direction, from generation to end use. It is based on a hierarchical control structure that features large-scale generation far from customers, minimal energy storage, and unresponsive load. Many existing grid controls and technologies are installed with this type of grid in mind. Examples of some traditional technologies include SCADA systems, manual switching, and off-line analysis (analysis not conducted in real-time).

FOR A MODERN GRID

As modern grid has significantly different operational, generation, and load characteristics. Sources of generation and storage are installed by customers at their own homes (and all along the grid), demand response programs and aggregation services offer incentives for load shifting, and more. In order to operate the grid in this new paradigm, flexible and agile technologies and systems are needed. Real-time operational capabilities required for a modern grid must facilitate and automate dynamic optimization of grid assets, integrate renewable and distributed energy resources, and quickly detect and respond to weather, cyber, or security disturbances.

Digitized technologies, autonomous switches connected with advanced distribution management systems and management systems, and advanced metering infrastructure are among needed components of the future grid. Note that these systems require enhanced, high-speed communications and data analytics to enable the high speed control necessary for managing the increasingly complex power system of the future.

TECHNOLOGY EXAMPLES

- DER Management Systems (DERMS)
- Advanced Metering Infrastructure
- Advanced distribution management systems

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FUNCTIONAL AREA | Consumer & Energy Services Engagement

Definition - in layman's terms:

- As technologies become cheaper and more broadly available, there is increasing interest from consumers and third-parties to interact with the grid.
- Engagement may be driven by potential cost-savings, potential profits, environmental reasons, or reliability purposes, yet leveraging consumer demand and supply can benefit the grid.
- The grid should evolve to improve and facilitate interactions between itself, consumers, and third parties to realize and maximize potential resilience and economic co-benefits.
- Components of an accessible grid include a user-friendly interface and standardized data availability to simplify information sharing and connectivity and to facilitate automated participation of agents, software, and third-party applications.

More technically speaking - industry terms to know:

- *Prosumer:* Refers to someone who both produces and consumes electricity. An example is a household with solar panels that both uses and delivers electricity to the grid.

THE GRID TODAY

Historically, electricity customers, whether residential, commercial, or industrial, have had a mostly hands-off relationship with the grid. Traditional electric service has provided a high quality and reliable service, with end use demand being fairly steady and passive in nature. Electric use for most customers remains a monthly bill to pay and forget about.

Customers with either larger load or specific energy interests have started engaging with their electric supplier more, whether by entering into demand response programs or installing solar and taking advantage of net metering arrangements. Certain technologies, like home management systems, are becoming more popular in new homes and allow consumers to become more energy efficient and aware of their electricity uses.

FOR A MODERN GRID

A range of new products, services, and devices are becoming increasingly available to consumers to enable them to better manage their electric use and costs. Consumers are choosing to interact with the grid more and energy service providers, like third-party aggregators, require better interfaces and market structures for engagement. Concurrently, grid operators need improved visibility at a more granular level into electricity needs and end uses. A modern grid should be set up to integrate available technologies, interested customers, grid operators, and dynamic signals and controls to facilitate grid interactivity, grid flexibility, and provide customers with requested services.

TECHNOLOGY EXAMPLES

- Home Energy Management Systems
- Advanced metering infrastructure
- DER Management Systems (DERMS)

FUNCTIONAL AREA | Emerging Grid Architecture

Definition - in layman's terms:

- Current grid infrastructure, wholesale market rules, and business models have been built over the last century for one-way electricity flow and passive end-uses.
- The future grid will require a fundamental transformation in grid operation and design and needs to manage increasing decentralization, DER deployment, renewable energy, and more.
- Current market rules, grid infrastructure, and industry structure are inadequate to operate the future modernized grid, making it critical to ideate and enact new grid architectures, system practices, business models, distribution level markets, and standards.

More technically speaking - industry terms to know:

- *Transactive energy:* An approach that allows for communication and trading between energy suppliers, customers, and resources and ultimately coordinates all electricity-related actions in order to minimize costs and optimize grid operation.
- *Grid architecture:* Refers to a framework used for thinking about how the grid as a system needs to transform to modernize and identifies bounds to assist policymakers and grid operators in making broader changes to the system.
- *Distribution system operator (DSO):* A neutral developer and operator of the distribution system, who manages competitive access to markets, enables customer access and choice, and optimizes the use of DERs in the distribution system.

THE GRID TODAY

The grid built over the last century has functioned reliably, securely, and affordably for one-way power flow and passive end-uses. Wholesale markets provide power for customers and revenue for generators while utilities or independent system operators (ISOs) manage the operation of markets, with distribution utilities maintaining the system delivering power. As DER deployment increases, and other electrification and decarbonization trends accelerate, the centralized bulk power system and associated market mechanisms are starting to face challenges.

FOR A MODERN GRID

The future grid will feature more distributed resources, a larger number of actors, and advanced technologies monitoring and controlling numerous grid-connected assets. As the characteristics of generators and electricity demand changes, the reevaluation of grid organization structure should occur to set up a more dynamic system that enables innovation and new business models. Especially as the distribution system becomes more complex, establishing distribution system operators to manage the grid as a platform will be vital for DER integration, enabling DERs as a system resource, and maximizing value for all grid-connected entities and assets.

TECHNOLOGY EXAMPLES

- Advanced distribution management solutions
- Networked microgrids

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TECHNOLOGY EXAMPLES

In this section, 10 grid modernization technologies are highlighted to show some components that are key to modernizing the grid. The 10 technologies include:

- Synchrophasors
- Distributed energy resource management systems
- Advanced metering infrastructure
- Home energy management system
- Interdependency coplanning
- Networked microgrids
- Volt-Var optimization
- Integrated distribution and transmission planning
- Automatic DER interconnections
- Advanced distribution management systems

In this section, each technology is further detailed in a one-pager.
Each page is laid out similarly and includes the following components:

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EXAMPLE TECHNOLOGY | Synchrophasors

WHAT IT IS?

Synchrophasor technology uses monitoring devices, called ***phasor measurement units*** (PMUs), which take high-speed measurements of phase angles, voltage and frequency that are time stamped with high-precision clocks. The high-speed measurements, typically taken 30 times a second, can reveal system changes undetectable through traditional monitoring systems used in the industry.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

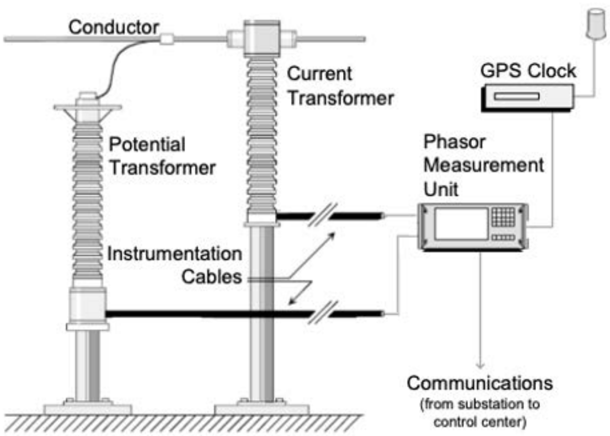
Traditional systems take grid measurements once every 2-10 seconds, while synchrophasors record 30 times per second. This data gives a detailed view of the status of the power flow on the grid, and allows for broad system situational awareness, oscillation monitoring, and equipment problem detection.

WHERE IS IT LOCATED?

Synchrophasors can be installed anywhere along grid infrastructure where power flows. This includes substations, transmission lines, and distribution lines. They are most commonly installed along transmission lines.

HOW MATURE IS THE TECHNOLOGY?

Widely deployed | In 2009, there were under 200 synchrophasers deployed across the country. After dedicated funding for synchrophasers were included in the 2015 American Recovery and Reinvestment Act, it's estimated that there are over 1,700 synchrophasors in use.



Representative synchrophasor installation in a substation. Source: US DOE. Advancement of Synchrophasor Technology.

EXAMPLE: DEPLOYMENT PROGRAM

As part of the Smart Grid Investment Grant (SGIG) and Smart Grid Demonstration Program (SGDP), DOE and partners invested more than $347 million to deploy synchrophasors throughout the US transmission system to improve system visibility and reliability. The effort increased PMUs on the system by more than 8 times by 2015 compared to 2009 levels.

FOR MORE INFORMATION

- PJM. Synchrophasor Technology Improves Grid Visibility. 2020.
- Pacific Northwest National Laboratory. Open Source Suite for Advanced Synchrophasor Analysis. September 2020.
- U.S. DOE. Advancement of Synchrophasor Technology. March 2016.

EXAMPLE TECHNOLOGY | Distributed Energy Resource Management Systems

WHAT IT IS?

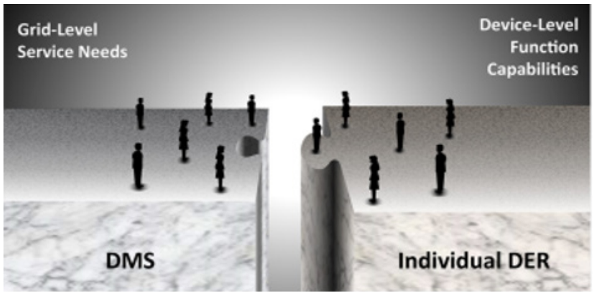
Distributed Energy Resource Management System (DERMS) is a software solution that incorporates a range of operations including asset repository, forecasting, and dispatch. It is particularly useful for adjusting the production and/or consumption levels of disparate DER directly or through an aggregator. DERMS connect individual distributed energy resources (DERs) and help to aggregate and optimize their operation based on grid conditions and feedback from the distribution management system (DMS).

WHY IS IT ESSENTIAL FOR A MODERN GRID?

An increasing number of DERs are rapidly connecting to the grid, and ways to manage individual DERs is critical to operating and monitoring the grid. DERMS monitor and control DERs placed throughout the distribution system, from the substation to the individual home or device and provide a way to connect individual DERs to the broader system.

WHERE IS IT LOCATED?

DERMS software is typically in a centralized utility real-time operations center.



The gap addressed by DERMS.
Source. EPRI. Understanding DERMS.

HOW MATURE IS THE TECHNOLOGY?

Ready for scaling | Standardization efforts are underway by research groups, and as of 2021 there have been a number of larger scale utility RFPs in the multi-million dollar range for rolling out non-pilot DERMS.

EXAMPLE: PILOT PROGRAM

Pacific Gas & Electric completed a pilot program in San Jose in 2019 with DERMS software. Funded by the Electric Program Investment Charge (EPIC) charge, it connected two aggregator platforms and includes up to 150 residential and 10 commercial customers with solar arrays and energy storage systems. See PGE's EPIC 2018 Annual Report, for more information.

FOR MORE INFORMATION

- U.S. DOE. Modern Distribution Grid (DSPx). Volume II. November 2019.
- Electric Power Research Institute. Understanding DERMS. July 2018.

EXAMPLE TECHNOLOGY | Advanced Metering Infrastructure

WHAT IT IS?

Advanced metering infrastructure (AMI) refers to a measurement and data collection system that includes a 'smart' meter at the customer site, the communication network transmitting and receiving data to and from the electric service provider, and the management system used by the electric service provider to operate the grid and/or send signals to the customer meter. Fundamentally AMI provides a mechanism for two-way electricity flow and communication on the distribution system.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

Smart meters are becoming more intelligent and capable of supporting the expansion of distributed energy resources. Technology advances are increasingly allowing AMI systems to work seamlessly with other grid edge devices, such as EV chargers and solar inverters, to maintain grid stability, efficiency, and flexibility. In addition to measuring energy use and voltage, the next generation of AMI systems use machine learning and analytics to respond to anomalies and status changes deeper into the distribution grid in real time to better manage capacity and prevent outages. At the same time they provide energy consumers with the insights to respond to variable pricing programs and incentives and support a decentralized and digitized grid.

An advanced meter is installed at a home.
Source. U.S. DOE. AMI and Customer Systems.

WHERE IS IT LOCATED?

The foundational component of AMI is the meter. Smart meters are installed at the customer site or where there is an end use requiring electricity from the grid.

HOW MATURE IS THE TECHNOLOGY?

Widely deployed | The Smart Grid Investment Grant (SGIG) Program invested more than $5 billion in the deployment of AMI and customer systems in 2009. This funding supported widespread deployment of AMI. Today more than half of all states have achieved a rollout greater than 50% and about 60 investor-owned utilities have fully deployed smart meters.

EXAMPLE: CASE STUDY

Supported by the Smart Grid Investment Grant (SGIG), Pepco installed over 277,000 smart meters in the Washington, DC territory through 2013. Benefits realized as a result of the AMI deployment significant include utility and customer savings and reliability improvements. See the project description and report for more information.

FOR MORE INFORMATION

- U.S. DOE. Modern Distribution Grid (DSPx). Volume II. November 2019.
- U.S. DOE. Advanced Metering Infrastructure and Customer Systems. September 2016.
- New Mexico Grid Modernization Advisory Group. Draft Whitepaper: Investment in Advanced Meter Infrastructure. January 2021.

EXAMPLE TECHNOLOGY | Home Energy Management System

WHAT IT IS?

Home energy management systems (HEMS) are located in customer homes with the purpose of monitoring, communicating with, and sometimes controlling various home energy devices. In addition to tracking energy use and consumption information, HEMS systems enable both the homeowner and utility to save energy and money by analyzing system and home energy needs, and offer control and scheduling options to adapt energy use behavior.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

HEMS are a critical component for customers to track their energy use and also see price signals and real-time information from their utility. By presetting and adjusting home energy use settings, HEMS is the software through which a customer can reduce or shift their energy use to respond to price signals from the utility.

Illustration of a home energy management system. Source. openPR.

WHERE IS IT LOCATED?

EMS are primarily software-based, meaning it is typically accessed from an application or website on a phone or computer. However, some available HEMS have physical hardware interfaces that are installed in the home as a monitor-type interface in a customer home, typically where a traditional thermostat might be located.

HOW MATURE IS THE TECHNOLOGY?

Developed technology, not widely deployed | There are many HEMS products available commercially that offer different capabilities based on customer type and services offered. Both open source and proprietary options exist, though deployment of HEMS system is not widespread.

EXAMPLE: PILOT PROGRAM

The Northern Indiana Public Service Company (NIPSCO) conducted a smart thermostat pilot program with residential customers in 2014. After studying customers before and after, the smart thermostat was found to reduce electricty use for cooling by 16.1% on average. See more about the program here.

FOR MORE INFORMATION

- Oak Ridge National Laboratory. Home Energy Management Systems: An Overview. 2018.
- U.S. DOE. The Smart Home. Webpage.

EXAMPLE TECHNOLOGY | Interdependency Coplanning

WHAT IT IS?

Electricity is a critical component of most infrastructure networks including oil and natural gas, transportation, communications, and water systems. With trends to decarbonize and electrify, the grid is becoming even more foundational to the economy. Interdependency coplanning refers to a planning process in which forecasts and models are used to identify how electricity supports these networks, and develop plans for hardening and making grid infrastructure resilient to potential disruptions

WHY IS IT ESSENTIAL FOR A MODERN GRID?

Multiple critical infrastructures are increasingly dependent on electricity to operate including electrifying vehicle fleets, digitized financial systems, and communication systems. Grid planning processes should be cognizant of these interdependencies and improve grid resilience and security.

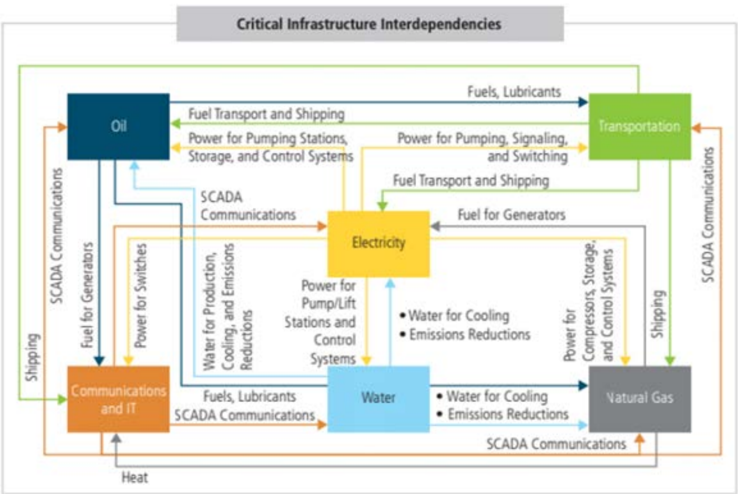


Diagram showing infrastructure interdependencies. Source. U.S. DOE. Quadrennial Energy Review.

WHERE IS IT LOCATED?

Interdependency coplanning is not a physical entity but should become a regular part of the planning process conducted by both state officials and utilities.

HOW MATURE IS THE TECHNOLOGY?

Early stage research and development | Given the complexity of each singular critical infrastructure, tools that model and support planning efforts to manage their interdependencies are under development.

EXAMPLE: FRAMEWORK FOR NETWORK CO-SIMULATION

The Pacific Northwest National Laboratory developed the Framework for Network Co-Simulation (FNCS) which sought to integrate tools modeling communication, transmission, and distribution simulators. See the following abstract for more information

FOR MORE INFORMATION

- U.S. DOE. Quadrennial Energy Review, Second Installment. January 2021.
- U.S. DOE. Quadrennial Technology Review. September 2015.
- Pacific Northwest National Laboratory. Interdependence of the Electric Power Grid & Information and Communication Technology. August 2015.

EXAMPLE TECHNOLOGY | Networked Microgrids

WHAT IT IS?

A microgrid refers to a connected set of electric loads, power generators, and control systems that can operate independent of the bulk power systems, and in some cases interconnect with it. Networked microgrids (NMG), sometimes called a microgrid cluster, refer to when two or more microgrids connect electrically through a primary or secondary distribution system, coordinating their controls systems.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

As more DERs connect to the grid, NMGs can act as points of control aggregation. Additionally, the shared loads and generation resources, increase the likeliness that electric demand is met by their own internal resources. As a result, NMGs have the potential to increase operational flexibility for the broader grid, increase system resilience, and reduce costs when co to either the distribution grid itself or independen microgrids.

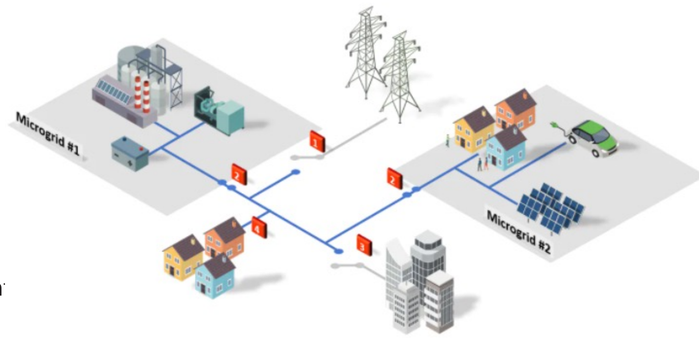


Illustration of two networked microgrids.
Source. T&D World.

WHERE IS IT LOCATED?

NMGs could be located anywhere there are electric power systems, however details around system ownership and operation are dependent on the type of utility and existing state regulation. Depending on location, NMG assets and the wired system may be wned fully or partially by either the utility or users and might be easier or harder to develop as a result.

HOW MATURE IS THE TECHNOLOGY?

Early stage development | While microgrids are more established, NMGs are a relatively new concept. Limited research and demonstration projects have occurred to date.

EXAMPLE: PILOT PROGRAM

In 2018, Commonwealth Edison (ComEd) announced a two-phase NMG project. First, ComEd developed a new utility-owned microgrid in Bronzeville, Chicago before the second step of integrating it with an existing microgrid at the Illinois Institute of Technology. See this article for more information.

FOR MORE INFORMATION

- National Renewable Energy Laboratory. Networked Microgrid Optimal Design and Operations Tool. May 2020.
- T&D World. The Regulatory Path Forward for Networked Microgrids. May 2020.

EXAMPLE TECHNOLOGY | Volt-Var Optimization

WHAT IT IS?

Volt-Var Optimization (VVO) software is a type of distribution automation software that manages system voltages and reactive power. VVO software monitors the distribution system and makes use of voltage control devices and/or smart inverters to improve the voltage profile, reduce energy consumption, and make grid operation more efficient.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

Consistent voltage and frequency is foundational to stable power flows on the grid. Renewable energy sources like solar power have irregular power production and sometimes introduce potentially harmful voltage fluctuations to the grid. As more renewables (and other DERs) connect to the system, VVO software supports grid stability by monitoring frequency and voltage changes and then automatically responds to smooth voltage volatility.

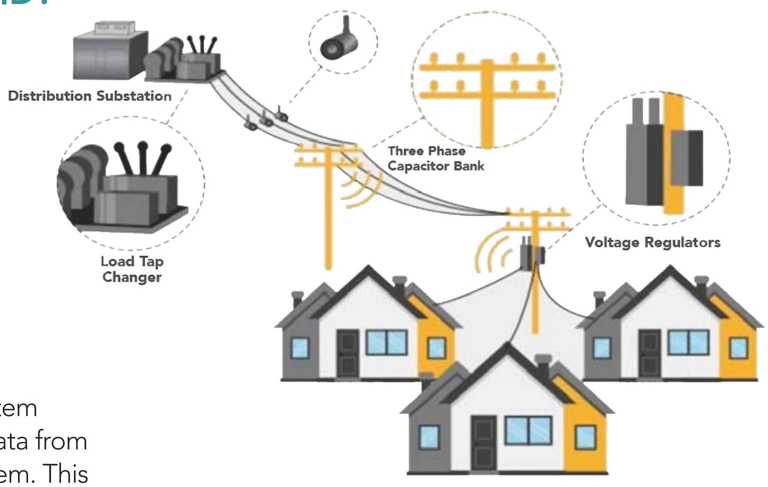


Illustration of VVO devices along the distribution system. Source: Networked Energy Services.

WHERE IS IT LOCATED?

VVO software can be integrated as part of a distribution management system (DMS) or as a separate stand-alone system operating in parallel. In either case, a VVO system receives data from and sends signals to components within the distribution system. This includes, but is not limited to, substation equipment, field devices on the distribution circuit(s), and the point of interconnection for DERs.

HOW MATURE IS THE TECHNOLOGY?

Widely deployed | Variations of the VVO technology have been deployed for well over 20 years. Currently there are many commercial vendors with VVO offerings, providing a range of functionalities. The ability to address complex system reconfiguration and the integration of DER exist, and capabilities vary by specific vendor offering.

EXAMPLE: DEMONSTRATION PROJECT

In 2008, American Electric Power coordinated the deployment of an VVO system across 11 distribution feeders at five substations throughout the Northeast Columbus Ohio area. In this demonstration project, AEP both modeled and then analyzed field data to show benefits from the project. See the project abstract for more information. Currently, AEP has VVO technologies operating on over 100 distribution circuits across multiple states.

FOR MORE INFORMATION

- U.S. DOE. Modern Distribution Grid (DSPx). Volume II. November 2019.
- U.S. DOE. Quadrennial Technology Review. September 2015.
- Pacific Northwest National Laboratory. Volt/VAR Optimization.

EXAMPLE TECHNOLOGY | Integrated Transmission and Distribution Planning

WHAT IT IS?

Integrated transmission and distrubtion planning, sometimes called integrated distribution planning or just integrated planning, refers to new comprehensive approaches to traditional electric grid planning processes. The processes for bulk resource, distributed energy resource, distribution, and transmission planning have historically been conducted independently of each other. Integrated transmission and distribution planning calls for new models of planning that connects these processes.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

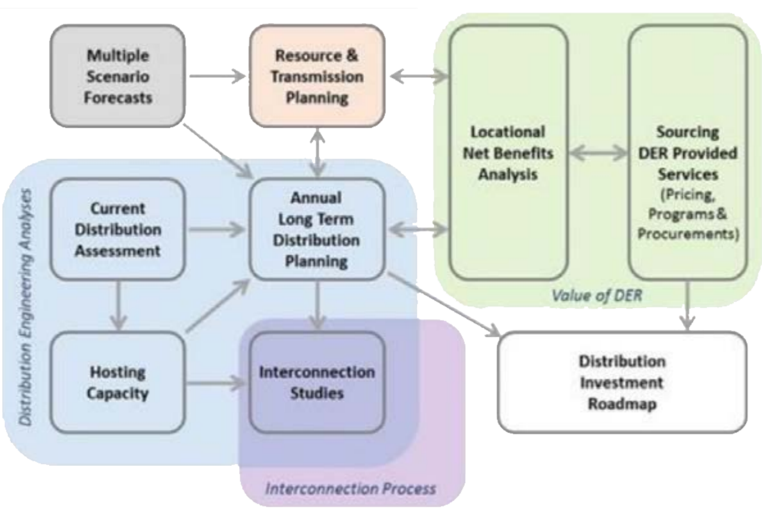
As a variety of changes impact the grid, including but not limited to increased distributed energy resources, intensifying extreme weather, and greater demand due to electrification, connecting planning processes can better align and streamline efficient grid investment and development.

WHERE IS IT LOCATED?

Integrated transmission and distribution planning is not a physical entity but should become a regular part of the planning process conducted by both state officials and utilities.

HOW MATURE IS THE TECHNOLOGY?

Widely discussed, early stage implementation | The concept is widely discussed among regulators and industry stakeholders, but integrated planning processes are nascent and piecemeal existing planning technologies.



Components of an integrated planning framework, including both distribution and transmission systems. Source: Paul De Martini, ICF.

EXAMPLE: TASK FORCE

NASEO and NARUC worked with members across 15 state teams to develop innovative visions for how electricity system planning can be improved. For details on the five roadmaps they developed, see the overview factsheet here.

FOR MORE INFORMATION

- NASEO and NARUC. Task Force on Comprehensive Electricity Planning. 2021.
- Lawrence Berkeley National Laboratory. Overview of Integrated Distribution Planning Concepts and State Activity. 2018.

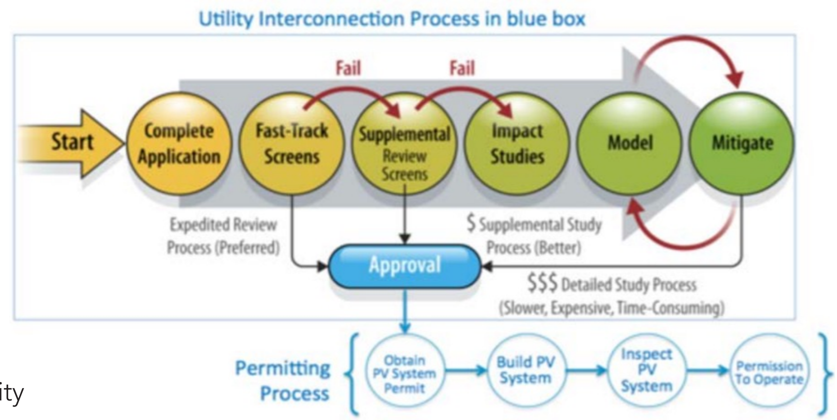
EXAMPLE TECHNOLOGY | Automatic DER Interconnection

WHAT IT IS?

Automatic distributed energy resource (DER) interconnection is the process for interconnecting a new DER resource to the grid through the use of automation to minimize the number of manual steps that must be taken before approval. Interconnecting DERs, typically solar PV and storage systems, can be a time-intensive and lengthy process, with multiple screening steps both administratively and technically. Automating and standardizing steps can save time and money for both the customer and utility staff.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

As new DERs seek to connect to the grid, increased applications for interconnection can overload the typical application system, causing both financial and customer relationship consequences. Automating and standardizing parts of the process can help mitigate this. This may also include using power flow analysis tools and developing hosting-capacity maps to support swifter interconnection approvals.



Typical utility DER interconnection process today. Source: NREL.

WHERE IS IT LOCATED?

The DER interconnection process is not a physical entity but state officials and utilities should work together to streamline and standardize the application steps.

HOW MATURE IS THE TECHNOLOGY?

Widely discussed, early to mid stage deployment | Across the U.S., interconnection applications to utilities range from paper forms submitted by mail and manually approved to online platforms that fully automate application processing. The more automated processes are, the easier it will be to incorporate new DERs to the grid.

EXAMPLE: CASE STUDY

New York state regulators requires all investor-owned utilities to deploy an online application system and standardized interconnection forms and processes. This process helps simplify the process and save time. See more from the Public Service Commission here.

FOR MORE INFORMATION

- National Renewable Energy Laboratory. An Overview of DER Interconnection: Current Practices and Emerging Solutions. 2019.
- IEEE Smartgrid. Automating the Utility-Customer DER Interconnection Process. 2020.

GRIDWISE ALLIANCE

EXAMPLE TECHNOLOGY | Advanced Distribution Management System

WHAT IT IS?

An advanced distribution management system (ADMS) is a software platform that digitizes and integrates numerous utility operational and monitoring systems including SCADA systems, outage management systems (OMS), existing distribution management systems (DMS), and workforce management and data visualization. It provides a comprehensive digital representation of the condition of the distribution network and supports optimal management of DERs and integration with utility tools for billing and data collection.

WHY IS IT ESSENTIAL FOR A MODERN GRID?

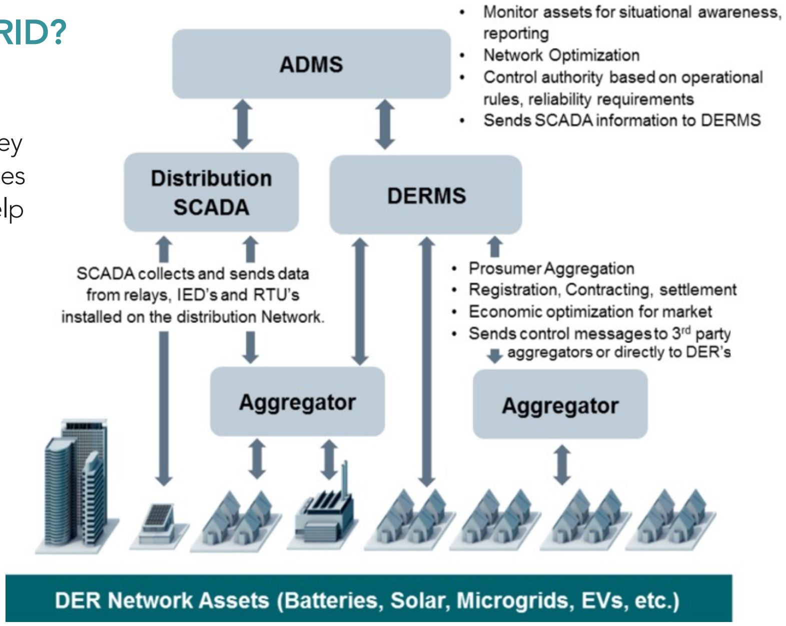
With the increase in DERs connecting the the grid, from solar PV to electric vehicles, ADMS systems are considered increasingly essential to the future of the utility business. They support a utility in transitioning from manual, paper processes to digitized, automatic process that use real-time data to help better integrate renewables and improve grid efficiency.

WHERE IS IT LOCATED?

ADMS is not a physical entity but a software platform that is installed and run from a utility control center.

HOW MATURE IS THE TECHNOLOGY?

Mid-stage development, ready for scaling | While early pilots of ADMS date back over a decade, the technology is still evolving and is only lightly adopted. Research into ADMS systems by national laboratories is underway and vendors continue to develop products for adoption by utilities.



ADMS has a complete view of the operating network.
Source: Powergrid International.

EXAMPLE: RESEARCH TEST BED

For several years now, the National Renewable Energy Laboratory (NREL) has operated a test bed to serve as a vendor-neutral evalutation platform for advanced grid controls implemented on ADMS platforms. Multiple use cases have gone through evaluation, and it continues to research ADMS capabilities. See more on this effort here.

FOR MORE INFORMATION

- U.S. DOE. Voices of Experience: Insights into Advanced Distribution Management Systems. 2015.
- National Renewable Energy Laboratory. Advanced Distribution Management Systems. 2020.
- U.S. DOE. Advanced Distribution Management Systems Testbed Development. 2020.