The Digital Grid: Building the Foundation With IoT and Data Analytics

A GTM CREATIVE STRATEGIES WHITE PAPER

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1 Executive Summary

Conditions are changing faster than ever in electricity distribution markets throughout the U.S. Utilities are facing increasing pressure to maintain reliability, improve resiliency, integrate renewable generation, enhance customer options and services, and ensure sound financial performance—all at the same time.

"Renewable generation is not going away given the decreasing levelized cost of energy for wind and solar PV, as well as the growing prominence of global sustainability initiatives. Integrating and operating these resources is a significant change for utilities," said Gary Rackliffe, vice president of smart grid North America for ABB.

Meanwhile, substations and other power grid assets are aging beyond their design life, and utilities are seeking a better balance between maintenance, life extension and replacement. Asset health is closely tied to the core utility values of safety and reliability, and grid operators need to make sound decisions on maintenance and replacement while maximizing the efficiency of their grids.

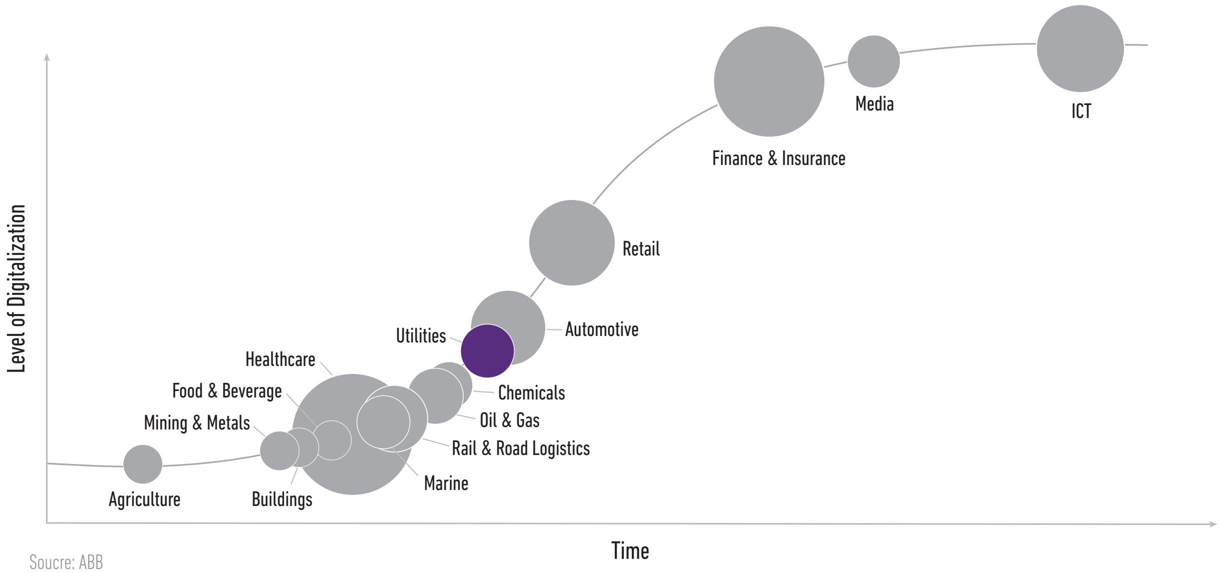
While these challenges are unique to the tightly regulated electric industry, the best solutions are not. Utilities can learn from organizations in the financial, retail and industrial control sectors that are further along in their technological evolution (see Figure 1).

One of the most compelling opportunities for technology investment is in the digital grid, which combines software with powerful data analytics and connected intelligent grid devices.

"The digital grid is not emerging," said Rackliffe. "The technology is already here."

The combination of connected, intelligent devices and analytics can help utilities gain insight into their operations and maximize the investments they've already made. It also provides data streams to make decisions on how to best serve customers and position the business moving forward.

Figure 1: Digital Disruption S-Curve by Industry.



Soucre: ABB

This paper examines the utility industry's path toward the digital grid through investment in connected, controllable devices, communication networks and data analytics. Digitalization is a fundamental component of the digital grid, allowing utilities to leverage data across the enterprise.

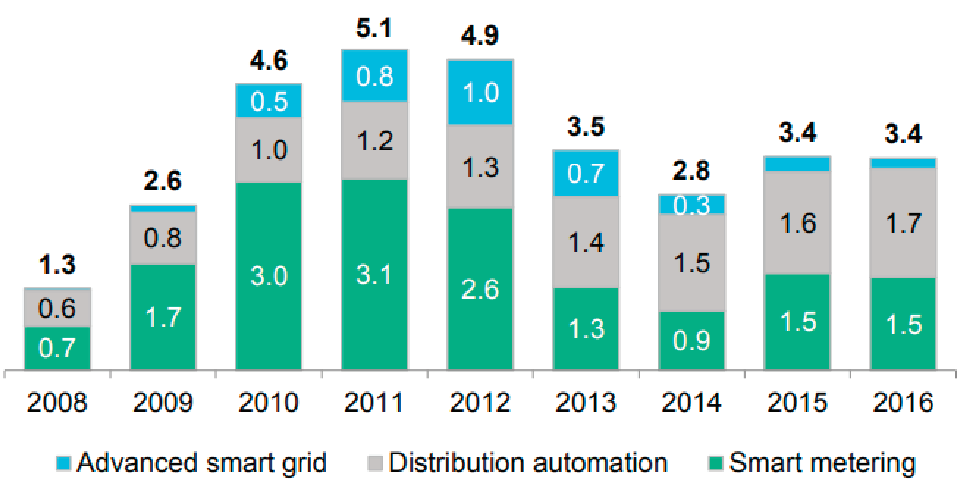
These digital grid building blocks enable utilities to better manage the grid and offer several important benefits:

- Integrated, enterprise-wide digital technology can provide unique value for electric utilities via increased reliability and reduced cost.
- Utilities should formulate digitalization technology roadmaps that provide immediate ROI as well as increased value over time, supported by further investments.
- The industrial IoT represents a platform for improved grid management through the use of controllable connected devices.
- Data analytics applications can leverage existing data streams to improve grid performance, outage management, asset health and resource planning.
- The digital substation concept functions as a microcosm of the benefits of digitalization.
- Utilities can manage the complexities of distributed energy resources (DERs) to capitalize on the opportunities they create.

The Digital Grid Migration

Digital capabilities have been proliferating across the transmission and distribution grid for many years. At the distribution level, a tsunami of changes (both regulatory and economic) have necessitated a more concentrated approach to digital grid investment. Many electric utilities have improved operational control and efficiency in recent years with investments in advanced metering infrastructure (AMI), distribution automation (DA), and, more recently, advanced distribution management systems (ADMS). Figure 2 illustrates this trend.

Figure 2: Technology deployments by category.



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But smart meters and their accompanying data streams, along with DA and ADMS, are just the beginning. Utilities are pulling in more data from more sources than ever before, but most are not integrating this data into grid-facing operational systems, according to a report from the Edison Foundation Institute for Electric Innovation.

"Utilities are now asking how you share and create value from the data provided by all the different sources across the utility enterprise," said Rackliffe. "How do you capture and access the data, and then make sure that you have the right applications to convert the data into actionable information?"

Most utilities are only scratching the surface of their digital potential when it comes to greater operational efficiency, increased reliability and a better customer experience.

Grid Dynamics Shift Faster Than Ever

Keeping the lights on is no longer the only metric used to define great electric service. Reliability is paramount, but there is also a need for a new value proposition for customers, whether residential or commercial. Improved customer communication, renewable power options and incentives for improving efficiency and power factor are all standard practice now. Value-added services like turnkey microgrids are likely to become more common as technology costs continue to drop and capabilities increase.

Embracing digitalization across the enterprise is the only way to create the new utility value proposition. One major challenge is the integration of DERs – and as the following infographic illustrates, the time to prepare is now.

To truly succeed with DERs, utilities must know what resources are on their system, where they're located, and how they're performing in real time, no matter who owns the resource.

Grid operators need the capability to manage fluctuations in loads, resources and voltages for every distribution feeder, as well as the capability to coordinate DERs with transmission and centralized generation resources.

Utility leaders can address the DER challenge by rethinking the role of information technology across their organization. As operational technology (OT) and information technology (IT) converge, utilities can leverage powerful insight and control that can be delivered only by connected digital solutions.

The increase in severe storms is another challenge for utilities. Hurricane Sandy in 2012 and Hurricanes Harvey, Irma and Maria in 2017 have ushered in a new era of storms that are larger and more intense than previously seen (see Figures 3 and 4). Meanwhile, consumer expectations for utility response to such events have only increased. Resiliency, not just reliability, is now the buzzword of the power industry.

As the challenges mount, key assets are aging. For example, many power transformers operating in substations today are well past their design lifespan. Managing the health of critical assets will only become more important going forward, a process that will rely on all of the elements of the digital grid.

DERs Are Here Today

Utilities may be preparing for just one type of distributed energy resource today, but they should take a holistic approach to technology investment to have the capability to integrate many types of DERs seamlessly in the future.

The U.S. installed about **15 GW** of solar PV in **2016**, nearly **2X** the amount in **2015**

Source: GTM Research

About **1/3** of households will have **smart thermostats** by **2020**

Source: Parks Research

In 2016, solar was the **#1 source** of new electricity for first time ever in U.S.

Source: GTM Research

By 2019, the levelized cost of energy (LCOE) for residential solar will reach grid parity in **30+ states**

Source: GTM Research

Grid-connected hot water heaters could allow for up to **100 GW** of **additional wind** and **solar energy** on the **U.S. grid**

Source: Regulatory Assistance Project

115% expected market growth of U.S. microgrid capacity from 2016 to 2020

Source: GTM Research

By 2022, the U.S. energy storage market will be **worth $3.2 billion, 5X** the size of the market in 2017

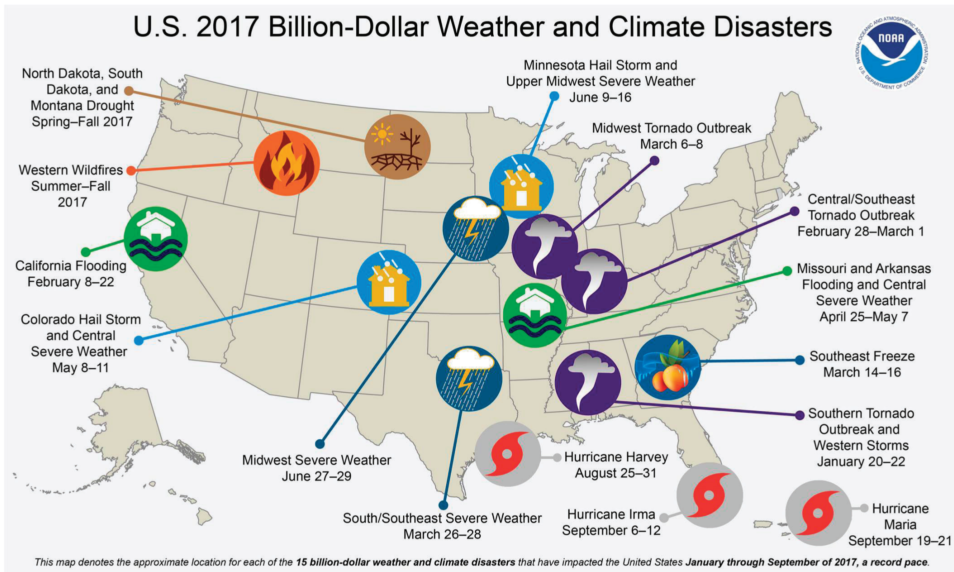
Source: GTM Research

U.S. **EV** growth

Source: GTM Research

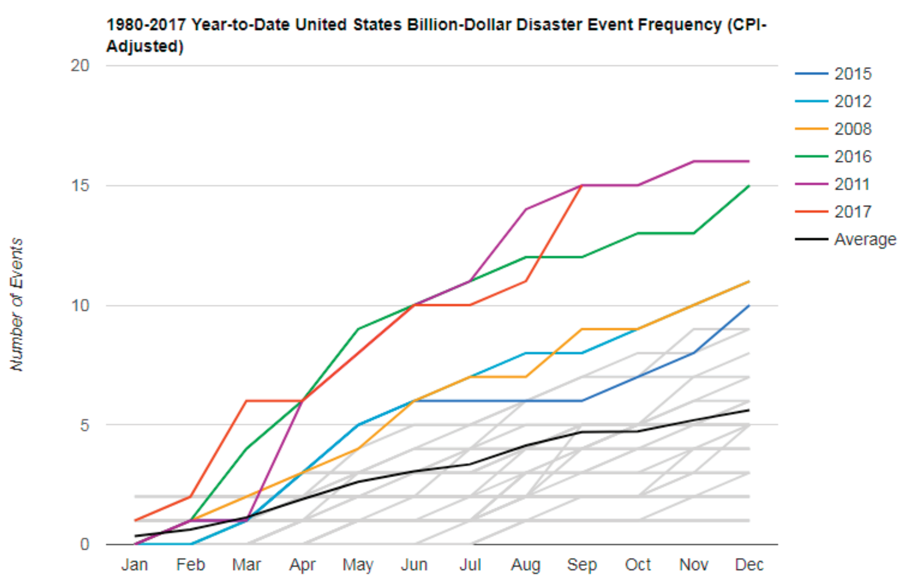
Utility IT infrastructure must also adapt. The siloed, proprietary technologies that run many critical grid operations are anathema to early-career engineers accustomed to readily integrated open systems. But such connected systems also bring a new set of cybersecurity risks. These and the other challenges laid out above all have readily available solutions, which we discuss in the following section.

Figure 3: Weather and climate-related events are increasing in frequency, intensity and cost.



Soucre: NOAA

Figure 4: Weather and climate-related events are increasing in frequency, intensity and cost.



Event statistics are added according to the date on which they ended. Statistics valid as of October 6, 2017.

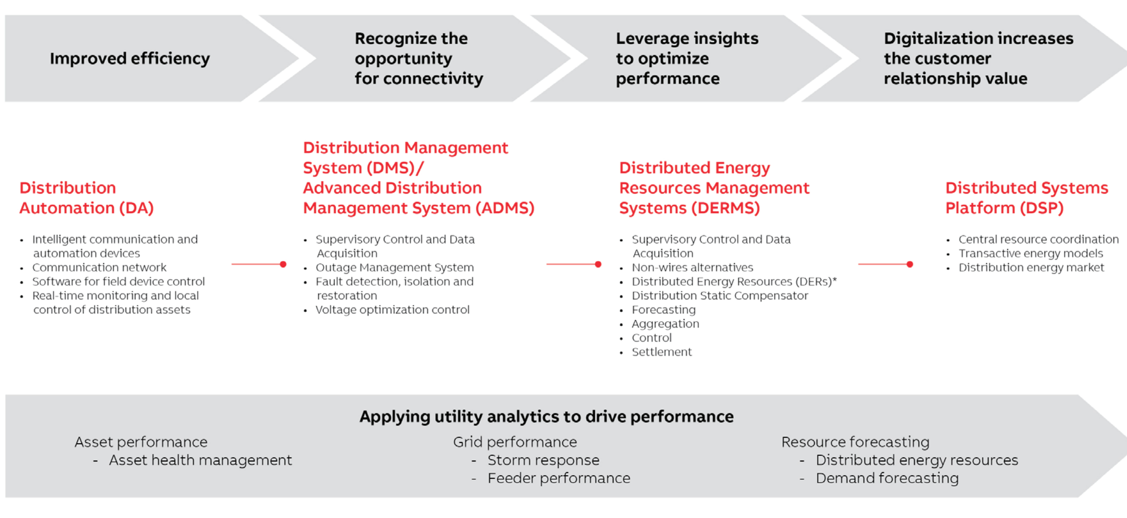
Source: NOAA

Foundations of the Digital Grid

The term "digital grid" means different things to different people. Expressed simply, it is an approach to grid management that applies software, communications, and integrated intelligent devices to improve performance. Figure 5 illustrates the migration from today's systems and processes to those of the digital grid of the future.

Fortunately, there are many paths to the digital future. Utilities can move at their own pace, adding capabilities where they can deliver the greatest value today and expanding to more applications and use cases over time. But whatever path is chosen, utilities should have robust roadmaps for technology adoption in order to reach their digital grid objectives.

Figure 5: Digital grid evolution



Soucre: ABB

Data Analytics

Data abounds within utilities, but disparate and poor-quality data is frustrating and can hamstring grid operators and other utility business units from identifying actionable insights.

"Today, data is overwhelming utilities rather than helping them to derive value from it," explains ABB's Rackliffe.

Analytics applications supported by sound data management practices, such as the ones described below, can improve operations, enable better modeling and forecasting, and improve asset management.

DER management. Analytics at the distribution level are essential to manage the increasing penetration of DERs. Distributed generation and microgrids alter grid dynamics and create new challenges for voltage management, protection coordination and short-circuit interruption limits. Other DERs, such as customer-sited energy storage and electric vehicles, present both opportunities and challenges to manage loads and capacities. Strong analytics and control systems that leverage AMI data, smart inverters and intelligent devices on the distribution grid can position the utility to thrive in a distributed energy world.

Asset health management. Better data can support an asset management system that merges data from multiple sources to analyze asset health and support proactive decision-making. For example, utilities can use predictive algorithms to analyze condition and operational trends in near-real time to detect a potential transformer failure before it occurs. This information enables utilities to make a decision about servicing or repairing the transformer or taking it out of service and replacing it.

Asset health applications can also help optimize workforce management, a concept ABB calls connected asset lifecycle management, or CALM. CALM integrates asset health management with workforce and asset management systems to take a pre-emptive approach to asset performance that can lower costs while increasing reliability and safety for workers.

Most advanced asset health applications are at the transmission level, given the high cost and associated risk of a catastrophic failure. But now asset health management at the distribution level is becoming increasingly viable as the cost of sensors has come down. Asset health assumes greater importance as DERs, such as EVs, are loaded onto the system and as regulators are asking utilities to analyze their distribution grids at the feeder level.

Integrated resource planning. More than 30 states now require integrated resource planning, according to the trade association Advanced Energy Economy. An example of digitalization is to use AMI data to create detailed feeder load profiles to evaluate the most cost-effective mix of centralized supply- and demand-side resources.

"AMI data becomes an important input to this load allocation process," said Rackliffe. "Now you can aggregate the AMI data from individual meters to the distribution service transformers. As a result, load flow analysis becomes more precise."

Optimizing Data Management

To succeed with analytics in any application, however, utilities must make data from multiple sources readily available to applications that use it to glean insight. Data from modern IoT devices is relatively easy to manage, because modern systems are designed for data sharing.

Data from legacy systems is a different matter, however. It might be generated by analog devices, siloed away in one department, stored in hard copy, or rendered in serial languages that do not mix easily with other data types. Below are some guidelines for better data management.

Know how to warehouse. To integrate data of diverse types from legacy systems and other sources, utilities need to "socialize" their data by converting it to a common format and delivering it to a shared repository. Known as a data warehouse or "data lake," these architectures make the data readily available to a wide range of applications.

Data and processing are handled in a variety of different ways, depending on the application, as well as the governance needs relating to privacy and security. Some analytics applications are designed to deliver high-level insight in an offline environment. They can draw data from a data warehouse as it becomes available, whereas operational systems may require a different solution to address latency concerns.

Adopt fog computing. To address latency, field area networks can use fog computing, where all processing and some data storage are handled in a local network close to the devices. Some of the most critical analysis that utilities need happens in real time or very close to it. For example, fault location, isolation and service restoration (FLISR) and volt/VAR optimization rely on real-time or near-real-time processing at the edge of the network.

Filter appropriately. Filtering is another essential data-management capability. A processor at the network edge determines which data is for local automation purposes only and which data requires transmission to a centralized repository for storage. By limiting the amount of data traversing the network, filtering preserves bandwidth and reduces costs for transport and storage.

IoT for Continuous Improvement

Beyond the initial investments in the proverbial low-hanging fruit, utilities must look for ways to build on those investments to further develop the digital grid business case. IoT technologies take grid management to a new level by transforming operational tasks into automated actions driven by software embedded with the types of data analytics described above.

"When you apply IoT to the grid, you can control devices, assess grid data, and use analytics to guide that control with the purpose of making the grid more reliable, efficient and resilient," said Rackliffe.

IoT technology enables devices to work on multiple levels:

- Perceiving states and conditions
- Networking with other devices
- Executing actions in response to application commands, which often are automated

The IoT incorporates connectivity and can leverage network protocol standards such as IEC 61850, which enables the deployment of intelligent devices in substations and on the distribution grid. When building the digital grid with IoT connectivity, analog devices can either be replaced with intelligent digital devices or paired with sensors and digital converters that derive data that can then be merged with other data streams. Schemes for peer-to-peer device control, local automation and control, and centralized control can also be configured.

Still, many utilities have invested in some networked, controllable devices, but have not mapped out how an IoT ecosystem should support all areas of the business. What does the industry need to do to make an IoT strategy integral to business strategy? First, it is imperative to take an open, collaborative approach that may not be embedded in company culture.

Think open. The use of devices that leverage standards based on open protocols frees the utility from dependence on a single vendor and enables the use of integrated applications and grid devices that provide complementary control and analysis at multiple levels, based on the common protocol.

Building digital grid capabilities involves investing in applications and hardware that enable greater control and more effective analysis

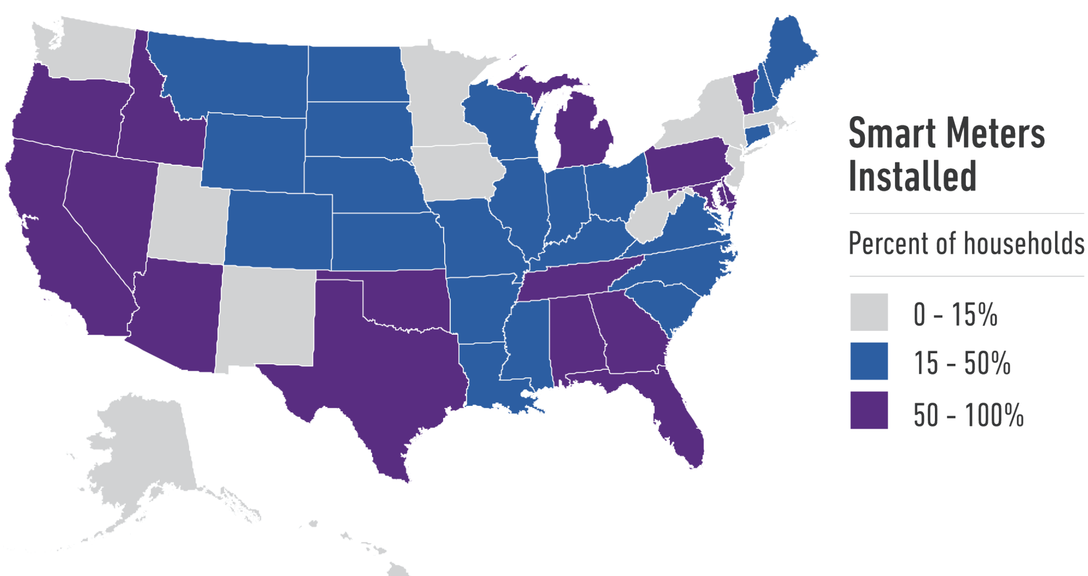
Break down siloes. The continuous improvement from the IoT is only possible for utilities that have already established a roadmap for IoT in the first place. Bringing all the potential beneficiaries of digitalization together to create a strategy allows all potential use cases to surface, making the total value of any given technology clear.

> "Cloud computing, either hosted or on-premise, is an enabler," explains Rackliffe. "Utilities may want to start with one discrete project that solves a single operational challenge, but the real benefit of digitalization comes as more devices are added and networked to provide value across a utility's entire operations."

Investing Toward the Digital Grid

Building digital grid capabilities involves investing in applications and hardware that enable greater control and more effective analysis. But data analytics are only as good as the quality of the input data. Prioritizing investment in the hardware and software highlighted below is often the first step in collecting the data that can transform utility operations.

Figure 6: Smart meters deployed by state, 2015.



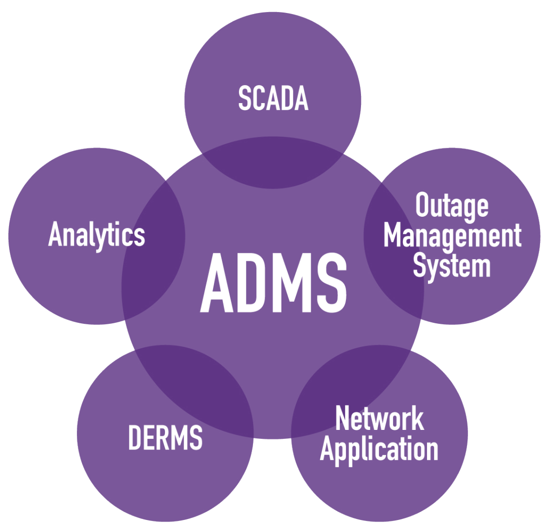
Soucre: Institute for Electric Innovation

Advanced metering infrastructure. More than half of U.S. utility customers now have advanced digital meters (see Figure 6), but AMI's full value lies beyond just more efficient meter reading. Meter data represents the raw material for a host of applications.

AMI is used today to enhance storm response by providing outage notification and restoration verification to outage management systems. Planners can similarly use AMI data to refine network models, better understand capacity and loading on feeders, and assess the potential benefits of DERs and non-wires alternatives.

Geographic Information Systems. Utilities have been using GIS for decades, but now there are upgrades that vastly improve data granularity and accuracy. To get the most out of GIS, utilities need to evaluate their current capabilities, especially with regard to how well their GIS integrates with other enterprise systems. The goal is actionable insight for day-to-day operations as well as long-term planning.

Figure 7: ADMS is made up of a variety of applications.



Soucre: ABB

Advanced Distribution Management Systems. An ADMS combines real-time monitoring and control with applications for management, optimization and analysis in an integrated software platform (see Figure 7).

One of the values of an ADMS is that it leverages a service-oriented architecture to interact with other enterprise solutions. For example, ADMS data can support a variety of downstream functions from outage notification and restoration verification in storm response, to transformer load management, network analysis and distribution resource planning.

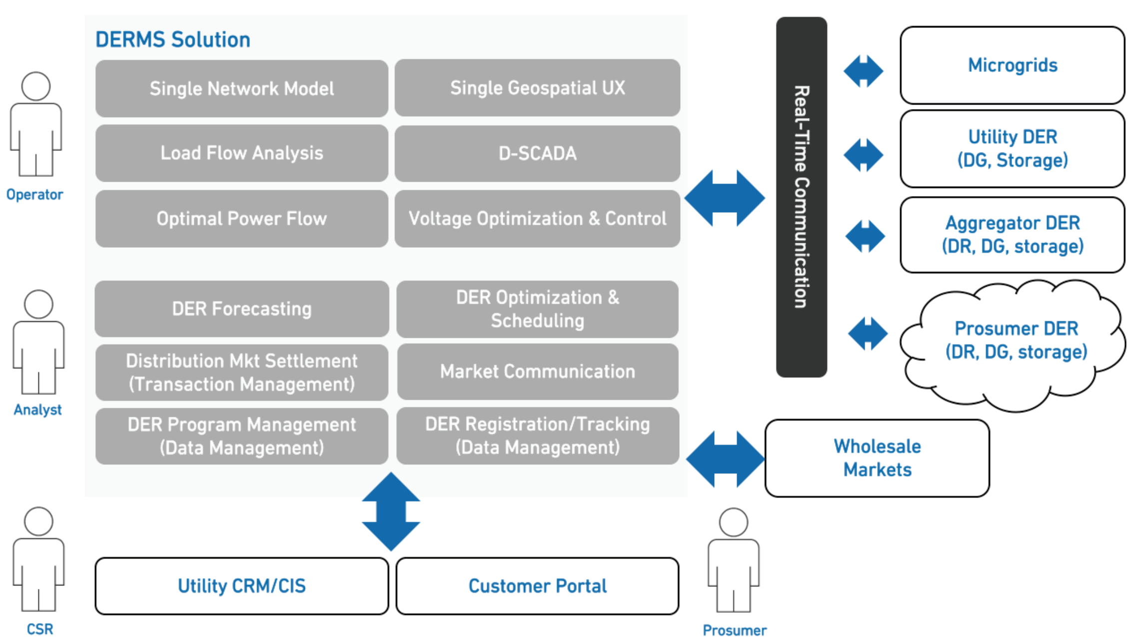
ADMS serves as the backbone for next-generation distribution management. Still, a report earlier this year from the U.S. Department of Energy found that fewer than one in 10 utilities surveyed currently has an ADMS plan in place. More than half said they had no plans for ADMS.

Distributed Energy Resource Management Systems. "Utilities need a mechanism to understand and manage DERs, whether the resources are behind the meter or connected directly to the distribution grid," said Rackliffe. "These resources are going to drive new utility business models."

A DERMS allows utilities to manage DERs from registration to optimization, control and settlements. It can also manage DER rate structuring, and DERMS data can offer insight for capacity planning. A basic DERMS architecture is shown in Figure 8.

To prepare for wider DER adoption, utilities should look for a DERMS that can manage voltage control and power quality. Utilities should think particularly about scalability, and evaluate not only the current use case for a DERMS (e.g., optimizing large commercial and industrial-owned DERs), but also whether the system will optimize hundreds of thousands of smaller grid-edge assets in the future.

Figure 8: DERMS reference architecture



Soucre: ABB

The Digital Substation

Situated at the intersection of transmission and distribution, the substation is a key component in power delivery, and the use of digital technology in the substation improves reliability, safety, security, resiliency and productivity.

"If you don't digitize the substation, there is no data to analyze," said Steven Kunsman, vice president of business development and marketing for substation automation, North America at ABB. Fortunately, the industry has worked hard to develop standards that facilitate the digitalization of the substation.

Whether retrofitting or building from the ground up, a utility can build substation automation around the IEC 61850 standard to incorporate analog and digital equipment from different manufacturers in a modern communications environment. Similarly, fiber-optic cables can replace massive amounts of copper cabling to reduce cost while improving safety and resiliency.

Utilities that invest in digital substations can realize many immediate benefits:

- **Increased system availability.** By replacing electromechanical, static or outdated digital secondary equipment with modern, connected devices, the substation can be linked to higher-level systems for continuous monitoring.
- **Increased system and personnel safety.** A digital substation allows for remote control combined with rule-based access and remote testing that keeps personnel away from primary equipment and eliminates the risk of inadvertently opening current transformer (CT) circuits.
- **Increased functionality and interoperability.** Upgrading to the open IEC 61850 protocol provides unrestricted communication and process capability, and helps to future-proof the substation, further protecting investments in digitalization.
- **Improved asset health.** Monitoring in the substation increases confidence in asset health and allows the utility to move toward condition-based maintenance.

The Digital Grid Delivers for CenterPoint Energy

For Houston-based CenterPoint, investing in the digital grid started with improving operational efficiency, minimizing the impact of outages, increasing reliability, and managing its workforce more effectively.

The transmission and distribution utility, which serves 2.4 million metered customers, put its digital transformation in high gear in 2009, when it received a $200 million stimulus grant from the U.S. Department of Energy to improve the reliability and efficiency of the power grid.

CenterPoint has increased power reliability by 36 percent on automated feeders and slashed outage identification time by half, while providing accurate restoration estimates to customers. It has also restored millions of outage cases without a customer phone call, avoided more than 200 million customer outage minutes, and saved consumers more than $20 million per year by automating utility services.

The key to these performance improvements is the utility's Intelligent Grid deployment, an enterprise-wide approach to digitalization. CenterPoint began by mapping its distribution grid and matching smart meter locations to the distribution transformers modeled in its ADMS. In addition to AMI and GIS, the customer information system and mobile workforce management systems are also integrated into the Intelligent Grid.

36%

increase in power reliability on automated feeders

Grid controllers take in data coming from IoT-enabled field devices, as well as smart meters and field crews. Cross-platform data-sharing supports self-healing on the grid through a network of reclosers and switches connected via high-speed wireless communications. The ADMS also integrates fault location, isolation and service restoration (FLISR) to reroute electricity around damaged circuits and restore power automatically to as many customers as possible before repairs take place.

When a severe storm hit Houston in 2016 and knocked out more 600 overhead line fuses and 650 transformers, CenterPoint restored power to 90 percent of 240,000 customer sites within 24 hours. More recently, Hurricane Harvey drenched Houston in more than 50 inches of rain and disrupted service to about 900,000 customers at various times. CenterPoint brought power back to more than 175,000 customers within 24 hours of the storm and more than 99 percent of customers were back online a little more than a week after the storm.

CenterPoint has developed its technology platform to incorporate advanced predictive data analytics so that it can use data from past storms to improve supply chain management and workforce deployment for the next event, as well as to determine the best measures for hardening the grid. The utility also plans to use predictive analytics for asset health applications, and is looking to strengthen its DER management capabilities.

Customer Expectations and Security

Customers increasingly expect to have services and options at their fingertips from any company they do business with. Utilities are not exempt. Customers are not comparing their utility just to other energy service providers, but also to retailers, banks, airlines and telecom companies.

Digitalization is key to improving customer service in an increasingly digitized and mobile world. Data from AMI, GIS and ADMS supports accurate customer communications during an outage and enables the kind of personalization that customers expect.

Cybersecurity

Utilities are not immune from cyber threats, and the essential nature of the grid makes dealing with them of the utmost importance. Recently, Accenture found that two-thirds of utility executives think there is at least a moderate risk of a cyberattack on the distribution grid in the next five years, but less than half feel prepared for such an occurrence.

Utilities must comply with the North American Electric Reliability Corporation's Critical Infrastructure Protection requirements. NERC CIP requires utilities to analyze risk on critical grid assets and enforce layered IT controls to protect those assets, including monitoring for security events and maintaining contingency plans for cyberattacks. Complying with NERC CIP and taking a proactive approach to security often means rethinking how the entire utility organization manages its digital assets.

"It is important to understand the security risks and replace fear with knowledge," said Kunsman. "When you use Ethernet-based protocols, security actually improves because you can apply security in layers."

Layer your defense. An important part of NERC CIP requirements involves strengthening security culture and implementing continuous monitoring. Sophisticated internet security solutions also use detection and mitigation measures powered by machine learning so that a persistent, long-term attack, such as occurred in Ukraine in 2015, can be disarmed even after the network has been penetrated.

"You can make it very difficult for hackers to break in, and even if they do, they can't get to the next level," explains Kunsman. "Also, there is monitoring so you can detect a hack that has occurred. In Ukraine, the hackers were in the network for six months before they turned the lights out."

Leverage your IT team. Utility IT teams are typically familiar with cybersecurity best practices. They can share this expertise with an integrated implementation team, including operations, to implement digitization without compromising critical system security. In fact, one of the critical success factors for any utility's cybersecurity strategy is nurturing a collaborative environment between IT and operations groups that previously may not have worked together much.

5 New Business Processes for the Digital Era

Deeper digitalization of substations and distribution grids, in particular, offers the opportunity to improve visibility, increase automation, control costs and capitalize on the variety of opportunities that advanced technology presents. Here are some of the ways utilities can get started.

The Modular Approach

Modularity in system architecture enables a utility to add technological capabilities over time. An ADMS may include SCADA, outage management, distribution applications and a DER management solution. The roster of distribution applications might also include power flow control, FLISR, overload switching, restoration switching analysis, volt/VAR control and short circuit analysis.

A modular approach allows utilities to add capability as they develop proficiency with each application and as operational requirements evolve. For example, DERMS might be unnecessary now but could become a must-have within five years. A modular approach allows the utility to tailor its platform to specific near-term utility needs, fit the project within the budget, and allow time to build a business case for the next expansion.

Optimize DER Deployments Early

With proactive planning and management, utilities can take advantage of DERs for their benefit by crafting new rates and offerings for customers who invest in everything from electric vehicles and solar PV to energy storage and smart building technologies.

Consolidated Edison is currently piloting proactive DER management in New York City with its Brooklyn-Queens Demand Management program, which leverages cutting-edge demand response, energy storage and energy efficiency to help defer a $1 billion substation investment. This project includes non-wires alternatives and is still in its early stages, but Con Ed is demonstrating that utilities can tap DERs to alter the economics of capital expenditure.

Utilities need to start building competency around IoT and data analytics now to prepare for a massive influx of DERs. That means making investments in digital platforms that can support DERs before they proliferate on a large scale.

> **"The integration of DERs is not just a question of resource dispatch for utility network operations," GTM Research analyst Andrew Mulherkar noted in a recent report on DERMS. "Instead, DER integration affects many core utility processes including grid planning, network operations and customer service."**

Ideally, utilities should look for a DERMS that will manage each asset from registration to interconnection to optimization to billing. By knowing exactly what is on the distribution grid and where, utility planners can model the impact and plan accordingly. Utilities can also use DERMS to manage new market programs around DERs and achieve integration with utility resources, aggregators and microgrids.

Conclusion

No matter how a utility is organized or regulated, it will benefit from an increasingly connected digital grid with more intelligent devices, more advanced management software and more robust analytics. For most utilities, it is not a matter of if, but when, these investments will be made.

Forward-thinking firms know they need to adopt a software-driven business model that leverages intelligent devices, networked communications and data analytics. Now is the time for utilities to seriously consider their digital evolution in both operational and financial terms.

By answering the following questions, utilities can develop a plan that meets specific operational and business challenges:

- What are the capabilities of your current enterprise software systems? Which systems will require upgrades to eventually provide feeder-level visibility, and later, control?
- What does a roadmap look like to pilot and then deploy IoT devices on the distribution grid?
- How can you leverage the data you already collect from diverse sources?
- Which software applications can be layered on top of existing systems to capture immediate operational value?
- Where would digital substations have the most operational impact on the system in the short term? As you digitize, will you build from the ground up or add secondary equipment to digitize signals?
- What can you do to influence DER deployments to better align with company goals?
- What capabilities do you need to manage proliferation of solar PV and other DERs and minimize adverse impacts? How will those capabilities need to evolve if the forecast changes quickly?
- How sophisticated is your grid modeling? What technology investment do you need to make for more granular modeling at the feeder level?

Renewables and DERs may be the ultimate drivers of the digital grid, but reliability and resiliency represent a compelling business case for adopting digital devices, advanced grid management software and data analytics immediately.

"We are in a period of unprecedented change for utility companies. New players with innovative businesses models are driving adoption of disruptive technologies at the edge of the network. Rapidly evolving consumer expectations, system interdependencies, and changing power flows are driving increased system complexity. The old paradigm is changing and digitalization can be a key enabler for utilities to address that change. A thoughtfully crafted, forward-thinking digitalization strategy will enable system-wide visibility and provide the business agility to adapt."
- Dave Goddard, Head of Digitalization, ABB

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