Guidehouse INSIGHTS

Member Report

Storm Reconstruction Guidebook: Rebuild Smart

Reduce Outages, Save Lives, Protect Property

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NEMA
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Section 1
Executive Summary

1.1 Introduction

Utility transmission and distribution grids are among the most dynamic, challenging, and critical infrastructure systems. The continued integration of advanced technologies into the power grid is critical to managing the effects of a growing trend in storm and natural disaster frequency, cost, and scale. Utilities must challenge existing models and regulatory constructs, and pursue innovative spending strategies and revenue initiatives to adapt their business to the growing natural challenges. Vendors must rise to the challenge of providing utilities with cutting-edge technology which solves critical utility issues today and works to address those of the future.

This report identifies and assesses the key technologies and solutions for the successful integration of grid hardening, storm restoration, and disaster management strategies across transmission and distribution networks. Key technologies and solutions covered in this report include:

- Smart Grid Solutions, including Smart Meters, Automation, Software Platforms, and other intelligent and connected solutions
- Microgrids, Energy Storage, and other Distributed Generation Systems
- Wiring, Cabling, and Components
- Equipment Relocation or Repositioning
- Disaster Recovery Planning

1.2 Key Recommendations

In addition to in-depth coverage of the above technologies and solutions, this report also provides recommendations for each, and suggests critical actions for utilities and communities to help prepare for, withstand, and recover from natural hazards, outage events and disasters. Below are three key recommendations that will be critical for utilities and vendors to be successful in the storm restoration and resiliency space.

- **Build the grid of tomorrow:** The energy and utility industry is deeply entrenched in a dynamic period of innovation—and disruption—at all levels. Many utilities are shifting away from sole reliance on central generation, while customers manage their energy usage like never before. Ratepayers expect near-perfect levels of electricity service, while regulators push utilities to meet reliability metrics. The intersection of data availability and advanced computing power has put holistic grid infrastructure management within sight, and utilities must act. Too many utilities are adapting their grids to meet today's customer and regulator needs instead of building the grid to surpass the needs of tomorrow. Building for tomorrow includes preparing a communications infrastructure that can handle vast and advanced software platforms and manage severe outage events. It also means implementing integrated software platforms capable of handling data in quantities orders of magnitude beyond what exists now. Most importantly, the deployment of assets on the grid itself will allow utilities to operate and maintain a high performing grid for years to come.

- **Continue to innovate to address resiliency challenges:** Recognizing modern growth opportunities is a critical factor for business growth, but understanding the needs of the next-generation reliable utility and providing innovation and product development to meet those needs is equally important. The most successful vendors in the resiliency technologies space will be those that continue to drive innovative solutions forward, demonstrating the benefits to utilities, regulators, and ratepayers. As the frequency and intensity of storms and other hazards natural disasters grows, so too should the pace of innovation and the rate of deployment. It is important to go beyond simply offering solutions for today's critical utility issues, and leading vendors must develop a portfolio of offerings capable of addressing those of the future. T&D grids are built on a foundation of centralized generation. As unidirectional power flows morph into interconnected, intelligent, and self-healing machines with energy and information flowing from asset to asset in all directions, vendors must lead the charge and ensure cutting-edge energy technologies are integrated safely and securely and facilitate the next generation of grid reliability and resiliency.
- **Consider and prioritize flexible options:** Every utility is unique in its strengths, challenges, and climate and regulatory landscape. This means every product and every project should be developed and deployed to match specific needs. Utilities that struggle with wildfires in California will need different resiliency technologies and equipment than those in Florida seeking assistance with hurricane restorations. Utilities that struggle with wildfires in California will need different resiliency technologies and equipment than those in Florida seeking assistance with hurricane restorations. This variety of platforms and products includes device hardware, networking communications, and IT and analytics. For example, a utility that seeks to upgrade its AMI hardware but is limited to using existing communications networks should be able to choose among many partners for AMI deployments, not just the original network provider. This type of flexibility will keep the market growing and allow vendors across the segment to witness success.

1.3 Rebuild Smart

Rebuilding after any major storm is a formidable challenge. The core principal of any major reconstruction effort should be to rebuild smart, ensuring that reconstruction funds maximize the deployment of technologies to mitigate future power outages, save lives, and protect property. Resilient and reliable power is critical for first responders, communications, healthcare, transportation, financial systems, water and wastewater treatment, emergency food and shelter, and other vital services. When smart technologies are in place, power outages can be mitigated or avoided and lives, homes, and businesses protected.

The 400-plus member companies of NEMA and its staff of experienced engineers and electroindustry experts—spanning more than 50 industry sectors—stand ready to assist industry and government officials when rebuilding after a disaster.

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Section 3

Rising Storm Frequency, Scale, and Cost Requires Innovation

3.1 Introduction

From 1989 through 2018, the global average number of natural catastrophic events was 520 per year, according to the Insurance Information Institute[1]. This includes geophysical, meteorological, hydrological, and climatological events, encompassing earthquakes, storms, floods, wildfires, and others. Fast-forward to 2019, and the planet witnessed 820 such events, after experiencing 850 events in 2018. In addition to the increased frequency of natural catastrophes, the intensity and cost of these events has risen sharply over the last decade. From 1980 to 2020, the US averaged 6.5 disasters that incurred damages of $1 billion or more, according to the National Oceanic and Atmospheric Administration. From 2017 to 2019, this number spiked to 14.7 disasters per year causing $1 billion or more of damage.[2]

In 2017, Hurricane Harvey crippled the south Texas area, submerging one-third of the City of Houston. The storm caused an estimated $125 billion in damages, 68 deaths, and caused power outages affecting millions of people, according to the National Oceanic and Atmospheric Administration[3].

The impacts of storms such as Harvey as well as floods, wildfires, and other events on the global electric grid have translated to a significant uptick in domestic power outages, both momentary and sustained. Reliability index data collected by the US Energy Information Administration (EIA) from 2013 to 2018 reflects the increase in outages. The major metrices used to gauge grid performance are outlined as follows.

- **System Average Interruption Frequency Index (SAIFI):** The average number of sustained interruptions (5 minutes or more) per customer during the year.
- **System Average Interruption Duration Index (SAIDI):** The average duration of sustained interruptions per consumer during the year.

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[1] Insurance Information Institute, "Facts + Statistics: U.S. Catastrophes," accessed November 2020. https://www.iii.org/fact-statistic/facts-statistics-us-catastrophes"

[2] National Oceanic and Atmospheric Administration, National Centers for Environmental Information, "Billion-Dollar Weather and Climate Disasters: Overview," accessed November 2020. https://www.ncdc.noaa.gov/billions/,,.

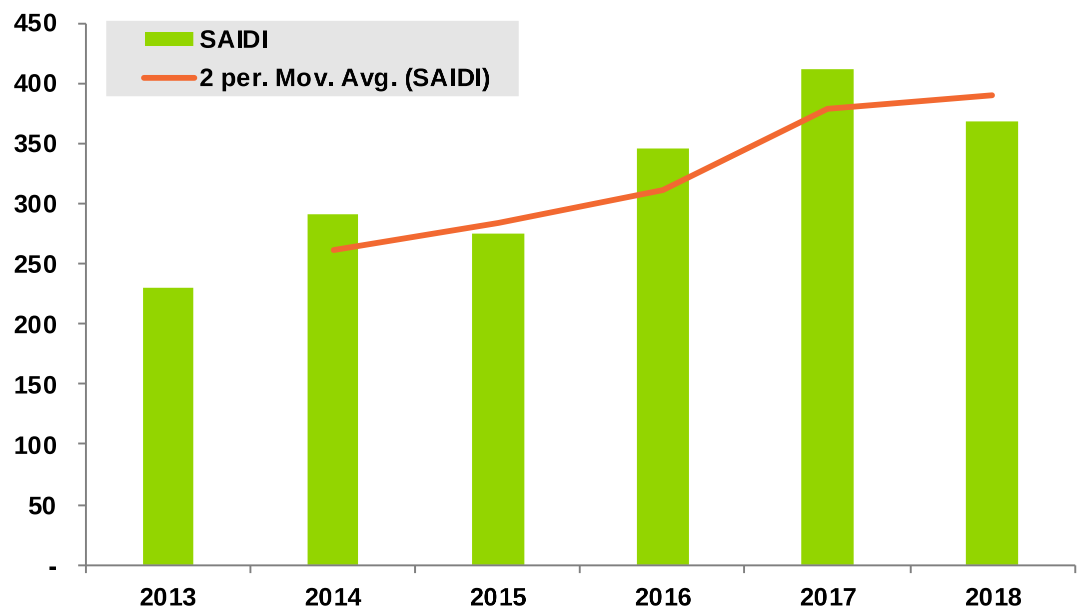
[3] NOAA. "Hurricane Harvey,". Accessed November, 2020.

- **Consumer Average Interruption Frequency Index (CAIFI):** The average number of sustained interruptions for customers that experience interruptions during the year.
- **Consumer Average Interruption Duration Index (CAIDI):** The average outage duration sustained by a customer during the year.
- **Momentary Average Interruption Frequency Index (MAIFI):** The average frequency of momentary (less than 5 minutes) outages per customer during the year.

These metrics are reported by utilities and used by regulators to measure the performance of a utility power grid by estimating the frequency and duration of outages. The metrics apply to outages that stem from issues on transmission and distribution (T&D) grids, although approximately 90% of outages occur on the distribution network. The indices are also considered by utilities, regulators, and other stakeholders when evaluating the potential and real impacts of grid modernization investment through rate cases, special initiatives, or other proceedings.

Since the EIA began collecting this information from US utilities in 2013, a steady trend indicates the increase in system outage frequency and duration. Chart 3-1 includes data from 500 utilities that reported SAIDI each year from 2013 to 2018 and includes cooperative, municipal, and investor-owned utilities.

Chart 3-1. SAIDI, 2013-2018



(Sources: Guidehouse Insights, US Energy Information Administration)

The data in Chart 3-1 represents just a short time period of collected data, but the trend illustrates the rise in average outage duration. Many utilities have invested significantly in their grid hardening and resilience programs, yet the SAIDI trend, reflecting the average duration of outages, continues to increase. This increase is likely due to the rise in catastrophic events and the magnitude of these events when they do occur.

When a storm occurs, the priority of the utility or power grid operator is to restore power and rebuild the network. Temporary solutions are often deployed to get power back in the short term, while long-term grid-wide restoration and resiliency planning also occurs during and after the post-storm process. Overall community safety during a storm and resiliency after a storm is closely tied to the condition and status of the electric power grid, and operators must realize this when prioritizing reliability and resiliency grid investments for rebuilding after a storm.

3.2 Technology Overviews

The rest of this overview section describes key technologies discussed in this document, noting their ability to contribute to a more resilient electric grid.

3.2.1 Smart Grid Solutions

Rebuilding the electric power system should incorporate the use of smart grid solutions—information and communications technologies with built-in computing power and automation, such as smart meters and high tech sensors—to isolate problems and bypass them automatically. These technologies provide resilience and flexibility to grid operators and help power restoration efforts after a storm.

By integrating information and communications technologies into the electric grid, utilities can minimize the frequency and duration of outages, immediately identify affected customers, shunt electricity around downed power lines to increase public safety, and reroute power across available line to enable faster restoration of services. For example, when disturbances are detected in the power flow, modern circuit breakers can automatically open or close to help isolate a fault. Much like a motorist using their GPS to find an alternate route around an accident, this equipment can automatically reroute power around the problem area so that electricity continues to flow to other customers. Smart grid solutions also enable utilities to protect the electric grid from cyberattack.

The following smart grid issues and options are discussed in this guide:

- Smart meters can function as both metering devices for revenue purposes and as outage sensors, communicating across meters to track outage locations and communicate this information back to the utility or distribution system operator. A few of the latest, most advanced meter options from providers such as Itron can identify outages as accurately as between two meters on the distribution network.

- Historically, the primary drivers for smart meter deployment have been cost reduction and energy savings related to the cost of manually reading meters. More recently, advanced metering infrastructure (AMI) deployments targeting the reliability and visibility benefits of using smart meters as outage sensors have increased.
- By leveraging a network of smart meters, utilities can identify affected outage areas and cut power in certain areas to minimize the risk of fire or injury, and enable demand response (DR) to manage customer electricity consumption in response to a stressed distribution system.
- Another benefit of smart meters is verification of power restoration, which is accomplished when a meter reports in after being reenergized. This response provides automated and positive verification that all customers have been restored, there are no nested (isolated) outages, and associated trouble orders are closed before restoration crews leave the areas. With modern AMI infrastructure, power restoration signals can be sent to the utility either immediately or as part of a 15-minute time-interval report.
- Distribution automation (DA) systems can reduce outage times by automatically detecting a fault, isolating the faulted section from the grid, and restoring service to the unfaulted sections. Specialized products such as S&C's IntelliRupter can detect faults and interrupt the power flow to minimize the affected area and maximize unaffected network uptime. Integrated distribution management systems (DMSs) and advanced distribution management systems (ADMSs), together with AMI deployments, provide control room operators with real-time information on outages rather than waiting for customers to call.
- If sections of the power grid are still operational after a major storm or weather event, a fault location, isolation, and service restoration (FLISR) system integrated into an outage management system (OMS) SCADA system, or ADMS can restore power to unfaulted portions of the line in seconds, and sometimes fractions of seconds.
- FLISR systems in tandem with advanced distribution automation (ADA) systems controlled with advanced distributed and centralized software platforms such as ADMS enable efficient grid restoration.
- Modern reclosers have shortened dead time during auto reclosing, include voltage and current sensors, and can be equipped with intelligent controllers.
- Another component of smart grid is flood-resistant fiber optics, which can be used to measure current, temperature, and other critical line characteristics.

3.2.2 Microgrids, Energy Storage, and Other Distributed Generation Systems

When power interruptions occur, microgrids, energy storage, and other distributed (i.e., decentralized) generation systems can ensure continued operation of critical facilities. A microgrid, sometimes referred to as an electrical island, is a localized grouping of electricity generation, energy storage, and electrical loads. Where a microgrid exists, loads are typically also connected to a traditional centralized grid. When the microgrid senses an outage, it disconnects from the central grid and uses its own generation and storage capabilities to serve the local electrical load. In critical situations, microgrids can direct power to high priorities such as first responders, critical care facilities, and hospitals.

Microgrid generation resources can include natural gas, wind, solar panels, diesel, combined heat and power (CHP) systems, fuel cells, batteries, or other energy sources. A microgrid's multiple generation sources and ability to isolate itself from the larger network during an outage on the central grid ensures highly reliable power.

The effectiveness of microgrids is further enhanced through energy storage. Storage systems not only provide backup power while the microgrid's generation sources are coming online, they can also be used to regulate the quality of the power and protect sensitive systems like hospital equipment that may be vulnerable to power surges during restoration efforts.

Microgrids offer additional advantages. Surplus power from microgrids can be sold to the central grid or stored for later use. In combination with energy storage and energy management systems (EMSs), microgrids can provide ancillary services to the broader electric grid such as voltage and frequency regulation. Microgrids reduce dependence on long distance transmission lines, reducing transmission energy losses. Also of increasing importance, microgrids can mitigate the effects of cyberattacks by segmenting the grid.

Microgrid, energy storage, and distributed energy systems discussed in this guide include the following:

- Microgrids are essentially miniature versions of the electric grid that include localized generation and storage. Localized and increasingly clean generation allows microgrids to provide power to campuses and small communities independent of a macrogrid. These stability islands can keep whole communities of ratepayers warm, fed, and safe and allow first responders to start their work sooner.
- A microgrid can coordinate a network of backup generators ensuring optimum fuel use.

- Microgrids can tie in alternative energy sources such as wind and solar, gas turbines providing CHP, and energy storage systems. They also have the ability to automatically decouple from the grid and go into island mode.
- A successful microgrid must have intelligent methods to manage and control customers' electrical loads.
- University campuses, military bases and other federal facilities, hospitals, large research and data centers, industrial parks, and wastewater treatment plants are good candidates for microgrids because they typically have a common mission and are managed by the same organization.
- Microgrids are appropriate for a densely populated urban area, such as Manhattan, where the concentration of energy use is high and significant scale justifies connecting multiple buildings as part of a microgrid network.
- New energy storage system designs offer safer and longer operational lifespans, and allow customers to install large battery systems that provide emergency power to critical functions when the grid fails. Equally important is their capacity to produce revenue and reduce costs during normal operation.
- Advanced technology battery systems have already proven their ability to nearly double the efficiency of the diesel generators they support.
- Energy storage systems can reduce thermal strain on the grid during peak load periods and provide a reliable backup power supply in the event of a major storm, other natural disaster, or cyberattack.
- Emergency relief centers can be sustained during outages by incorporating advanced energy storage systems.
- A fleet of large-capacity energy storage units distributed throughout the grid can support hundreds of homes, small businesses, and critical infrastructure during an outage. When combined with a community's renewable generation resources, the resultant microgrid is capable of operating for many hours or even days.
- For most facilities with the need to maintain power throughout every type of grid disruption, CHP, also commonly referred to as cogeneration, should be considered. CHP captures waste heat from the generation of electricity (typically by natural gas turbines) to provide heat and hot water, steam for an industrial process, or cooling for a data center. CHP is more energy efficient than producing electricity and heat separately.
- Integrating advanced battery storage systems with CHP has the potential to create a safe, resilient, and efficient energy campus microgrid.

3.2.2.1 Backup Generation

Onsite backup power provides a reliable and cost-effective way to mitigate the risks to lives, property, and businesses from power outages. For many facilities including hospitals, educational facilities, and assisted living facilities such as nursing homes, there is a life safety aspect to consider, requiring backup onsite generation.

Other facilities, such as cell tower sites, emergency call centers, and gas stations, have far-reaching impacts and availability is critical. For businesses with highly sensitive loads such as data centers and financial institutions, the economic cost of outages is higher than ever before. Backup onsite generation is an option for these facilities to mitigate outage risks.

Traditionally, diesel and natural gas generators are used to provide long-term backup generation. When combined with energy storage, continuous power can be provided without disrupting even the most sensitive medical and electronic equipment.

The following backup generation issues and options are discussed in this guide:

- Onsite electrical power-generating systems are readily available in a wide variety of designs for specific uses and customer applications.
- Remote monitoring and control systems that allow an operator to check the system status and operate the system remotely are becoming more commonplace.
- It is important to consult building codes for emergency power requirements.
- The overall cost and ease of installing backup generation depends on the layout and physical location of all elements of the system—the generator set, fuel tanks, ventilation ducts, accessories, etc.
- Backup systems need to be designed for protection from flooding, fire, icing, wind, and snow.
- Emissions and US Environmental Protection Agency requirements should be considered at the early stages of backup power decision-making.
- Lack of adherence to a preventative maintenance schedule is one of the leading causes of failure of a backup power system.
- It is important to work with a power generation firm that can help assess backup power needs to ensure the optimal backup power system is selected.
- It is prudent to have sufficient emergency generator fuel on hand to allow at least 48 hours of operation or as required by code.

- Florida requires some gas stations to have generators to run pumps in the event motorists need to fuel up for an evacuation.
- Generators must be connected properly; improper connections can result in electrocution, carbon monoxide poisoning, or fires.

3.2.3 Wiring, Cabling, and Components

For critical equipment, cabling resistant to long-term submersion in water and oil and other pollutants potentially present in flood waters that may affect less robust insulation materials should be used. In addition, classes of transformers, switches, and enclosures are designed to be submersible. Initial equipment installation can be more expensive than non-submersible equipment, but it can pay for itself in subway systems and substation environments that are susceptible to flooding.

Water-resistant wiring, cabling, and components issues and options discussed in this guide include the following:

- For cities where much of the power infrastructure is below street level, install submersible transformers and switches.
- Deploy switchgear specially designed for subsurface application in vaults resistant to flood waters containing contaminants.
- Medium voltage (MV) switchgear, especially for electrical substations, is available in gas-insulated form, which means that all electrical conductors and vacuum interrupters are protected from the environment. This type of containment makes MV switchgear conductors resistant to water contamination.
- In the rebuilding effort following a major storm, the question of how to rebuild existing circuits and which wiring and cables to install are key considerations, arguably the most important considerations from a cost perspective.
- Installing wire and cable that have specific performance characteristics (e.g., water-resistant or ruggedized) and using installation methods that reduce exposure to the elements (e.g., relocation, undergrounding, and redundancy) can improve an electrical system’s protection from storm damage.
- Damage to cables occurs because the flooded wiring is not designed to withstand submersion in water. The answer is to use robust wet-rated cables indoors in any areas that can be exposed to flood waters.
- When upgrading line capacity, storm hardening existing lines, or installing new lines, installers can benefit from using underground high voltage cable systems that have a history of high reliability and are largely immune to high winds and flooding.

- Covered aerial MV systems can greatly improve the reliability and reduce the vulnerability of overhead distribution during major weather events.
- Self-healing cables limit minor insulation damage to underground 600 V cables. Channels between insulation layers hold a sealant that flows into insulation breaks and seals them permanently, preventing the corrosion failures that typically occur with exposure to moisture.
- Using wet-rated products in industrial and commercial applications, especially in critical circuits, can reduce the time and cost of restoring operations after flooding.
- Residential wiring in basements and other vulnerable areas can be made more flood-resistant by substituting a wet-rated product for the commonly used dry-rated one. This substitution may allow power to be restored to residences more quickly without extensive wiring replacement.

3.2.4 Equipment Relocation or Repositioning

Another smart use of rebuilding funds is relocating or repositioning equipment or power lines. In light of the devastation caused by recent floods and storms, it is time to evaluate the location of critical infrastructure and identify situations where investing money today will protect vital equipment from future storms.

The following relocation and repositioning issues and options are discussed in this guide:

- The National Electrical Code (NEC) requires risk assessments for mission-critical facilities. An important part of the risk assessment is evaluating the positioning of critical equipment. For instance, are backup generators elevated aboveground so they are safe from water in the event of flooding? Are the pumps supplying fuel to the generators also located aboveground so it is still possible to fuel the generators in the event of flooding?
- A simple cost-effective idea is to elevate standby generators at sites prone to flooding to higher elevations. This concept is particularly important when installing new equipment and substations.

3.2.5 Disaster Recovery Planning

After a disaster, power should be restored to the most critical services first. Planning efforts should also carefully consider safety issues that can emerge when recovering from flooding.

Disaster recovery planning issues and options discussed in this guide include the following:

- Electrical equipment that has been submerged should never be reenergized without being thoroughly inspected. Equipment that has been submerged is likely to have debris disrupting its operation and damaged electrical insulation that can cause fires and shock hazards when the devices have been energized.
- All circuit breaker manufacturers require they be replaced after being submerged.
- Perform a pre-crisis risk mitigation audit and identify ways to minimize vulnerability in the event of a disaster.
- Train employees so they know what to do. Make sure they understand that flood waters conduct electricity.
- Engage a qualified first response service provider prior to an outage event with experienced personnel for the equipment at your facility.
- Identify sources of equipment repair and replacement.
- Plan for communication system failures.
- Install premises-wide surge protection to protect sensitive loads from pulses during power restoration.
- Install advanced arc-fault and ground-fault protection to remove power from storm-damaged circuits so that power restoration does not cause fires and electrocutions.
- Benefits to upgrading rather than replacing flood-damaged components include availability, new technology, and long-term reliability.

Section 4

Smart Meters Are A Key Tool for Outage and Disaster Recovery

4.1 Introduction

The original smart meter was perhaps the most transformative addition to the global smart grid since its inception. The ability to remotely read usage information and communicate with electric meters improves utility revenue streams, provides clarity and transparency in customer energy usage, and streamlines field operations, among other benefits. Smart meters have also grown into one of the most polished business cases to deploy advanced communications networks across smart grids. Each meter is both a data collection point and a communications node, enabling greater returns on utility investment while maximizing benefits provided to utilities and their customers. Smart meters have the highest deployment rates of any smart grid technology, and the global market, though slowing slightly, continues to expand.

Over the last decade, smart meter technology has been installed for millions of residential and commercial users in the US. For much of the industry, the primary business drivers for deployment have been cost reduction and energy savings associated with eliminating the need to manually read meters with a truck roll. The cost reduction business case is clear, but smart meters bring significant additional benefits for outage mitigation and disaster recovery. Advanced meters can include remote control switches for power disconnect, identify outages with last-gasp communications, disconnect power, and measure time of use without the need for physical visits.

AMI and smart metering technologies are not primarily deemed grid hardening or resiliency tools and lack active restoration capabilities. The technologies can, however, provide utilities with visibility into their distribution networks at a granular level. Meter-detected outages in some locations can be used by utilities to predict the effects of future events. Many meters are edge computing devices equipped with hardware and software that enables the meter to function as an outage sensor. These meters can communicate with each other, eliminate false outage alarms, and locate outages down to between two connected meters. The meters feed this data directly back to the utility, which can dispatch crews to repair the outage at the pinpointed location rather than scour the network to locate it with truck rolls from customer phone calls. This process can reduce distribution outage duration by 50% compared with traditional smart metering. Even the simplest AMI meters act as communicating sensors and become part of an automated, visible distribution network as soon as they are installed.

Additional AMI capabilities are being developed by major vendors such as Itron, Honeywell, and Landis+Gyr, and functionalities will eventually include active load and voltage control for both the supply and demand side of customer meters, active DR, and integration with other networked DA devices such as FLISR and Volt-volt/volt-ampere reactive (VAR) optimization (VVO).). The most advanced meters will be able to continuously calculate and analyze loads on individual distribution transformers, comparing the load with the stated capacity of the transformer. By communicating with other meters on the same transformer, the meter can identify when the transformer is getting close to overload capacity or if there is a storm-related outage. If the meter determines action must be taken, it can shut off controlled loads behind the transformer, increase local distributed generation (DG), divert the load to other transformers on the connected network, act to protect the transformer, or alert the utility to the customer outages. As the distribution grid continues to evolve, the importance of smart meters will continue to grow as a significant part of a successfully resilient and reliable distribution network.

4.2 Example Scenarios

As a storm rolls in, utility managers begin to prepare. They start by comparing real and reactive power measurements on commercial and industrial (C&I) meters to see which commercial customers are still running large inductive loads. These loads indicate the activity of large electric motors and which factories are running or shutting down. Smart meters provide these measurements over short periods, sending information back to the utility as often as every few minutes, allowing utility managers to see which motor loads are shed prior to a storm. Information on factory shutdowns can be forwarded to public disaster coordinators.

Next, utility managers verify that known vacant buildings and houses have been disconnected from the grid by sending messages to smart meters. This action helps to prevent fires in case of major structural damage that would otherwise go unreported. If circuits are still active, disconnect commands can be sent to properly equipped smart meters and executed within seconds.

As the storm blows through, inevitable power outages begin to occur as power assets are disrupted. In some cases, distribution feeders are cut and power is restored automatically with DA and reroute systems. In other cases, distribution feeders are completely disrupted and power is lost. In still other locations, individual drops are cut or transformers or other assets are damaged. Much of the distribution network nationwide has little or no instrumentation, which makes distribution outages difficult to detect and manage without customer input. However, that inevitably creates a scenario where utility operators are overwhelmed by waves of information from telephone calls, first responders, and their own crews. It is difficult to prioritize the work or to even know what kind of crew to dispatch to a particular location, even once the outage has been located within a broad area of the network.

Smart meters bring potential solutions to many of the problems outlined in the scenario above. Smart meters use capacitors or batteries to store sufficient energy to send out a last-gasp message in the event of power loss. As this information is collected and analyzed, a clear picture of the various outages begins to emerge. If a large group of meters goes out at the same time on the same distribution feeder, the utility can use the data from the meters to ascertain whether or not it is likely the feeder is damaged. Likewise, if all meters on a particular transformer or particular street report outages, the problem can likely be isolated to that location, especially if there is a known storm or other weather event in the area.

Smart meters can even be used to detect disruptions to individual drop wires if neighbors still have power. More importantly, these disruptions can be located, analyzed, and acted on more rapidly and more accurately than waiting for customer phone calls. This allows the utility and emergency coordinators to know where power is out and predict when it will be restored down to individual addresses.

In particularly bad situations with significant building damage, emergency coordinators may need to cut power to certain areas to minimize the risk of fire or injury due to energized lines until they can be inspected. With the use of smart meters, power can be shut off remotely to individual addresses reported by emergency personnel.

If generation or feeder capacity is adversely affected during the storm, the utility may choose to shed load by implementing a DR system. This system enables the utility to send a message to turn off water heaters, air conditioners, and other appliances on a temporary basis. Normally, DR systems are offered to consumers in exchange for favorable rates to balance and level loads; however, during a disaster situation, these same tools can be used to reduce the load on an otherwise stressed distribution system. Smart meters enable this capability by providing the communications path for the utility to send load commands to consumer appliances and verify their execution.

During the restoration phase of the disaster, smart meters are critical in reporting the resumption of power. Often there are nested outages in an area. When a utility crew notifies their dispatcher that power has been restored, it is a simple matter to verify that all smart meters in the area are responding appropriately, but often a second, hidden outage is exposed deeper in the neighborhood by the smart meters. If that is the case, the utility crew can easily fix it while still onsite rather than dispatching another crew later.

Smart meters are critical during disasters and during recovery. In preparation for an emergency, they can be used to disconnect empty buildings and detect large motor loads. During the disaster, smart meters provide practically real-time views of outages and disruptions before they are reported by consumers. The visibility they provide greatly reduces restoration time by giving operations personnel, field crews, and emergency coordinators a view of the restoration process.

4.3 Single Outage Events

Customers often call their electric service provider when they have problems with service in their homes. Some of these calls come as a result of a larger outage or utility problem. Many other calls are received for single customer outages where the problem exists on the customer's side of the meter. Without a smart meter, these individual custom outage situations are resolved through a phone conversation with the customer or, more often, a trip to the customer's residence.

Smart meters allow the utility to better understand if the outage is related to the utility service or a problem within the customer's premises. The utility can then take the proper action to resolve the problem in a timely and cost-effective manner. Smart meters provide power status information automatically and on request. The automatically generated information includes the power fail indication when power is lost and power restoration indication when power is restored. A Midwestern utility has benefitted from this capability since installing smart meters—it eliminated almost all unnecessary no lights trips and helped customers address problems more quickly.

4.4 Multiple Outage Events (Storms)

Multiple outage events come in just about every size and shape—from a single fuse to a massive outage caused by a major event such as a hurricane or an ice storm. All such outages have a negative impact on customers. Performing timely repairs and restoring service is a top priority for utilities. To restore power as efficiently as possible, the first step is to understand the scope of the current power outage. Most utilities use OMSs to leverage all available information, such as customer phone calls, to define the number and location of affected customers. On top of OMSs, utilities can use their ADMSs to further enhance the benefits provided by smart meters.

4.5 Summary of Outage Management Improvement Benefits

Prior to smart meters and more advanced technology, the only input to an OMS was customer phone calls or a utility's inspection crews. Customer phone calls will always be important, but in general, less than 20% of affected customers will report an outage for a variety of reasons (e.g., not being home or assuming that the outage has already been reported). As AMI gathers and sends data, the meter data management system (MDMS) and the ADMS process and analyze it using the tracing and prediction analysis functions of a real-time distribution network model to determine the impact. The OMS or ADMS can then predict or derive the scale, scope, and location of the outage and dispatch appropriate crews to restore service based on the information available.

Smart meters send a last-gasp message to the utility's MDMS, ADMS, DMS, or OMS before the meter loses power. Not all last-gasp messages make it through to the receiving destination, but usually enough messages are received to help the utility adequately determine which customers are affected. Smart meter outage data can increase the accuracy of outage predictions and help utility personnel to readily and accurately react to problems. The end result is customer power restored more quickly, and utilities operate more efficiently with decreased and streamlined outage restoration costs.

Another benefit of smart meters is power restoration verification. Restoration verification is accomplished when a meter reports in after being reenergized. This report provides automated and positive verification that all customers have been restored, there are no nested outages, and associated trouble orders are closed before restoration crews leave the area, reducing costs, increasing customer satisfaction, and further reducing outage duration.

During a major event and prior to smart meter technology, it was common for utilities to dispatch crews to restore service to a customer whose service had already been restored. Utilities maximize the value of smart meters for service restoration through automated integration with AMI and OMS. This integration provides utility personnel the ability to visualize the full scope of damage and perform service repairs efficiently.

Utilities can use smart meters to determine if an outage is within the utility's infrastructure or at a private residence, reducing unnecessary and expensive truck rolls. By gathering data from smart meters, utilities can quickly locate and repair utility-side problems. They use smart meters to find nested problems often caused by severe weather events. Benefits include reduced traveled miles, especially during severe weather, which improves worker safety and reduces carbon emissions from vehicles.

4.6 Outage Avoidance

Utilities, their customers, and their regulators all want to reduce the number and duration of power outages. Strategies and practices that reduce the number of sustained outages include trimming trees, maintaining the grid, and deploying automation to restore service. Smart meters report many abnormal events, such as momentary outages on a per-customer basis; these outages are often a precursor of a grid failure. This information can help a utility predict where a future sustained outage might occur and be better prepared when it does occur.

Auto reclosing equipment, such as circuit reclosers, track the operation count, but it is often difficult to correlate these counts to the number of actual events and problems. By collecting detailed momentary outage data on a select number of meters, utilities can identify the number of events and pinpoint locations where there is a lot of activity. By mapping momentary data, utilities can determine where additional tree trimming might be needed or where some equipment may be defective. Utilities can then take corrective action to eliminate the problem and prevent a possible sustained outage. If a utility is looking to improve its outage avoidance capabilities, then it must add mapping and analytical applications to maximize the value of smart meter data. These mapping and analytical applications are available but not yet widely deployed for this particular application.

4.7 Accurate Mapping

Once an area has been fully equipped with communicating smart meters and the relevant MDMS or ADMS, the meters can create a digital map of the grid it serves and verify the electrical phase to which a single-phase smart meter is connected. Smart meter data can then be used to verify and correct the utility's electrical maps in its OMS. It is essential that the relationship between a smart meter and its electrical circuit is correct to ensure the OMS predicts the scope of the outage correctly. Accurate understanding of the phase a meter is connected to will also improve the single-phase loading, leading to better asset utilization.

4.8 Outage History and Reliability Metrics

Smart meters timestamp all power-up and power-down events, meaning precise outage times and durations can be calculated. Utilities can use this information to more accurately calculate their reliability metrics (SAIFI, CAIDI, SAIDI, etc.) and identify overall performance and the best and worst performing circuits. Utilities can then develop the most cost-effective action plan for future grid modernization investments.

Grid resiliency, energy efficiency, and operational optimization have always been strong drivers for utilities. When integrated with ADMS, DA, and grid reliability programs and technologies, investments in AMI allow utilities to further reinforce and strengthen critical utility infrastructure before and during storms, reducing restoration costs and minimizing customer outages.

Section 5

Preparing and Restoring Power Grids Using Smart Distribution Technologies

5.1 Introduction

The growth in frequency and strength of natural disaster and climatic events poses a direct threat to the energy infrastructure, with large-scale power outages becoming more common place. The increase in outage frequency corresponds to a rise in repair and response costs for utilities to restore electric grids. The cost of outages is higher today than ever before because of society's and businesses' reliance on computers, electrically powered technology, data centers, and other critical infrastructure. While the trend of increasing storms may not be redirected, the resulting outages and corresponding costs and overall negative community impacts can be mitigated through the integration of digital and intelligent resiliency technologies, especially on the distribution networks.

The grid itself is the primary beneficiary of the delivery and installation of new, innovative technologies designed to help utilities mitigate and respond to outages and storm damages. These key technologies, including many discussed in this section and throughout this reconstruction guide, can minimize interruptions during an extreme weather event by effectively managing unplanned outages and enhancing the restoration of energy infrastructure after a storm, lessening the effect on human life and critical infrastructure.

5.2 Smart Distribution Solutions for Restoring Power Grids

The electric industry introduced the term smart distribution to classify some of the challenges facing electric distribution utilities. It covers fundamental requirements to maintain grid reliability and enable more efficient restoration from severe storms and other natural disasters. Smart distribution supports the concept of self-healing and autonomous restoration: the ability to restore healthy sections of the network after a fault without manual intervention. Smart distribution also enhances security of supply and power quality: the ability of the distribution grid to maintain supply to customers under abnormal conditions and deliver a quality of power that meets customers' needs.

Lessons learned from recent restoration efforts have created opportunities for new smart grid technologies. Examples from Hurricane Harvey and Puerto Rico provide important insights into preparing for and recovering from storms. At the core of the Puerto Rico recovery process was communications—it began within the organization and continued with field personnel and customers.

Keeping stakeholders informed helped significantly in saving lives and restoring electric service. Customers with smart phones were able to receive updates from their utilities and, in some cases, were also able to help utilities locate trouble spots. Communication between the utility control room and the field personnel was critical in assessing the damage and understanding the options for reestablishing service. After major storms across the country over the last several years, mutual assistance programs brought field personnel from all over the US to help with the restoration. Keeping communication infrastructure working is critical to efficient storm recovery efforts.

As part of grid modernization and reliability projects, utilities have had an opportunity to take a fresh look at how they could benefit from new technologies and simultaneously solve some of the weaknesses in their current operational IT systems. One area that has seen significant growth is in systems designed for control room operations. ADMS can include SCADA, distribution management, outage management, distributed energy resources (DER) integration, and meter data management modules on a single IT platform.

ADMS provides real-time situational awareness of the electric grid and customer outages and is accessible by field personnel during the restoration process. ADMS can integrate with smart meter data from the MDMS to provide control room operators with real-time information on outages and customer load profiles. Connecting with these meters from the control room allows operators to check for service restoration and power quality and notify customers via phone, email, or social media.

ADMS also includes advanced grid optimization applications for locating faults and automatically restoring the distribution through FLISR installations. FLISR is capable of working in tandem with DA equipment being deployed as part of a utility and grid modernization initiative. For sections that require manual intervention for restoration, ADMS provides additional information to help guide field personnel to the approximate location instead of having them locate the fault manually, reducing customer interruptions. Seamless FLISR integration with DA enables efficient restoration of the grid in what previously would have been a tedious and manual process. This integration significantly reduces the field rework required from recovery efforts that involve outside utility crews that may not be well versed with the local utility's procedures.

Another key application is integrated Vol/VAR control (IVVC), which provides conservation voltage regulation (CVR); CVR energy efficiently enables the shift or reduction of peak load while maintaining grid operations within regulated limits. CVR can be critical for utility restoration efforts when energy supply has been disrupted because of generator outages or loss of critical grid corridors. Volt/VAR control is an important function in grid modernization initiatives, as the functionality allows for smoother integration of renewable generation and DER.

ADMS platforms can include a distribution operations training simulator (DOTS) that is used to prepare control room operators and engineers to manage restoration efforts after severe storms. DOTS can recreate scenarios from previous storm events including simulating customer calls and smart meter power-off messages, providing a real-life simulation environment. DOTS can also be used to prepare the distribution grid for a storm by studying switching plans to safely island or disconnect portions of the grid, preventing further degradation during a storm and enabling faster restoration after the storm.

5.3 Smart Distribution Equipment for Restoration

New capabilities and functionality of existing devices can provide alternatives for automated system restoration and faster recovery from the effects of natural disasters. The recloser, which is typically deployed as part of critical DA upgrades, is a switching device intended to interrupt load and fault currents. By shutting off multiple times in a predefined sequence, the recloser can promptly repair service after a temporary fault. Traditionally, their role is to provide overcurrent protection, and they are typically installed in the distribution feeder.

Recloser locations are optimized to protect portions of the distribution system where faults are more prevalent to improve service reliability. Their ability to interrupt the fault and reenergize closer to the fault location allows for service continuity upstream. They can also be used to configure the distribution network in loops when used as a normally open tie device to increase operational flexibility. Some modern reclosers simply send energy pulses onto the network to determine a fault current instead of opening and closing the circuit multiple times each time a fault current is detected.

Modern reclosers have increased fault current interrupting ratings and shortened dead time[4] during auto reclosing. Because of their higher current capability, reclosers are being installed closer to or at the substation. Reclosers are also now capable of dead times in the range of 100 ms, allowing for brief service interruptions. Nevertheless, the reclosing time should be long enough to allow for the fault to clear.

Reclosers can be three-phase or single-phase operated. Most faults in a distribution network are single-phase faults. The development of single-phase reclosers allows for opening and reclosing of only the faulted phase. Single-phase tripping and reclosing increases service continuity, allowing temporary operation

[4] Dead time is defined as the interval between current interruption in all poles in the opening operation and the first reestablishment of current in the subsequent closing operation.

with only two phases. Furthermore, single pole-operated reclosers can perform controlled closing operations. In a controlled closing, each phase in the network is energized at optimum time instants to reduce transient voltages and currents. The optimized time instancing reduces stresses on network equipment and sensitive loads during service restoration.

Modern reclosers include voltage and current sensors. They incorporate two-way communications and can be equipped with intelligent controllers. These features allow for additional functionality and capabilities. Voltage and current measurements enable the implementation of additional protection schemes including directionality (discrimination of the faulted side) and under/over voltage protection. They also enable fault monitoring (success in fault clearing, outcomes of reclosing operations, accumulation of fault history, fault records of current and voltage) and load monitoring.

Two-way communication allows remote command transmission, status reporting (open or closed), and transmission of events and data. Communication allows integration of the recloser to the SCADA system and then potentially onto the ADMS platform for further integration and analysis. Intelligent controllers contain operational logic, estimate the remaining life and condition of the device, and can be programmed remotely for flexibility and changing conditions. They can also be programmed to store, send, and receive data and commands.

A large storm or other meteorological event can cause multiple faults within a short time in the distribution system. Some faults are temporary and can be cleared by reclosers, others are repetitive, and some are permanent. The maximum number of allowable reclosing operations may be exceeded during repetitive or permanent faults. In this situation, multiple reclosers are locked open, leaving feeders and sections of the distribution system without power. During and after a storm, a group of intelligent reclosers can be programmed to operate in a predefined sequence to automatically restore service to sections of the distribution system that have not been permanently affected. Information captured by the individual controllers during the event can be transmitted and analyzed at a central location to assess the network condition. This allows for optimization of resources and line crews needed to repair portions of the network affected by permanent faults and reduces the recovery time.

5.4 Short-Term Investment for Long-Term Advantage

Extreme weather events and their associated effects are causing electric utilities to question their current technological and operational systems. As essential components of a more intelligent power grid, integrated DMSs have proven to support storm preparation and restoration and reduce service interruptions. The initial cost to invest in smart grid systems and equipment is offset by reduced overall cost implications each time a storm occurs. These technologies can also dramatically lessen the effect on human life and critical infrastructure. Electric utilities that have invested in smart grid technologies can better prepare their personnel, manage their grids, increase customer satisfaction, and meet their regulatory objectives.

Section 6
DA for Resiliency and Reliability

6.1 Distribution System Susceptibility to Severe Weather Events

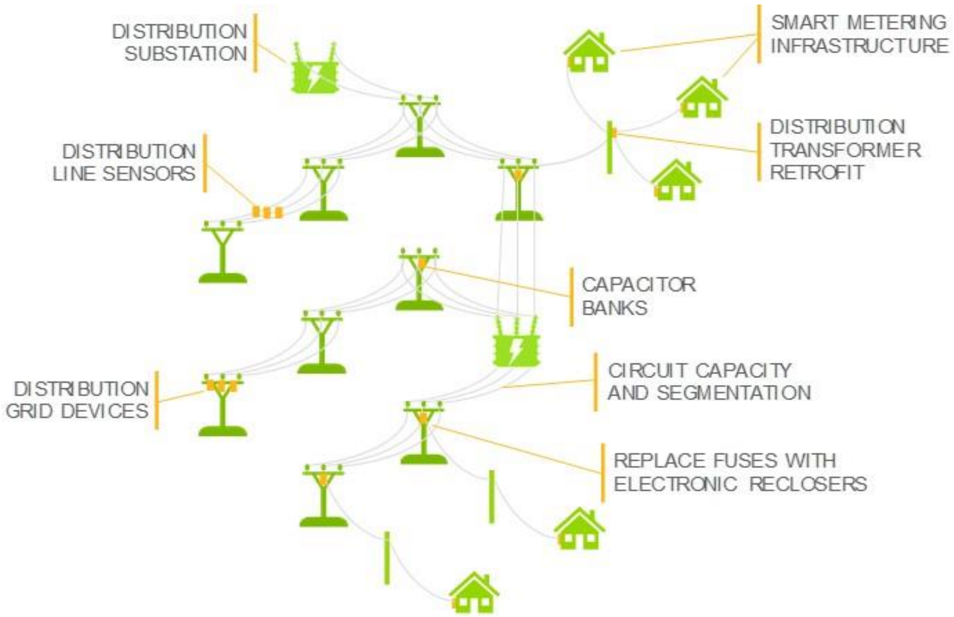
The distribution grid is among the most critical and dynamic pieces of the modern electric grid. It is also perhaps the fastest changing. Over the next decade and beyond, utilities will make significant investments in their distribution grids and specifically in DA designed to improve network performance and mitigate the effect of outage events such as the growing number of storms and natural events. Across all types of utilities, ranging from large investor-owned utilities to small and midsize cooperatives and municipal electric companies to distribution systems operators (DSOs), the importance of DA remains the same. Ratepayer, regulator, and stakeholder demand for improved reliability and resiliency is driving much of this investment, and the increasingly widespread deployments of DER is further growing the market.

DA gives utilities and DSOs enhanced control over and visibility into their grid and its performance. In addition to the grid transformation, customer requirements and expectations are evolving in a way that will further propel the market for DA technologies. Outages, regardless if they result from storms or not, are becoming less acceptable; utilities are often incented for improved network performance; and utilities need to manage the challenges of operating with an often-dwindling revenue stream. Global and regional electricity markets are also increasingly deregulated, creating competition among service providers and motivation for strong network performance.

Guidehouse Insights estimates that approximately 90% of outages occur on the distribution grid, and this figure is critically important when assessing the effects of DA on storm restoration and resiliency solutions. Historically, distribution grid investment has been reactive, with utilities responding to failing assets, financially damaging outage metrics, and a 40- to 50-year-old grid. Utilities must take a proactive approach toward distribution grid enhancement in anticipation of a foundational change in business models, and a shift to a grid required to support supporting intermittent renewables, shifting loads, capacity constraints, and bidirectional power flows. DA is often the first and most important step.

Below is a graphic that illustrates the critical sections and components within the modern distribution grid. Each one of the segments listed enable various automation schemes that can bring resiliency and reliability benefits to the electric grid and its customers.

Figure 6-1. Distribution Network Overview



(Source, Guidehouse Insights)

Due to the exposed nature of the networks, the overhead distribution system is vulnerable to severe weather events such as hurricanes, wind, rain, lightning, ice, freezing rain, and snow. These events can challenge the electrical distribution grid's resiliency and may result in power outages. Additional instrumentation and automations systems on the distribution grid will help with reliability and can help to restore services when there is an outage event.

Because of this vulnerability, consideration is often given to moving circuits underground. However, underground systems are significantly more expensive than overhead systems and are not immune to the effects of weather. Flooding can quickly overwhelm vaults and related underground facilities, leading to significant outages. Repairs with underground outages are typically more complex, more expensive, and result in longer restoration times.

6.2 Leading Practices and Distribution Grid Maturity

Utility distribution grids are operated using a wide range of systems. A common model is to use a manually operated system from the substation breaker to the line disconnect switches. The most advance systems include networked and communicating protective relays and controllers at the station and at strategically selected points controlled by advanced automation software and under remote dispatcher supervision.

To maximize the benefits and minimize the costs of DA systems, utilities often integrate them into rate cases, grid modernization initiatives, and other regulatory proceedings. They deploy varying automation levels depending on the criticality of the load, the number of customers served, and technical factors such as available communications infrastructure and existing levels of remote control. These systems can typically be capitalized. As long as the utility ROI leads to benefits for the ratepayers, utilities can typically receive approval for DA and distribution grid modernization projects. Most utilities also attempt to match the level of automation to consumers' willingness to pay for higher levels. In some markets, reliability is of a higher priority than others, and the utility investment in DA typically corresponds with that variance.

The most troublesome circuits are measured in total customer outage minutes and in the frequency of sustained outages. These worst performing circuits are ranked to receive the highest level of automation. Outages associated with overhead circuits occur more frequently than with underground circuits but are typically of a shorter duration.

6.3 Distribution Grid Automation and System Benefits

The most advanced automation systems can reduce outage times by automatically detecting a fault, isolating the faulted section from the grid, and restoring service to unfaulted sections. The distribution operator then directs a crew to repair the problem, restore the service, and return the system to normal. This can reduce the time and frequency of outages and the costs of locating the fault and manually operating switches. These systems can also improve safety for the public and utility workers because faults, such as downed wires, are cleared quickly and utility workers can efficiently manage their work because they can visualize and control much of the distribution grid.

6.3.1 Substation Automation

Many grid resiliency initiatives start and end with the distribution substation. An automated substation is equipped with a variety of sensors and monitoring devices, mechanical and intelligent electronic devices such as switches, reclosers, and protective relays, and an enhanced communications infrastructure designed to recognize an outage and take the necessary actions. Distribution substations contain the most expensive assets on the distribution network and are more commonly monitored and automated than feeders and distribution transformers. The majority of substation automation systems send advanced asset condition monitoring and performance data back to centralized SCADA or ADMSs for analysis and control. Communications for centralized control of a distribution substation is commonly managed with high speed fiber networks.

Approximately half of distribution substations in North America are equipped with some form of automation or a SCADA system. An estimated 10%-20% of these substations are equipped with ADMSs or advanced automation capabilities, and most are centrally monitored. As the industry continues to shift and utilities install centralized and DA systems, these numbers will also rise.

6.4 Advanced Grid Monitoring and Control

Advanced grid monitoring and control gives utilities and DSOs enhanced control over and visibility into their grid and its performance. In addition to the broad digital grid transformation, customer requirements and expectations are evolving in a way that will propel the market for these technologies and their deployments on the electric grid. Outages are becoming less acceptable, utilities are often incented for improved network performance, and network operators need to manage the challenges of operating with an often-dwindling revenue stream. Global and regional electricity markets are becoming deregulated, creating competition among service providers and motivation for strong network performance.

Over the next decade, most utilities around the world will make significant investments in their distribution grids and are expected to focus these distribution grid investments in automation, protection, and control technologies. Ratepayer, regulator, and stakeholder demand for improved grid performance drives much of this investment, and widespread deployment of DER is growing the market. The following sections discuss the most critical advanced monitoring and control technologies expected to transform and provide dynamic resiliency benefits to grids around the world.

6.5 Industry Trends

As with most mature systems, benefits can become increasingly difficult and expensive to achieve. The utility industry continues to look for advances that reduce the cost of saving an outage or an additional outage minute.

The most common advance is further reducing sensor and communication system costs, with elevated sensor benefits and integration with distributed and centralized software platforms. Potential price reductions come from leveraging additional functionality to realize benefits. It is common to use the communications network for other automation functions such as VAR optimization and AMI backhaul. These functions help reduce the infrastructure costs of the communications network.

Some utilities use their AMI systems to detect or verify customer outages, reducing the time to respond to an outage and improving the ability to detect a nested outage. Many utilities also use AMI systems to verify an outage when they receive a no light call, which reduces the costs of validating the outage manually.

Utilities are also using social media to better understand the location of a problem and to communicate with customers. Social media provides a significant amount of data that can be analyzed and visualized by the operators, maintenance, and field crews.

Severe weather challenges the electrical distribution grid's resiliency; however, the commitment by utilities to further modernize the grid can reap the benefits of reducing outage times, improving customer service, and managing costs better. These efforts prepare the utility and its distribution grid for the next big challenge.

6.6 Recommendations

Utilities and grid operators must continue to push the boundaries of grid intelligence and automation to create a more stable, reliable, and resilient grid. Ratepayers, stakeholders, and regulators have increased their demands for an improved grid network in developed regions of the world, while the construction and enhancement of new grids in undeveloped regions will likely drive additional growth. Vendors and manufacturers must continue to innovate and offer utilities and DSOs compelling automation, protection, and control options with a demonstrable ROI in the short and long term.

6.6.1 Recommendations for Utilities

Forced to operate within the current regulatory and financial limitations of the grid modernization landscape, utilities must continue to challenge existing business models and pursue innovative strategies to propel grid performance enhancement. Recommendations for utilities to the successful deployment of DA technologies follow.

- **Target high ROI projects:** One of the most effective ways for a utility to approach any grid modernization initiative is to target the projects with the clearest path to gaining a positive ROI. Current ratemaking constructs allow for a predetermined rate of return on all deployed capital, and utilities can leverage this knowledge to pinpoint the ROI for any given project.
- **Pursue innovative ratemaking practices:** In addition to targeting high ROI projects to accelerate deployment under current ratemaking schemes, utilities can and should pursue innovative ratemaking practices to deploy as much DA as possible. A common alternative to traditional ratemaking is performance-based ratemaking, which is a practice that rewards or penalizes utilities for meeting or failing to meet grid performance thresholds commonly based on the grid indices identified earlier in this report.
- **Focus on high-impact areas of the grid:** When rolling out any grid modernization initiative, utilities should focus on the areas of their grid where upgrades will have the greatest effect on the most customers. Automation solutions will significantly affect heavily loaded distribution grids and those with high exposure to weather and natural disaster events.
- **Automate for the Future – Not the Present:** The energy landscape is undergoing significant transformations, and this change will not stop anytime soon. DA investment must be made with the mindset of preparing the grid for

ongoing energy transformations. Functionalities such as high-speed communications, advanced cybersecurity measures, and flexible integration with ADMS, SCADA, and analytics should all be prioritized; the deployment of equipment without these capabilities should be limited.

6.6.2 Recommendations for Vendors

As utilities continue to grow the market for DA systems, vendors and manufacturers must continue to provide innovative and cost-effective solutions to maximize grid performance. By doing so, they will provide the path of least resistance for utilities toward the adoption of DA solutions, increasing the stability and reliability of the distribution grid while growing as a business and an industry. By following the recommendations outlined below, vendors will be well-positioned in this growing market for DA products and solutions.

- **Provide Options and Be Flexible:** When building a portfolio of DA offerings, it is critical that vendors and OEMs provide utility customers with a variety of options to suit specific needs. In addition to specific and standalone DA products such as reclosers, switches, sensors, and others, vendors must provide integration options for software, communications, and cybersecurity solutions. Without these, utilities are likely to look elsewhere when selecting a partner.
- **Become a Partner, Not Just A Vendor:** Utilities seek partnership in most vendor relationships, and such is especially true for DA deployments. The most successful vendors will be those that can adapt to utilities' needs and provide tailored solutions throughout each phase in a project. Utilities will commonly seek to customize a software platform or array of DA assets to fit their systems best, and vendors should be prepared and equipped for this as well.
- **Develop and Present the DA Business Case:** Utilities are typically only permitted to recover on CAPEX with a clear and positive business case with demonstrable impacts to their grids. Vendors must proactively help utilities formulate and display this business case to regulators, ratepayers, and stakeholders. Metrics for grid performance such as SAIDI, CAIFI, and others should be highlighted, as well as proposals for improved customer experience.
- **Provide Retrofit and New Build Options at Multiple Price Points:** Despite the benefits of a holistically developed grid system overhaul, most utilities approach a grid modernization initiative in phases or as a culmination of a number of independent projects. For this reason, is it imperative that vendors offer DA products and solutions for utilities seeking to both replace and retrofit current distribution grid equipment.

Section 7
FLISR and Grid Integration

7.1 Introduction

Electric utilities often employ a portfolio of software platforms to identify, manage, and restore outages. These systems typically include DMS, ADMS, OMS, among others, and these systems can help utilities determine the location of a protective device that responded to a fault on their distribution system. Such a system can also help utilities prioritize restoration efforts based on the scope of the outage and the number of customers affected.

When a trouble call is received, the utility dispatches a crew to find the site of the problem. If the utility has SCADA capability, it may have an idea of the location but not the exact fuse that blew or how far the fault was from the recloser that locked out. Fault location and power restoration can take 20 minutes to several hours. One North American utility stated that a called-in outage takes an average of 68 minutes to restore. Outage management after an area-wide storm often requires a great many utility crews and a large amount of material. Power restoration can take days or longer.

If most of the distribution system is still functional, a FLISR system, integrated into the DMS or ADMS, or distributed at the grid edge, can restore power to unfaulted portions of a faulted line in seconds. The most recent iteration of FLISR is complex and often involves localized, distributed edge intelligence capable of recognizing faults and restoring power within seconds without communicating with a centralized system. With these advanced FLISR systems, distribution lines are not only monitored but also equipped with enhanced high speed local communications and can communicate with other devices on the distribution network to reroute power over a healthy portion of the network. Some FLISR systems are even communicating with meters and distribution transformer sensors to locate and isolate outages.

When a Fault occurs, reclosers and sectionalizers check the integrity of the network by reclosing, and if there is permanent damage on the faulted network, the fault is isolated by two open switches. Then the FLISR system reroutes power to all customers outside the affected area, and the number of affected customers is greatly reduced. This type of system is viable only if the feeder is looped and not radial, with a normally open point within the circuit. Most modern grid networks are designed this way, but many older networks have radial feeders. On a radial feeder with just one power source, having two connections on each, adding an alternate connection to the end of a distribution circuit allows switching equipment such as reclosers and sectionalizers, maximizing their benefits.

FLISR can reduce outages to mere seconds or less for customers outside the damaged section of line and reduce outage time significantly for those inside the damaged section (dispatch will know exactly where to send the crew to restore power). For the affected outage area, fault location devices without localized intelligence can sense an outage and send the outage and locational data back to a utility's centralized IT platform for analysis. The centralized IT system then sends a command back out to the network to isolate the fault and reroute power over a healthy network. This centralized approach takes longer due to data latency and communications network congestion.

FLISR systems using distributed intelligence offer a key advantage: they can still operate if there is a communication failure from devices in the field back to the utility's central operations. With switching decisions made locally, FLISR systems using distributed intelligence can respond quickly; there is no need to continually transmit data back to central operations and wait for instructions.

The majority of distribution networks, especially in regions with aging electric grids built 40-50 years ago, are not automated and are not equipped with FLISR systems. In most cases, implementation of a FLISR system requires the acquiring equipment to provide sensing and line automation. Several kinds of FLISR systems are available; each can locate and isolate faults without the need for a dispatcher or field crew and can minimize the outage area by rerouting power. Some can only handle a limited number of intelligent electronic devices. Others cannot rebalance load after the system has been reconfigured. The location where restoration decisions are made by the FLISR system can have a dramatic effect on the speed of restoration.

7.2 Centralized FLISR Systems

Centralized FLISR systems use SCADA-enabled switches and sensors located at key points in the distribution system to detect an outage, locate the faulted area, isolate the fault, and restore service to unfaulted areas. Some switching operations can be performed automatically depending on the capabilities of the intelligent electronic devices and sectionalizing devices and the speed of SCADA system communication. In many cases, the system only sends an alarm to the control center that must be acted on by a dispatcher. Restoration can take upward of 20 minutes.

In a centralized FLISR system, secure, reliable two-way data communication and powerful central processing are essential. Point-to-point or point-to-multipoint communication is used with data collected in the distribution substations transmitted back to the FLISR system. New ADMS platforms can be used to enhance FLISR performance throughout the distribution network and incorporate predictive asset performance modeling.

The system individually polls each substation control and intelligent electronic device served by that substation and collects each response before issuing a restoration command. This arrangement is susceptible to a single point of failure along the communication path. The addition of redundant communication paths is usually cost-prohibitive.

Centralized FLISR systems require a large amount of bandwidth to operate. Adding devices on the system creates latency and increased restoration time as the system polls devices and collects data. A point-to-multipoint system can be easily overwhelmed and unable to process information sent from multiple field devices to the control center. So when the FLISR system is needed the most—during a widespread storm, natural disaster, cyberattack, or period of high loading—a centralized system is most likely to experience problems. This is a major reason why distributed FLISR systems are becoming more popular and bring additional benefits over centralized systems.

Centralized FLISR systems can also be the costliest and have the longest deployment time. They require time-consuming integration with the DMS, fine-tuning, and data scrubbing of the geographic information system (GIS) before they are reliable. The higher the level of automation desired, the more logic needs to be programmed into the system, which can make future growth challenging. Further, integrating a centralized FLISR system with an existing DMS or SCADA control system can decrease valuable data processing power and bandwidth that is needed for power flow analysis and supply balance.

7.3 Substation-Based FLISR Systems

Substation-based FLISR systems use logic controls located at the distribution substations; these systems work with fault sensors and intelligent electronic devices out on the feeders. A substation control center or relay house is typically required. Many of these systems can be integrated with substation-based capacitor control or Volt/VAR optimization systems.

With substation-based FLISR systems, sizable load is dropped if substation breakers are used for fault interruption. If reclosers are used for fault interruption, the protection and sectionalization schemes of the intelligent electronic devices must be resolved before the system can begin service restoration. When protection and sectionalization has been completed, the FLISR system polls the intelligent electronic devices in much the same way as with a centralized system, collecting data on the status of each switch before issuing a restoration command.

Substation-based FLISR systems can take 3-5 minutes to restore power to unfaulted sections depending on the settings of the intelligent electronic devices and the distance between the substation controls and the devices. A substation-based FLISR system can have a single point of failure: if the main substation control communication fails, the entire system is offline.

If communication equipment, control power, and a control house are not already available at the substations, adding them can be prohibitively expensive. Substation-based FLISR systems can be complicated to set up, difficult to expand, and lengthy to implement depending on the intelligent electronic devices selected, communication, and desired extent of integration with an existing SCADA system.

7.4 Distributed Intelligence FLISR Systems

FLISR systems with distributed intelligence and mesh networking are the simplest to configure and fastest to deploy. They can be readily integrated into an existing SCADA or distribution automation system, too. These systems typically operate in seconds and can be set up with the ability to self-heal—reroute power and shed nonessential load under multi-contingency situations. Depending on the number of intelligent electronic devices included in the system, a distributed intelligence FLISR system can be up and running within a few days or weeks.

Distributed intelligence FLISR systems offer a high degree of scalability as well. One or two automatic restoration points can be added at a troublesome location on a feeder or the entire distribution system (from the substation on out) can be automated with multiple sources and interconnections. Distributed intelligence FLISR systems can be integrated with a variety of fault detection and sectionalization devices and operate faster than centralized or substation- based FLISR systems. By starting with a few of these devices on the most outage prone feeder areas and increasing their numbers as requirements grow or as the budget allows, distributed intelligence systems are the easiest to expand.

With mesh network communication, each device can communicate to and around one another. Redundancy is built into the communication paths, providing self-healing capability for the communication network if one or more members of the mesh become inoperable. Distributed intelligence FLISR systems include safety features to prevent automated switching while crews are working on the feeders.

Unlike centralized FLISR systems, distributed intelligence FLISR systems can be deployed without implementing a DMS or GIS. Extensive data scrubbing of an existing GIS is not needed, and there is no need for controls or a control house at the distribution substations. Though completely compatible with SCADA systems, distributed intelligence FLISR systems do not require a SCADA system to operate.

Distributed intelligence FLISR systems require intelligent electronic devices to be deployed on the line. In many cases, the control software can be deployed on existing equipment by adding an interface control module. If a DMS is used, implementing a distributed intelligence FLISR system will free up bandwidth and processing power to these systems, allowing them to provide power flow analysis and other functions that require more data, time, and data processing power.

7.5 Recommendations for FLISR Integration

Implementation of a FLISR system typically involves several steps:

- Communication site survey to ensure acceptable signal strength between intelligent electronic devices and the headend SCADA radio, if applicable
- Overcurrent protective device coordination study to select appropriately rated protective devices and their settings
- Intelligent electronic device settings determination
- Factory acceptance testing of the intelligent electronic device to verify the system will work with the utility's specific protection settings, available fault currents, connected loads, etc.
- Training of the utility's personnel
- SCADA integration, if applicable
- Commissioning of the system

Section 8
Improving Grid Resiliency with Software Platforms

8.1 Grid Management Platforms

As assets throughout the electric grid become more complex so does the collected and transmitted data. Some automation hardware such as FLISR and VVO function by making a split-second decision based on a set of collected data processed locally on the device. However, the majority of IT and analytics deployments are focused on the installation and interconnection of a centralized software platform. In many of these systems, data is collected from sensors, instrumentation and protection devices, drones, meters, or other devices and transmitted back to a control room or centralized computing platform. From there, the data is processed, and actions are taken if needed. The following major software platforms are critical in storm response and outage mitigation, as well as for overall grid automation and intelligence.

- **ADMS:** An integrated platform designed to merge distribution grid operations management systems, unifying the distribution grid software portfolio into a single solution. Operations management systems include FLISR, VVO, and AMI with SCADA and protection systems. The integrated architecture has grown in recent years to include EMS and DER management system (DERMS) modules, though this is not universal across vendors. To operate a modern ADMS, the data requirements (level of fidelity) are far superior to that of a traditional data management system. This allows utilities to maintain the operating state of the network with a single source of truth and aims to dramatically improve the poor connectivity models used across the utility industry.
- **OMS:** AMI and DA technologies enable full instrumentation of the distribution network, allowing automatic detection and even recovery from outages. Outages are detected through the correlation of smart meter data in a MDMS or through grid monitoring via a DMS or SCADA solution. The integrated data is analyzed to decide the likely cause and location of the fault. Work orders are produced for maintenance teams and dispatched through mobile workforce management systems; initial remediation is then carried out through operational control of switches and circuit breakers. Customer calls are still taken, but inbound information can be provided by a wide range of channels such as telephone response systems, websites, text messaging, and social media.
- **MDMS:** A system originally designed to support a utility's basic billing cycles or meter-to-cash operations. The importance of MDMS has grown dramatically with the need to support near real-time, (at least day-ahead) meter-based

information rather than simple monthly billing cycles. Some MDMS vendors are adding additional capabilities such as data analytics and consumer portals to their offerings. Other vendors, specifically those with a broader suite of utility applications, may choose to deliver a base MDMS that is excellent at receiving and conditioning data from one or more AMI systems. The vendor can then create a metering data system of record that is openly available to specialized utility applications from many vendors.

- **SCADA:** SCADA management systems provide the operator and control interfaces within utility control rooms (and at larger substations) for the various controllers implemented throughout the grid, particularly at transmission substations. As the overall automation of the grid increases through additional intelligence in the network and with advanced applications, these functions are integrated into advanced DMS, ADMS or EMS applications. Historically, SCADA solutions have been widely used within the high voltage transmission system, down to the substation where high voltage is stepped down to MV. Increasingly, the utility deployment of SCADA and the requisite connectivity extend to distribution substations to improve visibility throughout the entire distribution network. SCADA supports a variety of DA applications such as FLISR or integrated Volt/VAR control.
- **Grid operations analytics:** Grid operations analytics is a broad field that includes use cases for grid management and planning, system control, and outage management. Meter operations analytics have also been grouped into this category (this does not include meter analytics that pertain to customer billing, energy efficiency, or DR). These are applications that utilities are turning to data- and analytics-based decision-making and implementing advanced applications beyond those supported in DMSs, OMSs, and meter data management and network management systems. For the most part, this category of analytics is mission-critical, and utilities have been resistant to relinquishing an on-premise platform. Despite this resistance, demand for cloud-based grid operations analytics solutions has grown.

8.2 Outage Management Systems

OMSs are software applications, often integrated with other utility applications, used to detect, diagnose, and plan assistance in the restoration of power during an outage. Traditionally, outage management might have been handled by a call center and process workflow to track reported faults and confirm maintenance teams were dispatched to the presumed location of the problem. Today, much more sophisticated outage management solutions are emerging that span the entire energy IT space. It has become common for OMSs to be deployed as a function of advanced distribution management systems, in the form of modular software platforms that encompass DMS, OMS, and SCADA.

Outage management is also one of the first areas in which analytics is typically applied, given the premium placed on reliability in terms of utility objectives. These solutions have evolved around the notion of reliability-based outcomes: more accurate storm forecasting, proactive crew and vegetation management, and integrated workflows.

Most vendors agree that the notion of a self-healing grid is becoming realizable for utilities, and it is increasingly considered a subfunction of outage management. Recent case studies have enhanced awareness around operating and reliability benefits that can be achieved with infrastructure upgrades.

New OMSs have the ability to more effectively integrate with utility engineering systems, which improve reliability and resiliency. This integration is accomplished through IVVC and FLISR, generating more granular information during outages that improves the outage model and restoration process. More robust IT systems within the utility require IT and operational technology (OT) teams to converge in both an informational and functional context.

Regardless of whether a utility decides to adopt a configured OMS, a hybrid combination of a DMS/OMS, or an enterprise ADMS, adding granular data from all over the grid creates several advantages to quickly identify an outage. This leads to more operational efficiency in the restoration of power. More data allows for even better outage reporting and preventative analysis. The value stems specifically from prioritizing restoration efforts and decreasing truck rolls. Moreover, analysis of historical outage, geographic, and weather data can help a utility determine where to make physical infrastructure investments to increase resilience.

In recent years, direct and indirect drivers have caused regulators in North America to put more pressure on utilities to improve outage prevention (resiliency and reliability) and minimize the effects of outages once they occur. To date, much of the effort surrounding improved reliability on the European grid has been in the form of resiliency through wider adoption of DA. However, OMS solutions that also focus on improving the restoration process have been deployed in a number of utilities in Western Europe, specifically within the UK.

8.3 Cybersecurity Is Critical

Outages are also linked to cybersecurity concerns. Cybersecurity threats pose a unique challenge for utilities because of their lack of predictability. Unlike traditional outage events related to weather or asset depreciation, which can be predicted by using historical data or advanced management and forecasting systems, utilities cannot foresee cyberattacks with any level of accuracy. While large-scale attacks have been limited to date, the hack on the Ukrainian power grid in December 2015 and the more recent WannaCry ransomware attack are motivating utilities to expand beyond traditional, compliance-based management practices and begin actively addressing cybersecurity.

The electrical grid is one of the US' most important infrastructure assets. Every aspect of the economy and virtually every aspect of modern living depend on the reliable flow of electricity into homes and businesses. A system failure due to a cyberattack, especially during severe weather conditions or other event, can have devastating impacts at local and regional levels.

As utilities rush to restore service during an outage, they need to have confidence that the system can be restored to a known good state—ensuring a system or process starts from and operates in a verifiable and acceptable condition. This confidence depends in large part on a utility's ability to identify intentional or unintentional changes to operational programs or equipment settings, which could cause additional damage or prolong outages if left undetected. As a result, utilities must maintain a high level of trust in their systems to ensure the return to a known good state.

Effective cybersecurity requires multiple layers of defense to protect the core of an operation from unauthorized intrusions and activities. Common defense-in-depth applications include behavioral policies, firewalls, intrusion detection systems, and patch management processes. Trust-based controls can enhance cybersecurity and improve overall network resilience.

8.4 Establishing Trust

The modern electrical grid consists of many different assets that work together to control the flow and delivery of power. The utility relies on each piece of equipment to perform a specific function, and often that equipment is remotely located.

Although the operator implicitly trusts the equipment to continuously perform in the intended manner, the possibility exists that an individual, either with evil intent or inadvertently, might modify the equipment settings or operating program, thereby resulting in damaged assets, extended outages, or compromised safety.

This raises several questions fundamental to the establishment of trust:

- **Providence:** Who built the equipment? Who delivered it? Who installed it?
- **Management:** Who manages it? Who might have tampered with it or modified it?
- **Status:** Is the equipment patched? Is there a virus? Is there a rootkit?

These issues concern supply chain management and the operation of equipment installed in the grid. Utilities control their supply chains and only have authorized trained personnel that install and maintain the equipment. Utilities conduct system performance tests to ensure the components and systems are operating correctly after installation and whenever systems are modified. However, these operational tests are often not enough to ensure the system is secure.

Secure operations require knowledge that the equipment is configured and is operating correctly. If both conditions exist, the utility has confidence in the trust level of the grid and will know that a specific level of security is in place to help defend against intrusions and unexpected events.

8.5 Determining Consistent Operation of Equipment

When a utility powers up complex equipment, the operator must have confidence the asset will consistently perform in a known good state. To achieve this, modern equipment often includes a trusted platform module (TPM) to control the device's boot sequence. A TPM is an integrated circuit that measures the software resident in the equipment when it starts.

At power on, a TPM will measure and validate the startup code by taking a hash on the file and comparing it to a known good hash prior to allowing program execution. A cryptographic hash function is an algorithm that takes a block of data, such as a file or program, and returns a unique number similar to a long serial number. The cryptographic hash value establishes the identity of the device, with any subsequent changes to the data or program resulting in a change to the hash value. By comparing the measured hash value to the known value, the TPM can identify code modifications and alert the utility operator, who will determine if the equipment should be permitted to come online. TPM functionalities can improve a utility's situational awareness and strengthen the resilience of its networks to a range of threats.

8.6 Configuration Control

Controlled equipment configuration consists of two activities: establishing operational parameters and updating embedded software. Equipment operators need to know if and when operational parameters change and fall out of tolerance limits. Utilities also need the capability to remotely and automatically update embedded software as security patches become available.

Most utilities manually configure and update embedded software, either in their center or by sending a technician to the field. This is a slow and costly process that often results in multiple revision levels running across a utility's equipment base. Historically, utilities have been slow to implement timely updates.

By deploying a modern two-way communications network, a utility can remotely configure a device's operational parameters and continuously monitor that equipment for anomalies or changes to settings. If such events occur, the control center is automatically notified and an operator is assigned to determine a course of action.

In this scenario, the operational center maintains the configuration of all devices in a central secure database. As unauthorized change alerts are received, the utility staff can take action to determine the appropriate next steps, including remotely pushing the correct configuration settings back out to the device. If an authorized technician changes the device in the field, the utility staff in the control center can pull the configuration from the reprogrammed device and update the central repository with the new configuration. As with TPM functionalities, configuration control can improve utility response time to unexpected events and improve system resiliency.

8.7 Software Updates

Vendors periodically release updates to the software programs that run utility systems and equipment. As in the case of current configuration control practices, utilities typically dispatch a technician to the field to manually update the devices. This need for manual intervention inevitably leads to multiple software versions running across a utility's equipment base.

Using the same communications networks leveraged for reliability and resiliency systems, utilities can remotely update field devices from the control center. This process can be secured through a combination of vendor-specific private key certificates and embedded public key certificates. Specifically, a software vendor digitally signs a software update with a unique private key certificate. By using the vendor's public signing key, the utility can verify the software update came from that vendor and was not altered in transit. The vendor also embeds the public key certificate of authorized users in the hardware prior to shipping. This methodology of certificates allows a device to verify a user's signature prior to accepting a software update, introducing an additional trust-based control to the utility's operations.

To avoid the simultaneous operation of inconsistent software versions, the system that updates the embedded software must function in a full transactional mode. This allows an operator to specify a group of devices to be updated with a single software package. At the end of the updating process, all equipment will be running the same revision level; however, if one device fails to update, all of the devices roll back to their previous version to ensure consistent and reliable operations.

8.8 Ukraine Case Study

The now infamous 2015 attack on the Ukrainian power grid is arguably the most seminal event in the history of smart grid cybersecurity. This multilayered attack began in December 2015 with a phishing campaign targeting three of the nation's distribution system operators (DSOs). Workers at these utilities were sent a malicious Microsoft Word file, and upon enabling the macros, an executable file entitled “vba_macro.exe” deployed the BlackEnergy malware, infecting their computers and opening a backdoor for the attackers. This malware enabled access into remote access tools to control operator HMIs and allowed attackers to open the breakers, affecting at least 27 substations and 225,000 customers.

It should be noted that five other targeted DSOs successfully prevented attacks on their systems. Their utilization of network intrusion detection systems (NIDSs) helped prevent damage to utility operations and also saved the companies from global embarrassment in the following months. Similar but smaller-scale events have also been reported in neighboring countries, including Turkey and Israel.

On December 17, 2016, a subsequent attack caused power outages across the capital city of Kiev, for about an hour. This time, attackers targeted transmission facilities and shut down the remote terminal units (RTUs) that control circuit breakers. This shed even further light into the vulnerability of Ukraine’s power grid, which is becoming a test bed of sorts for these types of cyber-attack.

8.9 Roadmap Recommendations

Utility operators should consider establishing trust in the equipment on their systems to improve grid resiliency. While trust-based controls are typically designed to defend against cyber-based threats, these same controls can drastically enhance a utility’s ability to detect and recover from equipment anomalies or system integrity problems, especially during weather-related events.

To establish an appropriate level of trust, utilities should focus their efforts on three activities:

- Confirm that equipment consistently starts in a known good state through the use of TPM and software verification techniques.
- Deploy an automated secure communications network to control and update equipment operational configurations.
- Use the secure communications network to conduct transaction-based software updates of field devices.

8.10 Case Study: Case Study: GE Predix

US utility Exelon is deploying GE’s Predix platform across its six operating companies. Predix will be used to analyze data from across the entire Exelon business from sensors embedded in generation, network assets, and smart meters. Exelon has many different objectives for Predix. The first use case was in power generation, where it was used to create digital twins of wind, nuclear, and thermal generation to perform predictive maintenance analytics. Since then, it has also been used to analyze weather and outage information to predict where outages may occur and to position crews before a storm hits.

Section 9
The Growing Power of Microgrids

9.1 Introduction

The aftermath of Hurricane Sandy reminds us of the fragile nature of the US power infrastructure and its inability to withstand high levels of stress. Moreover, once infrastructure is broken, the time required to repair it greatly compounds a lack of safety, comfort, and efficiency. Even considering highly evolved processes—utility crews from around the nation converging on affected areas—the days and weeks that follow are costly to cities and communities. Layer on top of these extreme weather events the wildfires challenging grid reliability on the West Coast and the COVID-19 pandemic, and it is clear the challenges facing grid managers are only multiplying.

The widespread destruction to the grid caused by Sandy and subsequent hurricanes and extreme weather events knocking out power in other parts of the East Coast, Florida, and Texas is reinforcing creative thinking about resilience. Leveraging these opportunities to deploy advanced microgrids that use increasingly cost-effective renewable energy and sophisticated controls being offered by companies such as ABB, Eaton, GE, Schneider Electric, and Siemens to boost energy security, improve efficiency, and increase air quality is now technologically possible. Microgrids and networks of similar DER aggregations can offer cost-effective solutions that deliver multiple benefits at scale. NEMA published *Powering Microgrids for the 21st-Century Electrical System,* which introduces the concept of microgrids as an integral component of the power delivery system of the 21st century.[5]

Microgrids are essentially miniature versions of the electric grid that include localized DG, quick load shedding capabilities, and advanced energy storage such as lithium ion batteries from pioneers like Tesla. They offer the capabilities to island and run parallel to the macrogrid or sustain energy delivery from local DER if the grid is not available. Offering reliability, stability, and renewables integration, microgrids are inching their way into the mainstream in the US. They represent a global market, with remote power systems still the largest market segment; the Asia Pacific region is leading on future capacity additions for these fully islanded systems. The figure below highlights key microgrid components.

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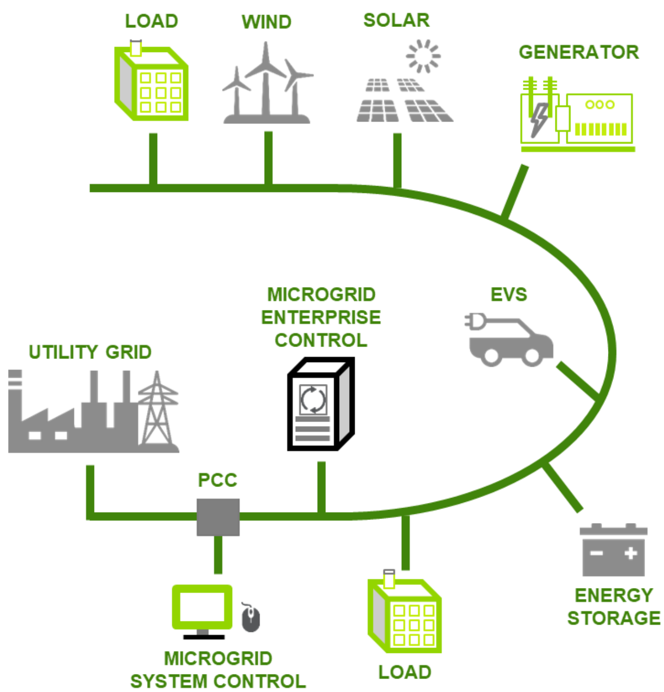
[5] NEMA, Powering Microgrids for the 21st-Century Electrical System, August 19, 2016, https://www.nema.org/standards/view/powering-microgrids-for-the-21st-century-electrical-system.

Figure 9-1. Key Microgrid Components



(Source: Guidehouse Insights)

Safety and prosperity depend on the modern grid more than ever, but it is routinely rocked by natural disasters. Volatile weather may cause power outages of up to 2 weeks. Large utilities in California now purposely impose public safety shutoffs due to the threat of wildfires. Unplanned outages cost millions of dollars and put lives at risk. The US Department of Energy (DOE) estimates that the US spends more than $150 billion annually on power outages. While the US grid is good, its reliability does not compare well to other industrialized nations in Europe and Asia. Backup generation helps, but too often the emergency fuel is exhausted before the grid is restored, or generators fail due to poor maintenance and upkeep.

For reliability, a compelling feature of microgrids is their ability to island, or separate from the grid; ideally this islanding is seamless and maintains renewable energy resources online. Localized and increasingly clean generation allows the microgrid to provide power to campuses and small communities independent of a macrogrid. These stability islands can keep whole communities of ratepayers warm, fed, and safe.

Importantly, microgrids allow first responders to start their work sooner. Emergency services, communications, shelters, fuel movement, and supermarkets cannot tolerate weeks without the grid. Community microgrids can be a super set of emergency power systems that use and ration DER assets through prearranged plans and automated controls. Universities such as New York University and

Princeton demonstrated how well-managed cogeneration systems kept campuses running for nearly 2 days.

Other innovators are also demonstrating the power of microgrids. The Montgomery County, Maryland microgrids support a correctional facility and a Public Safety Center.[6] At 7.6 MW, these side-by-side microgrids incorporate solar PV and fossil generators, including cogeneration. Along with cybersecurity and other infrastructure upgrades, the most notable aspect of this microgrid is the way it was financed. Schneider Electric provided infrastructure and controls; it also offered the county, which was strapped for funding, with an innovative energy as a service (EaaS) business model. The company guaranteed a price and took on the risk for performance. Montgomery County did not have to devote any capital to project development. A subsidiary of Duke Energy, the large utility, was the source of financing. Such energy as a service projects are now projected to be the most common way to finance microgrids in the future.

Cogeneration and emergency backup generators are increasingly used to anchor local renewable generation sources integrated into microgrids. Renewables that are always on are grid-tied, meaning they must go offline when the electrical grid is disrupted. When the microgrid islands, the anchor resource provides a stable source of voltage and frequency, which makes these grid-tied resources transition to microgrids. These anchor resources are becoming energy storage assets or even renewable generation, harnessing virtual inertia through sophisticated power electronics embedded in inverters. This happens regardless of macrogrid availability. Other features of microgrids are sophisticated switching between diverse sources and blackstart capability. If power is disrupted, restoring the ancillary systems providing lubrication, cooling, and starting current are necessary to restart generation or cogeneration.

By bringing generation closer to the loads, a higher penetration of renewables can be achieved, mitigating costly transmission system upgrades to manage the intermittent nature of utility-scale renewable energy facilities. Diverse energy resource portfolios that may include biomass or small hydro can fill supply gaps due to a lack of sun or wind. Energy storage then becomes the backstop, minimizing use of backup diesel generators, if available.

Further, advanced energy storage devices featuring high speed power electronics can make the microgrid more fault-tolerant, boost reliance on renewables, and lower control costs. Energy efficiency is still the first step in optimizing a microgrid. The project economics are vastly improved by gas-fired cogeneration, CHP, if there are significant thermal loads. Universities and hospitals are ideal sites.

[6] https://www.montgomerycountymd.gov/dgs-oes/Microgrids.html

- When a facility needs heat, the heat from local generation is far easier to deploy in the form of hot water or process heat.
- Absorption chillers can be paired with CHP to cool data centers and other buildings requiring state-of-the-art resiliency technologies.
- Localized generation that serves as the foundation for microgrids mitigate the up to 7% electrical T&D losses reported by the EIA.

Recent projects seek to further monetize microgrids through participation in the ancillary services market. By providing local power for peak demand and regulation services, microgrid owners are reducing onsite energy costs while providing grid services upstream, bolstering the performance of the overall distribution and transmission systems.

Permitting, interconnection requirements, codes, utility tariffs, and standards must continue to evolve to enable microgrids to more easily optimize diverse DER and interact with the larger utility grid. Many utilities in the US have been challenged by state regulators in proposals to place the costs of microgrids into their rates. The important work on IEEE 1547 *Standard for Interconnecting Distributed Resources with Electric Power Systems* continues to be updated and expanded. IEEE 2030 standards governing energy storage and microgrid controls are creating a framework to assist in the commercialization of microgrids. It is important for more utilities to adapt to and embrace the microgrid momentum, yet it is the private sector's hardware, software, and financial products that are driving the market forward.

While upfront costs, pricing, and regulation are being managed, increased collaboration with utilities, public utility commissions, and public-private partnership will help the technology reach its wide-scale potential. Guidehouse Insights shows that over 11,000 MW of microgrid capacity is online or under development in the US and that total microgrid capacity globally exceeds 34,000 MW. By 2029, the value of DER assets being rolled into microgrids is expected to reach nearly $30 billion annually[7].

9.2 Powering Reliability with Microgrids

The US power delivery system's complex network of substations, transmission lines, and distribution lines are not designed to withstand or quickly recover from damage inflicted simultaneously on multiple power system components. The number and duration of power outages in the US continues to rise, driven primarily by weather-related incidents and now augmented by purposeful outages initiated by utilities for safety reasons due to wildfires.

[7] ., "Guidehouse Insights, *Market Data: Utility Microgrids"*, 2020, https://guidehouseinsights.com/reports/market-data-utility-microgrids

By contrast, outage duration for the rest of the industrialized world has historically been less than 10 minutes per year and is generally getting better. However, even countries with highly reliable power grids such as Japan are investigating in microgrids due to typhoons and other extreme weather events, including snowstorms. The growing prevalence of physical and cybersecurity threats also pose significant challenges for organizations' mission-critical operations in ensuring reliable access to power supplies.

Historically, when a disaster strikes the result is infrastructure improvements to address the specific cause of each power failure. Many times, planning fails to anticipate future emergencies. A large earthquake, nuclear explosion, or terrorist attack could cause suffering and disruption over a much larger area than a hurricane. Establishing safe haven enclaves to serve as bases of rescue and recovery could go a long way to address the human and economic impacts of future, unanticipated events, only amplified and complicated by the COVID-19 pandemic.

When an outage strikes, the effects often stretch far beyond the initial impact zone. Regional outages inhibit the ability to protect those in danger and provide basic needs such as food, sanitation, and shelter. Recovery could happen quicker if islands within each area could maintain power and serve as centers for critical services and recovery.

Standby and backup diesel generators are often the only power source available. However, backup generators pose some problems:

- Typically serve only the buildings they are attached to, so nearby buildings do not get power
- Often have less than 72 hours of diesel fuel in their tank, and fuel deliveries may be significantly delayed
- Often sized for the maximum load and do not use fuel efficiently when loads are much less

9.3 Microgrids as the Solution

To optimize available generation and make power available to a larger area, microgrids offer a viable solution during sudden power outages. A microgrid can isolate itself via a utility branch circuit and coordinate diverse generators and energy storage in the area rather than having each building operating independent of the grid and using backup generators. Using only the generators necessary to support the loads at any given time ensures optimum use of all the fuel in the microgrid area.

A microgrid integrates a number of features beyond backup diesel generators:

- Renewable energy sources such as solar and wind but also biomass and hydroelectric resources
- Gas turbines and central plants providing CHP
- Energy storage in the form of flywheels and batteries (including the batteries located within EVs)

The microgrid senses loads and fault conditions and can reroute power to as many critical areas as possible given any situation. In that way, it is self-healing.

Thus, a microgrid is defined as comprising five key elements:

- Local electricity generation
- Local load management
- Ability to automatically decouple from the grid and go into island mode
- Ability to work cohesively with the local utility, providing capacity and grid services if allowed by market designs

Backup generators only support loads immediately attached to them, and they usually only come into action during utility power outages. A microgrid consists of onsite generating sources that may include different combinations of diesel generators, gas turbines, fuel cells, solar PV, and other small-scale renewable generators, storage devices, and controllable end-use loads; these onsite generating sources enable a facility to operate in a utility-connected mode and in island mode, ensuring energy reliability. In other words, the microgrid offers significant value, even when the grid is up and running. Assets included within the microgrid can create new value and revenue streams with the right regulatory support.

In addition to microgrids, DR brings significant benefits to utilities seeking to mitigate stress on their grid. DR programs call on individuals or businesses to reduce or increase their consumption of electricity or natural gas over a set period due to some form of incentivization to minimize strain on grid systems or balance renewable generation. Reduced energy use is typically due to financial rewards for participation, including but not limited to lower electricity rates, bill credits, or rebate programs. The prescribed change in electricity can be manual, initiated by the customer after receiving notification from the utility, or automated through DR management systems. While natural gas DR programs are relatively new, electric utility DR programs originated in North America and have been in place for more than three decades. These programs reduce energy demand across residential, institutional, and C&I customer segments.

9.4 Key Challenges

There are two key challenges to making microgrids work: utility interconnection and microgrid controls.

9.4.1 Utility Interconnection

While having the capability to operate in island mode is a defining feature of a microgrid, the local electricity generators within it are usually connected to the utility grid. This connection allows a facility to purchase energy and ancillary services from the utility and sell locally generated electricity back to the utility grid during times of peak demand. When the microgrid is operating with the utility grid, the utility is responsible for frequency and voltage stability. The microgrid control system needs to operate the generators and loads within it to maintain consistent power flow. Microgrids should be coordinated with utility grid management to minimize the risk of transmission disruption or danger to line workers and others exposed to power currents. Therefore, a utility-microgrid interconnection agreement allowing two-way power flow typically needs to be developed for each microgrid. Regulators, nevertheless, are beginning to recognize that standardizing and shortening interconnection processes is vital to scale up this industry.

9.4.2 Microgrid Controls

A successful microgrid must have intelligent methods to manage and control all loads. Energy sources have defined output capacity and, if overloaded, will severely distort the voltage output or completely shut it down. When a microgrid separates from all the generation capacity of the grid and relies solely on local generation, load management must be established to properly balance the power generation capacity. This load management is extremely critical whether a given site has multiple generation sources or simply more load demand than available local power generation. As local generation capacity is ramped up, the loads are brought online in an intelligent predefined strategy. Typically, critical loads come first and other loads are adjusted to never overload available generation capacity.

There are many approaches to controlling loads: at the building feeder level, circuit level, or discrete level. However, the load manager must be able to turn off power quickly and, when restoring power, know the capacity so the generator is not overloaded.

Microgrid control is relatively easy when all generation resources within it are in close proximity, such as a central utility plant on a college campus. In a distributed microgrid where generation sources (e.g., backup generators) are connected to distribution circuits spread across a large geographic area, voltage and frequency regulation is extremely important. Generators of different sizes and response behaviors cannot simply be hooked up and synchronized over a large area. Such a grid would be unstable because generators on the distribution circuit react to one another by picking up and dropping their share of the load. A supervisory strategy needs to be employed with central controls to ensure stability. The effects can be minimized in a newly designed grid, but most microgrids will be cobbled together with existing generators that have a wide variety of vintages and behaviors.

The more diverse the resource mix, the shorter the response time required to balance loads and generation. There is a growing consensus that a distributed controls approach, pushing out intelligence to each device level, is also an important priority, especially as variable renewables comprise a larger portion of the supply portfolios of microgrids. The best approach to controls is likely a combination of distributed controls for instantaneous adjustments and a higher level supervisory control scheme that incorporates weather and grid condition factors into longer-term decision-making for the microgrid.

Microgrid design and operation require extra focus on safety. If the utility is down in one area, it does not necessarily mean that all branch circuits will be blacked out. Safety dictates that everyone be aware of the possibility that microgrids could reenergize loads under the microgrid's control.

Campuses, military bases, and wastewater treatment plants are good candidates for a distributed microgrid. They often have a common mission and are managed by the same organization, facilitating coordination. They also have central plants that can be used for baseloads over a broad area with distributed generators. These types of generators are used when loads are too low to justify running the central plant or to support the central plant over a larger area.

9.5 Applicability and Benefits

A microgrid approach makes sense for many organizations, primarily those that have a high demand for energy in their facilities and where loss of critical operations poses a significant risk of revenue loss, data loss, or safety and security. Microgrid candidates include the following:

- Military bases where power shutdown would pose unacceptable security risks.
- Federal facilities, including research laboratories, where wavering energy reliability could mean loss of data and millions of dollars in lost time.
- Hospitals that need to seamlessly deliver patient care regardless of weather or other conditions.
- Large data centers that are the heart of most organizations' business operations.
- Research-driven colleges and universities that need to safeguard and maintain years of faculty work.

- Local governments that need to offer operational assurance to large businesses in their district, attract new companies for stronger job creation, and offer shelter during emergencies.
- Commercial campus settings where 24/7 power reliability is crucial for protecting long-term investments such as R&D or simply to stay up and running during extended outages to avoid major financial losses.
- Densely populated urban areas, such as Manhattan, where concentration of energy use is high and significant scale justifies connecting multiple buildings as part of a microgrid network.
- Instances where bringing in new electrical lines to meet a facility's power requirements will be cost- and time-prohibitive to the organization and local utility. These so-called non-wires alternatives are the types of utility microgrid projects that have found the most success with regulators.

Distributed microgrids provide additional benefits to utility operators by integrating renewable resources in distribution circuits. Utility distribution circuits are not designed to absorb large amounts of distributed or renewable generation. If microgrid operators can integrate renewables such as rooftop solar while providing frequency and voltage stability, their jobs becomes easier. Advanced controls make this a commercially viable value proposition.

9.6 Vision

One can envision that a resilient and robust utility infrastructure of the future can be built out of interconnected microgrids at universities, hospitals, industrial parks, and neighborhoods. Individual microgrids would be nominally connected to form a single utility grid but could also isolate from the grid and operate independently in case of disruptions. Moreover, this would enable easier integration of distributed and renewable generation, while also incorporating EVs and other assets. Microgrids developed where there is no utility grid take on an even more strategic purpose. They can serve as platforms for other fundamental services, including the water provision, telecommunications, and support for economic activities.

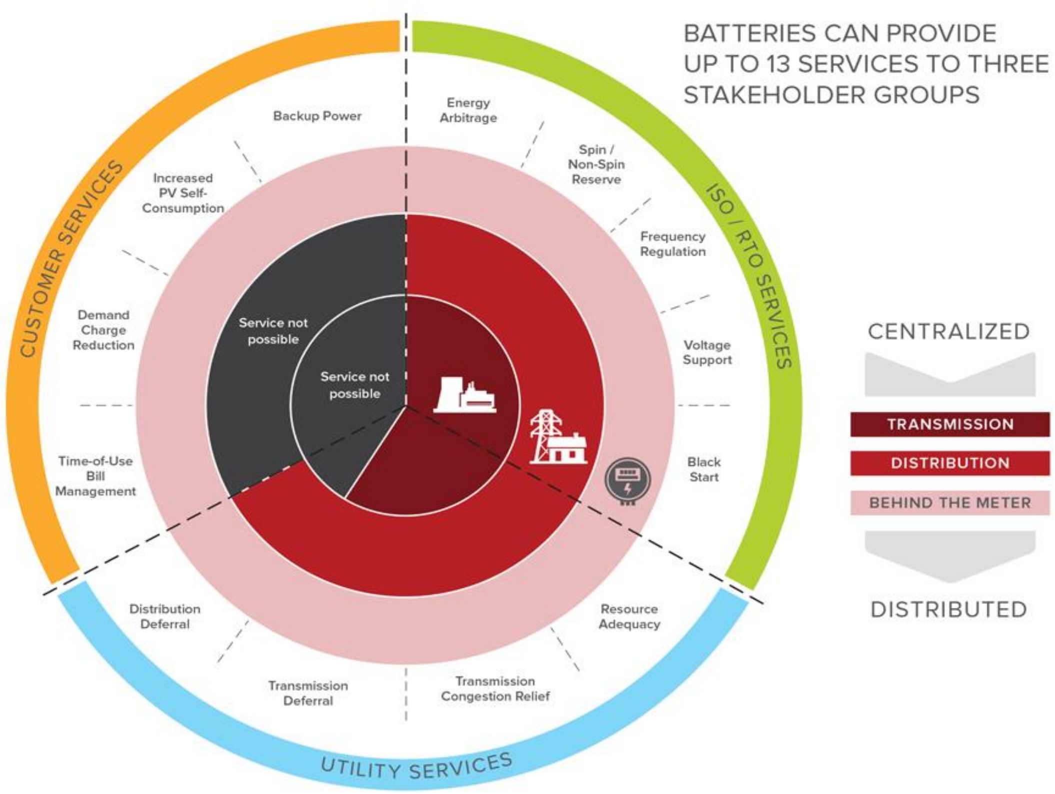
Section 10

The Role of Energy Storage in Disaster Recovery and Prevention

10.1 Introduction

From flashlights to uninterrupted power supplies, energy storage assets have a long history of supporting critical infrastructure and services during times of natural disaster. By providing power and lighting during large-scale weather events such as Hurricanes Sandy, Irene, and Katrina, energy storage systems of all shapes and sizes reduce the time it takes for first responders to begin recovery efforts. While extremely valuable when needed, most energy storage assets remain idle for long periods of time and are viewed as sunk costs without the ability to generate revenue. Furthermore, many energy storage systems require mandatory and ongoing maintenance procedures, which if not completed properly, put the entire performance of the systems at risk.

Figure 10-1. Services Provided by Energy Storage on the Grid by Stakeholder Groups



(Source: Rocky Mountain Institute)

Emerging technologies in the energy storage field are changing this paradigm. Rather than representing fixed costs, energy storage systems are transforming into active assets that can be used to create sustainable revenue streams. Whether through participation in new energy markets opened by the Federal Energy Regulatory Commission or through their inherent ability to extend life-cycling capabilities, these new energy storage systems are poised to lower operating costs by reducing peak demand charges, increase onsite power generation efficiency, and extend emergency generator runtimes. It is a new approach that enables energy storage—once a costly, passive but necessary disaster recovery asset—to emerge as a cost-effective, active participant that stands to make power systems and consumer services more resilient, more efficient, and more responsive to the need for a sustainable, readily adaptable energy environment.

10.2 Emerging Markets for Energy Storage

New energy storage system designs offer safer and longer operational lifespans, and allow customers to install large battery systems that provide emergency power to critical functions when the electrical grid fails. Equally important is their capacity to produce revenue and reduce costs during normal operation. Recent Federal Energy Regulatory Commission orders have enabled battery systems to participate in the wholesale energy markets and perform frequency regulation, energy arbitrage, and DR functions. New York Independent System Operator and PJM (a regional transmission organization) have enabled energy resources to participate in their energy markets, and multiple battery installations are creating revenue that supports these installations. Additional examples of this new approach are outlined in the following sections.

10.2.1 Utility Deployment

Utilities are continuing to exploit new battery technology’s enhanced safety and lifespan capabilities by installing batteries at substations and in community energy storage systems. Battery systems help utility resources be efficiently used by extending their peak demand capabilities. In addition, during periods of grid stress, these energy storage stations can provide either the substation or the larger community with valuable extended operating power to allow end users to charge their communications equipment or even their vehicles.

Two applications for utility-scale energy storage are emerging as the most popular and impactful on the grid: solar plus storage and peak capacity/resource adequacy.

- Solar plus storage includes colocated projects built with solar PV and storage at the same site. Energy storage provides ramp rate control, output smoothing, and bulk energy shifting for solar PV. These projects are primarily contracted through power purchase agreements. Prices for solar plus storage power purchase agreements have fallen dramatically in recent years; they now average $0.03/kWh-$0.06/kWh in the US, which is competitive with fossil fuel generation.

- Peak capacity/resource adequacy projects serve a similar function by shifting large amounts of energy, but they are standalone resources not tied to a specific generation asset. These projects are primarily developed in urban areas where either regulations or high costs prohibit the development of new fossil fuel generation or T&D infrastructure.

GE is one company leading the development of large-scale utility energy storage including solar plus storage and peak capacity projects. In 2018, the company launched its GE Reservoir Solutions products—a fully integrated energy storage platform for alternating current- or direct current-coupled systems. The 1.2 MW, 4 MWh Reservoir Storage Unit is the fundamental building block of this modular system. The Reservoir Solutions platform uses Predix and Edge controls technologies to provide data-driven insights that help energy operators enhance their systems. The software suite is built on GE's existing control platform for conventional power plants, including fleet management, component life analytics, and dispatch optimization.

In 2019, GE Renewable Energy announced it was selected by project developer Convergent Energy + Power to supply battery energy storage systems for three projects in California for a total capacity of 100 MWh. The energy storage systems support two primary goals. First, they provide targeted local capacity to enhance grid reliability during peak periods. Second, as fast-acting stabilization devices, the battery energy storage systems can charge and discharge rapidly to regulate frequency and contribute to grid stability, helping to balance and facilitate the ever-growing penetration of variable renewable energy.

10.2.2 Behind-the-Meter Applications

Retail customers, including large pharmaceuticals, manufacturing plants, and office complexes, are turning to energy storage systems as a cleaner, more cost-effective way to manage their peak demand and peak energy charges. In the event of a power outage, these systems are designed to operate as an uninterrupted power supply and provide seamless power to critical infrastructure. For example, since the earthquake and tsunami disaster in March 2011, Japan has been a major proponent of this approach.[8] Energy storage deployment between utilities and homes has emerged as a key component of their recovery and rebuilding effort.

[8] Smart Grid Insights, *Energy Storage: Asian Systems and Apps,* August 2012, http://files.energystorageforum.com/Energy_Storage_Asian_Systems_and_Apps_August_2012_Smart_Grid_Insights_Zpryme_Research.pdf

Behind-the-meter energy storage is becoming increasingly popular in markets with high electricity prices. For these customers, cost management and onsite solar consumption are the primary drivers while resiliency and backup power is often a secondary concern. Both residential and C&I customers are adopting energy storage globally.

Leading battery manufacturer Duracell recently launched its first stationary energy storage product using lithium ion batteries. Its Energy Bank product is now available for residential customers in the UK. The product offers up to a 6,000 W output designed to manage time-of-use energy pricing and provide backup power.

Considerable innovation is also taking place for C&I customers. Energy component supplier Eaton is a pioneer in the behind-the-meter energy storage market in Europe. The company offers fully integrated and containerized solutions designed to manage energy costs and increase resiliency for C&I buildings. Notably, its new xStorage Container product is designed to incorporate either new batteries or second life batteries already used in EVs.

10.2.3 CHP and Microgrids

Another means of leveraging the value of active energy storage systems is to integrate them with other onsite power systems. Integrating batteries with a CHP system, for instance, has the potential to create a safe, resilient, and efficient energy campus microgrid. In this scenario, natural gas-powered engines provide the facility's base electrical needs. By using the engine's high temperature exhaust, it meets the facility's heating and cooling needs. The battery charges when the electrical load is low and discharges when the facility's load exceeds that of the engine's capabilities, providing the much needed additional power capacity for the microgrid. During outages, the battery system is configured to work alongside the generator backup system to optimize generator runtime and increase fuel efficiency.

10.2.4 Backup Power: Diesel Fuel Use Reduction

In remote grid telecom applications, advanced technology battery systems have proven their ability to nearly double the efficiency of the diesel generators they support.[9] This reduction in fuel use has a positive impact on the user's operating costs but also serves to reduce fossil fuel consumption overall.

During extended outages or natural disasters, the supply of diesel fuel can become severely limited. Although cell towers and data centers support many critical

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[9] *Sodium-Metal Halide Batteries in Diesel-Battery Hybrid Telecom Applications.* General Electric Company, 2011 *(http://geenergystorage.com)*

communications services, they are not alone in needing priority access to fuel. Other consumer services can be affected as well.

When New York University's Langone Medical Center experienced backup generator failure during Hurricane Sandy[10] it prompted a mass evacuation of patients from the facility. An energy storage system could not only provide backup power support to a health or emergency facility, it could also reduce an existing generator's diesel fuel usage as a whole, extending services to those who need it most.

10.2.5 Energy Storage Vision for Rebuilding

Deploying energy storage below the grid will increase grid resiliency and promote greater efficiency and more sustainable energy generation. By growing the amount of energy storage nationwide, the ability to incorporate larger penetrations of sustainable but variable energy sources would be enhanced.

10.2.6 Power Plants

By deploying correctly sized energy storage at power plants, blackstart capabilities become more widely available for use as needed. On an ongoing basis, these energy storage systems can increase revenue by participating in ancillary services or energy markets.

10.2.7 Substations

System deployment at substations can provide required overload support when the equipment is aging or if there is substantial load growth due to unexpected increased demand. Energy storage systems could also provide daily voltage and ancillary services support, thereby providing a solid revenue stream.

10.2.8 Critical Infrastructure

Critical infrastructure such as police command centers, fire stations, cell towers, and hospitals often have diesel generation as backup power. By deploying energy storage systems at these facilities, the diesel system can be optimized to decrease generator runtime. New energy storage battery technology deployed at remote communication stations has already proven that the runtime capability of a single unit of fuel can be raised by almost a factor of two when the battery is continuously paired with a diesel engine. The energy storage component can then also be used on a daily basis to decrease the facility's total energy bill by reducing energy purchases during peak times and lowering energy and demand charges.

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[10] Rijssenbeek J., Herman Wiegman, David Hall, Christopher Chuah, Ganesh Balasurbramanian, Conor Brady, "Sodium-Metal Halide Batteries in Diesel-Battery Hybrid Telecom Applications." Paper published at the 2011 IEEE 33rd International Telecommunications Energy Conference, October 2011.

In addition, designated community, communication, cooling, or heating centers located on campuses, convention centers, or other public facilities can be enhanced by updating infrastructure and incorporating energy storage systems to provide support during outages. These facilities can also use energy storage to reduce their energy costs by leveling peak demand and peak energy charges.

10.3 Integrating Energy Storage into the Distribution System

Energy storage systems can reduce thermal strain on the grid during peak load periods and provide a reliable backup power supply during grid outages. These systems make the grid more resilient to damage caused by extreme weather, natural disasters, and cyberattacks. In addition, energy storage systems, when coupled with renewable energy sources, can help electric utilities meet peak demand requirements without the need for additional conventional generation from burning fossil fuels. Hurricane Sandy caused major damage to the infrastructure used to transport fuels including the natural gas used in gas-fired backup generators.

10.4 Large-Scale Energy Storage Systems

Large-scale energy storage systems allow electric utilities to better utilize renewable generation produced by commercial wind and solar plants. These systems, installed at collector substations, can provide megawatt-hours of energy storage and include controls that permit this power to be dispatched when it is needed the most—during periods of peak usage. Large-scale systems dramatically reduce greenhouse gases by deferring, or eliminating, the need for additional generation produced by traditional generating sources. These systems displace peak energy costs with off-peak costs.

There are greater demands for electricity at certain times of the day. The grid can add more generation, charge time of use, or provide technology that shaves the peak, which is commonly referred to as peak shaving. The peak shaving capability of large-scale energy storage systems is especially valuable during heat waves when high electricity demand and high temperatures can cause significant thermal strain to power grid equipment. Such thermal strain can shorten the life of power grid assets and lead to equipment failures that result in outages.

Large-scale energy storage systems can be combined with a FLISR system to achieve dynamic islanding upon the loss of power to the feeder from the serving substation. Service is restored to the maximum number of customers based on load information captured by the FLISR system before the loss of power and the amount of energy available in the battery. The island is minimized as the battery is depleted or power is restored to the feeder.

10.4.1 Example Results of a Large-Scale Energy Storage System

Electric service in Presidio, Texas, is supplied by a troublesome, difficult-to-access 69 kV line. Repairs to this line frequently take a long time. Because of its limited connection to the grid—and its high summer and winter peak loads—Presidio often experiences protracted power outages, especially from storm-related damage.

To improve power quality and reliability, the serving utility, AEP, procured a large-scale energy storage system they implemented in conjunction with a distributed intelligence FLISR system to provide dynamic islanding for the entire town. The energy storage system has substantially improved power quality and decreased the number of outages experienced by utility customers in the Presidio area.

10.5 Small-Scale Energy Storage Systems

Small-scale energy storage systems use pad-mounted energy storage units distributed along residential feeders at the edge of the power grid. These battery-based units permit the integration of the community's intermittent renewable generation resources—such as rooftop PV panels and wind turbines—into the grid, where these increasingly popular resources can be dispatched when needed.

The battery-based energy storage units can be aggregated to collectively provide peak shaving, improve power quality, or improve local voltage control to reduce losses and improve distribution feeder efficiencies. This aggregation of energy storage units can eliminate the need for costly, time-consuming infrastructure buildouts. Distributed energy storage can be a means for peak shaving because it does not require customer involvement. The mesh communication system used to link the energy storage units can help the utility quickly find the site of a problem on the distribution system without first dispatching a crew to locate it.

The energy storage units offer reliable, local backup power for consumers as well. The close proximity of the energy storage units to consumers helps ensure the availability of supplemental power in the event of an outage. A typical 25 kVA energy storage unit can offer supplemental power to several homes for up to 3 hours, which is more than sufficient for the duration of many outages. They can also be deployed at traffic signals and used for emergency lighting, emergency communications, and more.

A fleet of larger-capacity energy storage units—typically rated 250 kVA—distributed throughout the grid can support hundreds of homes, small businesses, and critical infrastructure during an outage. When combined with the community's renewable generation resources, the resultant microgrid is capable of operating for many hours or even days. Groups of these larger-capacity energy storage units can be arranged as virtual power plants and suitably planned to be storm-ready in anticipation of an outage. With the deployment of virtual power plants, utility crews can concentrate on service restoration elsewhere on the system.

One key emerging application for distribution-scale energy storage is supporting EV charging stations. A battery storage system can feed from the grid during low demand and release power to charge an EV during peak demand time. Energy storage can aid in peak shaving to make EV charging solutions more cost-effective. A battery storage system is also needed to support the integration of renewable energy resources (e.g., solar PV panels) into EV charging stations. Leading EV charging provider ChargePoint, a partnership with storage system provider ENGIE, has been installing batteries alongside some of its charging stations since 2015 to reduce operational costs.

Small-scale community energy storage projects have been deployed in the US, the UK, New Zealand, and elsewhere.

10.6 Recommendations

Energy storage has traditionally been viewed as an expensive must-have for disaster recovery efforts. While recent events support the importance of grid modernization through energy storage systems, the idea that these systems could be used to generate revenue streams and reduce operating costs is a newer concept. Emerging battery technologies prove that energy storage can simultaneously and safely create ongoing value and provide support in times of crisis.

Around the world, increased energy storage deployments are being spurred by customers looking to gain more control over their energy bills and utilities aiming to build resilience and flexibility into their grid operations. Driven by technological progress, legislative and regulatory tailwinds, and grid challenges associated with intermittent renewable generation, ESS technology is at the forefront of industry consciousness. Despite the rapid growth of ESSs, more needs to be done to accelerate ESS integration by both stakeholders delivering the technology and those adopting it. As a result, an industry-wide focus is necessary to identify where rapid performance gains are possible.

On the industry side, ESS suppliers need to focus on reducing costs and system complexity by engineering storage for adoption at scale. Innovation and standardization need to be delineated across the physical, electrical, and software elements of the system. Regarding software, standardized interfaces ensure that rapid innovation can be incorporated into existing systems at a reasonable cost. This software architecture ensures utilities can select various ESSs without having to redesign their entire system and residential and C&I customers can integrate ESSs within existing management systems.

Section 11
Distributed Generation, CHP and Grid Resiliency

11.1 Introduction

Making the grid more resilient to natural disasters is critical to protecting customers and significantly reducing the magnitude of outages and the economic costs associated with them. The Electric Power Research Institute provides a three-pronged approach for improving grid resiliency that consists of the following: hardening (infrastructure), recovery (restoring power), and survivability (equipping customers). DG directly supports two of these focus areas. First, DG resources can harden the grid by providing uninterrupted power onsite for critical facilities and by generating power near high density load centers embedded into the distribution system. Second, when coordinated with technologies like FLISR, DG can improve recovery efforts after a disaster by increasing the speed of power restoration.

11.2 Hardening and DG

One of the most obvious means to harden the grid is to bury power lines to prevent outages from fallen trees and broken poles; however, doing this for the whole system can be prohibitively expensive, sometimes up to 20 times as much as overhead lines, especially for transmission systems. The most cost-effective way to ensure uninterruptible power for critical infrastructure, such as hospitals and communication centers, is to embed generation onsite. For most facilities that need to maintain power throughout every type of grid disruption, CHP is the most efficient DG solution, although new DG alternatives like solar PV plus storage are becoming attractive. DG can also strengthen the grid by placing power-generating assets within the distribution network. When power-generating assets are sited near demand centers, they help maintain power to critical portions of the grid even when transmission lines or larger centralized power plants are down.

11.3 CHP and Hardening Facilities

CHP, also commonly referred to as cogeneration, is a highly efficient method of generating electricity and useful thermal energy from a single fuel source. This simultaneous generation is a distinctive and valuable characteristic of CHP and often results in 80% overall fuel efficiency. Three technologies are primarily used in CHP applications: gas turbines, gas reciprocating engines, and boilers used with steam turbines. In CHP systems using any of these technologies, waste heat from the combustion process is captured to provide useful thermal energy to a variety of applications: hot water for an apartment complex, steam for an industrial facility, cooling for a data center, or heating for a hospital. This is in addition to the electricity provided directly to the facility and, in some instances, exported back to the grid.

Installing CHP has many advantages. Emergency preparedness is the most prominent advantage. Apartment buildings, hospitals, airports, and other facilities stayed online during major storms while their surrounding communities plunged into darkness. CHP was more reliable in these situations because the power generation equipment was used continuously leading up to the disaster and thus, was regularly serviced and connected to an uninterrupted fuel supply through the natural gas grid. Not only can CHP keep critical infrastructure online in an emergency, but it is dispatchable, meaning it can be called on to provide heat and power at a moment's notice; this is not true of onsite wind and solar technologies, meaning CHP can complement intermittent generation.

There are non-disaster benefits of installing CHP systems as well. Due to the use of waste heat, these systems often achieve efficiencies of 70%-80%, significantly higher than producing the heat and electricity separately, which has average efficiency levels of 40%-50 in the US. Higher total efficiencies result in lower fuel usage, decreased energy costs, and reduced emissions. Additionally, CHP systems use low priced, domestically abundant natural gas. This makes CHP a valuable asset to reduce a facility's energy costs, even without considering the benefits it will provide when a facility is weathering a disaster.

DG is a topic often discussed in the context of energy generation and implementation. Increased interest in DG systems is partly attributed to the recent blackouts in Puerto Rico, where around 500,000 people remained without access to electricity 4 months after Hurricane Maria first hit the island.

The issues arising from centralized stations, which are based on the southern half of the island in the case of Puerto Rico, were made obvious by Hurricane Maria. In addition, the sustained blackouts resulted from the stations being separated from urban hubs in the north by the island's mountainous center, making it difficult to repair the damaged grid. To tackle the problems that hurricane seasons bring to the island, Coca-Cola Puerto Rico Bottlers signed a long-term offtake agreement to install a CHP with a Siemens engine in their facilities.[11]

11.4 Hardening Distribution Grids

Strategically placing power generation assets within a distribution grid is an effective way to ensure uninterrupted power for many customers who are unable to build their own CHP plants; this is known as a non-wires alternative. A recent example is the case of New York Power Authority's Power-Now sites. In early 2000, the New York Power Authority implemented six widely distributed power

[11] Martin Energy Press Release, "Martin Energy Group Closes Strategic Capital Partnership With Orion Energy Partners to Fund Distributed Generation Infrastructure," Business Wire, March 21, 2019, https://www.businesswire.com/news/home/20190321005190/en.

generation sites throughout the city near major load centers. Equipped with 10 aeroderivative gas turbines, they can provide more than 450 MW of power.

The plants kept running through Hurricane Sandy and delivered critical voltage stability to the New York City grid. Prior to Sandy, these units proved their worth in the wake of the September 11, 2001 terrorist attacks. The New York Independent System Operator, which runs the state's transmission system, limited deliveries of electricity into the area from upstate plants. On another occasion— during the Northeast blackout in August 2003—the plants helped return power to New York City while stabilizing the downstate transmission system.

New York is pushing forward with the embedded generation model. Con Edison launched its Brooklyn-Queens Demand Management (BQDM) project in 2016 and has been expanding it since then. The Brooklyn-Queens Demand Management project includes baseload CHP, energy storage, DR, and energy efficiency.

11.5 Recovery and DG

After a natural disaster hits, the priority for the electric grid is to restore power to parts of the system that were damaged, severed, or otherwise left powerless. Typically, this takes the form of repairing damaged lines and bringing power plants back online that were shut down as a result of the disaster. However, there are circumstances where plants cannot be brought back online easily or transmission lines are damaged beyond simple/rapid repairs. These circumstances can lead to leaving large swaths of customers in the dark for days or require forced energy reductions that can last for weeks or even months after the disaster occurs.

In these situations, an effective solution is to have a fleet of mobile, trailer-mounted power plants that can be rapidly deployed to areas with the largest or most critical power needs. This type of solution uses proven technology, such as gas turbines and reciprocating engines, which can quickly connect to and provide power for an existing grid. For example, after the Fukushima earthquake and tsunami damaged transmission lines and brought numerous power plants offline in Japan, trailer-mounted gas turbines were a critical part of the strategy that helped prevent widespread blackouts in the summer of 2011.

The advantages of an energy-dense fleet with a small footprint that has natural gas or dual-fuel capabilities is that it can:

- Be connected to the buried and undisturbed natural gas grid.
- Avoid liquid fuel supply issues that arise after a disaster (e.g., fuel shortages in New Jersey and New York after Sandy).

Utilities can improve recovery for residential, commercial, and industrial areas by rapidly bringing in power-generating fleets, which bypass more drawn out transmission restoration efforts.

11.6 Recommendations

DG is a critical component of grid resiliency investments because of its ability to harden the power system and improve recovery efforts after disasters.

- **Hardening of a facility:** CHP should be used to provide uninterrupted power because it is dispatchable, does not rely on liquid fuels, and has non-disaster related benefits including lowering energy costs and reducing emissions. Additional funding and policy incentives are needed to spur private sector investments.
- **Strategic locations:** DG assets should be placed in strategic locations within distribution networks, specifically near high density load centers.
- **Recovering from a disaster:** To prevent long-term power outages, mobile DG technologies (e.g., trailer-mounted gas turbines and reciprocating engines) need to be deployed to help get power to customers quickly by providing emergency/bridge power before the grid is fully restored.

  Government involvement: Government leaders at the federal, state, and local levels should focus resources on infrastructure that includes DG applications as part of a larger strategy for a more resilient grid.

Section 12

Incorporating Generators and System Upgrades for Storm Preparation

12.1 Introduction

The results of several major storms and the growing trend toward more severe climate events is a perfect illustration of the reliability weaknesses in the electrical distribution infrastructure. Without power, little else works—from the cellular communications that have replaced landlines for many people to heating that depends on electricity to operate blowers. Many community restoration efforts are impossible without a functioning and reliable electric grid.

Most people think of the electrical transmission and distribution system first, and the local utility companies that operate the T&D networks. In many disasters, such as ice storms or windstorms, it is these lines that are affected and when they are repaired, power is restored to residences.

Hurricanes and wildfires present more severe forms of damage. In addition to the public electrical infrastructure, these events often cause widespread destruction of the private electrical infrastructure that exists within each house or building. When this damage occurs, recovery is usually much more difficult because of the following factors:

- The damage is much more diffuse—in many different buildings rather than concentrated in key lines and substations.
- The damage is likely to be hidden and inaccessible within the structure of a building.
- The individual owners of the buildings are unlikely to have the technical knowledge employed by the utility. This lack of knowledge can lead to unwise and unsafe recovery actions.
- Restoration efforts can be dangerous for public safety workers, with the structural integrity of buildings damaged or destroyed completely.

12.2 Electrical Equipment Safety

Safety is a significant issue when recovering from the flooding that occurs during storms like Hurricanes Harvey and Maria. Electrical and electronic equipment that has been submerged should never be reenergized without being thoroughly inspected by competent technical personnel. Equipment that has been submerged is likely to have debris and damaged electrical insulation that can cause fires and shock hazards when the devices are energized.

This applies as much to electrical equipment as it does to the wiring of a building. All manufacturers of circuit breakers, for example, require that those devices be replaced after being submerged. The corrosion and dirt left behind affects their calibration and ability to trip, leaving them ineffective for their critical protective functions.

The enclosures that hold the circuit breakers can sometimes be cleaned and refurbished by factory service personnel, but this is usually only cost-effective for the largest gear. For smaller load centers, replacement is usually less expensive.

If the infrastructure within a building has not been damaged, there is still the issue of providing the building with electrical power until utility service is restored. Hospitals and other critical facilities have long had onsite standby generators. As electricity has become more vital to leverage other energy sources, more facilities are required to have at least some level of standby generation. For example, Florida requires some gas stations to have generators to run the pumps in the event motorists need to fuel up for an evacuation.

12.3 Backup Generation

Backup generation is becoming just as important in emergency preparedness as having a 3-day stockpile of food and water. Less than 5% of homes in the US have backup generation, but this percentage is growing. Most often this backup generation capacity is not enough to replace the utility completely, but it is enough to operate critical devices, run HVAC blowers for heat, charge phones, and run refrigerators so food will not spoil.

Standby generators can range from small portable units to larger machines that are permanently wired to the building. In all cases, a few key concerns must be addressed:

- There must be a means of transferring the load from the normal utility source to the generator. For a portable unit, this can be as simple as unplugging an appliance from a wall outlet and plugging it into the generator, but for a larger generator wired into a building electrical system, some type of transfer switch is needed. This switch may be a manual transfer switch that requires someone to physically operate the switch or an automatic transfer switch that switches power to the generator when it is running and then back to the utility when it is restored. No human action is needed to make these switches. The transfer switch also includes an interlock that keeps the generator from back-feeding power to the utility.
- It is essential that generators only be connected to a building electrical system using a listed transfer switch installed by a knowledgeable electrician. If a user connects a generator to the facility wiring without disconnecting the utility, dangerous conditions can result. First, power going out on the utility lines

causes them to become energized, which can electrocute line workers. Second, when power is restored it will be out of phase with the generator and can cause catastrophic destruction of the unit (e.g., a fire or flying shrapnel).

- More sophisticated transfer switches can warn of overload conditions or even rotate power among loads to optimize generator use. Some building owners or homeowners opt to install generators large enough to completely replace their utility feed, but in many cases this expense is not warranted. Smaller generators can be used to operate only key loads, but it is possible to overload those generators if too many appliances are switched on. While the generator has circuit breakers or shutdown devices that intervene to prevent damage to the unit, this will cause another power disruption and key loads, such as freezers, may be left without power.
- There must be enough fuel to operate the generator for the intended standby period. Depending on the type of engine on the generator, this may be gasoline, diesel, propane, or natural gas. If natural gas is used, the stability of the gas main during a widespread outage must be evaluated.
- The siting selection for a generator must be considered to avoid dangerous impacts such as carbon monoxide poisoning, noxious fumes and other indoor air quality and safety issues.

For each of these key concern areas, additional caution must be taken in the event of a flood, wildfire, or other disaster where there may be potential damage to the backup generation unit. Serious injury and damage to the generator and connected devices can result without proper precautions and backup generation inspection prior to startup.

12.4 System Upgrades

Building owners and managers should consider two more electric system upgrades. These upgrades further protect the building and the appliances and loads within.

The first is premises-wide surge protection. Surge protectors are typically installed in an enclosure with circuit breakers to protect loads, especially sensitive ones like TVs and computers, from damaging electrical pulses. Pulses are often caused by lightning or switching transients generated by reclosers or feeder switches in the utility system. During power restoration, surge protectors continue to guard from electrical surges created as work is done on the utility lines.

The second improvement is the addition of advanced arc-fault and ground-fault protection for circuits that supply power within the building. This protection is provided by circuit breakers that contain electronic sensing equipment, providing improved protection that can sense broken wires or damaged electrical insulation and remove power from a circuit before a fire begins. In most new residential construction, devices offering this higher level of protection are required by code, but they can also be retrofitted into older homes and businesses. Such a retrofit should be considered to harden the building electrical infrastructure.

12.5 Recommendations for Preparing for Generator Installation and Use

Follow these next steps for generator use to ensure preparedness in case of a disaster:

- Evaluate the size of generator needed based on key loads required to run during an extended outage.
- Decide if the generator will be fixed mount or portable.
- Decide on the type of engine and fuel it will use.
- Look at the physical placement options for the generator. While this is needed for fixed mount units, there must also be a plan for portable units. Indoor operation is never an option because it is extremely unsafe.
- Consider how the generator will be connected to appliances. If existing building wiring is used, decide on the correct type of transfer switch—manual or automatic—and the features required.
- Look at the connection point in the building electrical system. Determine if it is possible to electrically isolate and connect to a point that is higher than any anticipated flood waters.
- Find a qualified electrical contractor that will install the transfer switch and generator; see that the generator is inspected as required by local codes.
- Verify adequate fuel supply and test the generator and transfer switch on a regular basis to verify correct operation.
- Consider adding premises-wide surge protection at the circuit breaker enclosure.
- Consider adding arc-fault and ground-fault circuit protection in the electrical infrastructure.

Section 13

Upgraded Wire and Cable Systems Can Accelerate Storm Recovery

13.1 Introduction

Storms have the potential to inflict massive damage on electrical wiring systems. Hurricane Harvey and other recent storms have illustrated the devastating impact that wind, snow, ice, and flooding can have and the pervasive damage extreme weather can inflict on to infrastructure. The technologies, materials, and practices chosen to rebuild with should benefit from the lessons learned. Wire and cable can play an important role in hardening the electrical system for future storms.

The reliable delivery of electricity requires that every foot of wire and cable along the path—from the transmission line to the wire behind the outlet—be valued at initial purchase cost and for its ability to withstand damage from storms.

Homeowners, C&I business owners, and utilities will incur significant costs as they rebuild their wire and cable networks. The design of replacement circuits should ensure they are located out of harm's way when possible and buried underground when appropriate. Furthermore, the materials selected should be the most rugged available and suitable for wet locations.

13.2 Install Wire and Cable Solutions More Resistant to Storm Damage

In the rebuilding effort following hurricanes, floods, and other major storms, the question of how to rebuild existing circuits and what cables to install are key considerations. Many cable constructions can withstand storm damage, such as submersion, as well as mechanical loads and impact. Installing wire and cable that have specific performance characteristics (e.g., water-resistant or ruggedized) and using installation methods that reduce exposure to the elements (e.g., relocation, undergrounding, redundancy) can improve an electrical system's protection from storm damage.

13.3 Effect of Flooding

Much of the storm-related damage to cables occurs because the flooded wiring is not designed to withstand submersion in water. In the low lying neighborhoods of New York City, for example, many residential basements are flooded when major storms strike, damaging the residence's electrical system and leaving occupants stuck in the cold and dark.

This problem is compounded by the fact that, due to safety precautions, electrical equipment must be inspected before the power can be turned back on. The reason for this is that NM-B conductors, commonly used in residential wiring, are rated for dry applications only. After being exposed to water, they are subject to corrosion and may become a shock hazard.

In many cases, a solution can be to install robust wet-rated cables indoors in any area that can be exposed to flood waters. The NEC defines wet locations in Article 100: "…installations underground or in concrete slabs or masonry in direct contact with the earth, and locations subject to saturation with water or other liquids, such as vehicle washing areas, and locations exposed to weather and unprotected." Wet locations require moisture-resistant, wet-rated cables.

13.4 Impact of Wind

When replacing pole-mounted T&D circuits in the wake of storms, serious consideration should be given to underground installation, especially for critical distribution lines and those lines that have histories of weather-related disruptions.

Underground installation can reduce outages related to external factors such as wind, downed trees, and flying debris. Reducing exposure to these threats can significantly reduce customer interruptions and outages. The relative costs of underground and overhead options can vary substantially for individual projects, making generic value-to-cost ratios of limited use.

13.5 Key Technologies, Applications, and Products

The key technologies discussed in the following section can be implemented in many application areas: high voltage transmission and medium and low voltage distribution in industrial, commercial, and residential installations.

13.5.1 T&D

13.5.1.1 High Voltage Underground Transmission

When upgrading line capacity, storm hardening existing lines, or installing new lines, installers can benefit from using underground high voltage cable systems. Available from subtransmission voltages at 69 kV all the way to extra-high voltage levels of 345 kV and beyond, cables using extruded dielectric insulation have been used in North America for decades.

These highly engineered systems have a history of high reliability, minimal maintenance, and are largely immune to high winds and flooding. Despite the advantages that high voltage underground transmission brings, it is important to consider that these lines are often 10 times as costly to install as their overhead alternatives. In many of the country's most urban areas, these underground lines are often required, but they may not be the best choice in much of the rest of the nation.

13.5.1.2 MV Distribution

Underground power distribution cable systems at voltages up to 46 kV can use a variety of cable constructions suitable for direct burial and submersible installations. State-of-the-art cables include moisture-resistant conductors, water- and tree-retardant insulation, and weather-proof shielding and jacketing options. Combined with the right accessories, transformers, and switchgear, main feeders converted to underground cable systems provide a major benefit to infrastructure.

There are also better alternatives to standard overhead lines. Covered aerial MV (CAMV) systems can greatly improve the reliability and reduce the vulnerability of overhead distribution during major weather events. Treed areas, narrow rights of way, coastal, and multiple circuit installations all benefit from covered aerial MV's compact, long-span designs, and ability to operate through intermittent tree contact.

13.5.1.3 Cable-in-Conduit

Cable-in-conduit products provide installers with a conductor of choice already installed in robust plastic conduit on reels ready for direct burial in a trench, allowing for rapid cable replacement. Additional cable protection and reduced outage times increase reliability for low voltage and MV applications from streetlights to feeder cables.

13.5.1.4 Self-Healing 600 V UD Cables

Self-healing cables limit minor insulation damage to underground 600 V cables. Channels between insulation layers hold a sealant that flows into insulation breaks and seals them permanently, preventing the corrosion failures otherwise unavoidable when exposed to moisture. Applications range from service to the home to streetlight and agricultural applications.

13.5.2 C&I Applications

Using wet-rated products in C&I applications, especially in critical circuits, can reduce the time and cost to restore operations after flooding.

13.5.2.1 Type MC Cables

Wet-rated products such as jacketed Type MC multiconductor armored cable can be used indoors where the conductors could be exposed to flood waters. The cable armor also provides crush-resistance in case of building damage. Although the individual conductors within Type MC cables are moisture-resistant, another level of protection can be added by sealing the open ends of the armor on the cable, which prevents water that may be carrying contaminants from entering the cable assembly. Type MC cable is available in 600 V ratings and also in MV ratings, with conductor sizes from 18 AWG to 2,000 kcmil.

13.5.2.2 Type TC Cables

Type TC cables are used for power and control applications in industrial installations. These cables are heat-, moisture-, and sunlight-resistant. They provide a moisture-resistant jacket over the conductors to protect them from water damage. Type TC cables are rated for use in wet locations. They can be installed indoors or outdoors, direct buried, in conduit, or in metal cable trays.

13.5.2.3 Heavy Wall Insulation for Single Conductors

In single conductor applications, rugged heavy wall conductors, such as RHH/RHW-2/USE-2 multi-rated, provide an insulation thickness of 0.045 inches of cross-linked polyethylene (XLPE). These conductors have better resistance to moisture and physical damage, and can withstand severe conditions better than thin wall insulated conductors such as THHN/THWN (0.015 inches of PVC and a 0.004-inch nylon jacket) and XHHW (0.030 inches of XLPE).

13.5.2.4 Residential Applications

Residential wiring in basements and other vulnerable areas can be made more flood-resistant by substituting a wet-rated product such as UF-B for the commonly used dry-rated NM-B. This substitution may allow power to be restored to residences quicker without extensive wiring replacement.

13.6 Recommendations Contractors and Building Owners Should Be Prepared for Storm Recovery

Contractors and building owners should proactively plan for storms and emergencies by following the below recommendations:

- When building or rebuilding, specify standard manufacturer’s catalog products so warehouse stock is available quickly from sources across the country.
- Be prepared to access help from other parts of the country and know contractors and manufacturers who are familiar with the type of construction and wire and cable products typically used locally.
- Understand the variety of key technologies available to manage the risks associated with wiring and cable systems in storm restoration. A deep understanding of the available options creates a more resilient system.
- Proactively make a connection with a reputable wire and cable manufacturer who is knowledgeable about moisture-resistant cables and can provide emergency support for engineering, installation, and repairs related to flood damage.
- Have a recovery plan with distributors and manufacturers, including and understanding of who to call, what to order, and how to get the materials quickly.

- Know ahead of time manufacturers and trade associations that can be contacted for the latest recommendations in managing storm damage. For example, NEMA and UL have industry positions on managing flood-damaged electrical products. Be familiar with this information.

Know processes for replacing water-damaged cable, including:

- Know what equipment and effort will be needed to replace damaged wire and cable.
- If an electrical system has become wet, have it inspected by a qualified electrician before reenergizing it.
- It may be possible to pull new conductors into metallic conduit, but the conduit must be inspected by a qualified person to confirm the conduit's integrity and that it is free of any foreign objects.

Section 14
Submersible Transformers, Switches, and Switchgear

14.1 Introduction

When Hurricane Maria made landfall in Puerto Rico, a storm surge of 9 feet was measured, with wind speeds of 155 miles per hour. Overhead lines were destroyed, and underground electrical distribution equipment located in flood-prone areas was swamped, resulting in the catastrophic disruption of the Puerto Rican electric grid. Little of Puerto Rico's electric infrastructure was underground; if it were, some of this damage may not have occurred. Despite this, underground distribution systems are extremely hard to repair and can be costly, especially compared to the cost of repairing overhead lines.

This experience in Puerto Rico has highlighted the need to make underground distribution systems more resilient to flood-related damage. The deployment of switchgear specially designed for subsurface application in vaults subject to flooding can help achieve this goal. This type of switchgear can continue to function indefinitely when subjected to flooding from water containing typical levels of contaminants such as salt, fertilizer, motor oil, and cleaning solvents.

High speed fault-clearing configurations of this switchgear are available for application in networks that provide essentially interruption-free service; a fault occurring in any segment of the network is rapidly cleared and automatically isolated, but service to customer loads is not interrupted (or the interruption is minimal).

14.2 Submersible Transformers and Switches

Two products that fall into this category are submersible transformers and switches. These are essentially the same as the transformers and switches used in distribution grids all over the US. The difference lies in the capability to operate underwater.

Such devices are used primarily in cities where much of the power infrastructure is below street level. The vaults that house such equipment may lie well above the flood plain but are susceptible to localized flooding during exceptionally heavy rains. Transformer vaults, in particular, typically have a grate at street level to allow heat to escape, but this also means they are exposed to street-level runoff.

Submersible transformers use a variety of materials and design features to ensure continuous operation: a sealed tank, less corrosive steel, corrosion-resistant paint, high resistance to short circuits, increased capacity to support overloads, and the ability to withstand seismic events. The tanks are also designed to direct fluid downward in the unlikely event of a rupture to minimize the expulsion of material upward to street level. Some transformers use no fluid insulation, eliminating the risk of leakage or fire associated with oil insulation. The design of submersible switches is similar in terms of materials and performance.

While submersible devices have been used for years, they have become more common recently. Switches in particular offer a good example.

While distribution grid operators could manage outages at the substation level historically, the application of switches provides a much finer level of control. In other words, instead of taking down large sections of a city, a utility could isolate flooded areas more precisely. Having submersible switches in place means the utility can continue to operate those devices—remotely—even when the surrounding area is completely flooded.

In the wake of mounting storm severity and frequency over the last decade, utilities have begun to reassess their ability to handle flooding on a wide scale. Con Edison in New York elected to install submersible switches at key points on its distribution grid and employed them during Sandy, shutting down sections of lower Manhattan. While power is being supplied via alternative pathways, the submersible switches help speed the recovery process by allowing power to be restored to the primary circuit as soon as the surrounding equipment is determined to be safe.

14.3 Submersible Automated MV Switchgear

In addition to submersible transformers and switches, MV switchgear is available featuring load interrupter switches and resettable fault interrupters installed in a gas-tight tank that contains pressurized gas insulation. This type of switchgear can be furnished in submersible models suitable for installation in vaults subject to flooding. In these models, the tank is manufactured of Type 304L stainless steel to guard against corrosion due to the extremely harsh environmental conditions. The tank is capable of withstanding up to 10 feet (3 meters) of water above the base.

The switchgear includes a separately mounted submersible low voltage enclosure, also manufactured of Type 304L stainless steel. The low voltage enclosure in high speed fault-clearing configurations houses a multifunction, microprocessor-based relay for each fault interrupter in the switchgear. A multifunction, microprocessor-based relay is also applied on each substation circuit breaker feeding the loop of switchgear units. All current- and voltage-sensing wiring between the switchgear tank and the low voltage enclosure is submersible as well.

14.4 High Speed Fault-Clearing System

In this system, switchgear units are connected to each other in a loop. The relays are configured to communicate with each other through a fiber optic cable network.

The relay protection arrangement ensures that only the fault interrupters on either side of a faulted cable section open.

In closed-loop applications, both ends of the loop are fed from the same utility substation bus. With this arrangement, load is not lost while a fault is cleared, although some utility customers will experience a voltage dip.

Open-loop applications require an open switching point in the loop. This approach enables two feeders from different substations to be interconnected. However, with this arrangement, some customers may experience a 3-to 4-second loss of voltage while the normally open switch is closed.

Each relay is capable of functioning as a remote terminal unit and can communicate with the utility's SCADA primary station via process automation protocols. The remote terminal unit can accept a wide variety of inputs, such as a vault personnel sensor, vault water level sensor, vault explosive gas sensor, vault temperature sensor, and transformer voltage, current, and temperature sensors.

14.5 Recommendations

Implementing an automated underground distribution system typically involves several steps:

- Engineering analysis to determine the ideal automation strategy for the underground distribution system
- SCADA integration, if applicable
- Communication survey if the system is to communicate with the utility's SCADA system
- Project management
- Training of utility personnel
- Commissioning of the system

Section 15

Emergency Preparedness and the Importance of Equipment Repositioning

15.1 Introduction

In recent years, the US has faced several different types of major outage events, including devastating floods, tornadoes, and hurricanes to destructive wildfires. These disasters have forced utilities and infrastructure providers to reconsider and prioritize ensuring the safety and reliability of infrastructures and facilities.

In 2008, Article 708, Critical Operations Power Systems (COPS) was added to the NFPA 70 NEC to provide mission-critical facilities with a higher level of protection so these facilities will still function in the event of an emergency. The NEC mandate applies specifically to vital facilities that, if destroyed or incapacitated, would disrupt national security, the economy, public health, and safety. These facilities include hospitals, police and fire stations, emergency call centers, and government facilities involved in national security. In some cases, the directive is applied to a specific area within a facility that is the designated critical operations area. In others, the entire facility is designated as a critical operations area.

For these mission-critical facilities or designated critical operations areas within a facility, NEC requires a risk assessment be performed to identify potential hazards (natural hazards or human error), the likelihood of their occurrence, and the vulnerability of the system. Based on the risk assessment, an emergency operations plan must be developed and implemented to mitigate potential hazards. An important part of the risk assessment is evaluating the positioning of critical equipment. For instance, are backup generators elevated aboveground so they are safe from water in the event of flooding? Are the pumps supplying fuel to the generators also located aboveground so that it is still possible to fuel the generators in the event of flooding? The addition of DG and microgrids further adds to the importance of understanding the positioning of critical equipment prior to a storm or other hazard event.

Beyond these mission-critical facilities, other organizations such as schools and office buildings affected by or in potential danger of natural disaster, should consider implementing similar measures to prepare their infrastructures for disasters.

Implementing some of the protective measures included in the NEC mandate can be expensive. How can organizations that are not required to comply with it determine which of these measures is most worthwhile?

Such organizations and operations must first determine their respective desired state or the desired operational or mission capacity during critical events. For instance, what aesthetics need to be considered, how environmentally friendly do they want it to be, what building requirements do they need to meet, what hazards might occur and how likely are they, and how prepared for those hazards should the infrastructure be? And finally, how much money do they have to spend to get to that desired state? In short, in addition to a risk assessment, a cost-benefit analysis relative to their desired state and available funds must also be performed.

The factors a facility’s management has to consider when determining their maximum effective reliability needs will vary depending on the type of facility, what equipment is critical to desired operations, and where the equipment will be located. For example, a sewer plant is typically located near a body of water, so it is subject to flooding. As a result, when weighing potential risks and the cost of preparing for those risks, a facility manager will likely want to focus on positioning his power and emergency systems on higher ground to prevent damage and possible power interruptions from flooding. Other types of facilities, such as data centers or hospitals, will have different risks to consider when determining reliability needs and preparing for certain risks.

During major storms, in some locations the water and sewage in basements can be up to 6-feet deep. When storms cause a facility’s power to go out, the facility can switch to generators located above potential flood levels. However, if the fuel pumps responsible for fueling the generators are located in the basement, which is underwater, the generators will fail, and the facility will remain flooded.

During Hurricane Sandy, this happened to a particular facility. Following the storm, the facility began its restoration process and took steps to better prepare for the next storm. With funding to restore the facility, including damaged electrical equipment, management decided to reposition equipment to prevent it from damage in the event of a future storm. The facility’s management installed new equipment in new electrical rooms on the first floor.

While deciding where to reposition certain pieces of equipment, the facility’s management considered several factors including cost, emergency preparedness, and future maintenance of the equipment to be relocated. For instance, to ensure ease of maintenance in the future, the contractor built in the ability to have generator backup easily implemented by adding dual main services to all of the replacement switchboards. In addition, all main and tie circuit breakers were specified to be a draw out type to facilitate an enhanced preventative maintenance program. This type of circuit breaker is easier to maintain and service than the older style (power switched with fuses).

Such discussions and actions following major storms are good examples of how facilities can look to not just recover, but recover in a way that makes infrastructure more robust and reliable. Many facilities could learn from such examples and prepare for future disasters or events by thinking strategically and investing in a comprehensive reliability assessment. An important part of that reliability assessment will consider the positioning of a facility's equipment and identify what equipment is most important to protect.

A reliability assessment allows facility managers to think beyond getting the power equipment back up and running. It can lead to longer-term considerations such as the reliability of the power distribution system and all utilization equipment, including HVAC, pumping, and communication systems, supported by power equipment. Facility managers must consider the reliability of power and critical equipment relevant to environmental factors, as well as possible external threats and how to function and maintain the appropriate and necessary levels of reliability.

Once key power and utilization equipment has been identified, facility management can consider how to position equipment to increase reliable electrical power and operations during future emergencies or disasters. Natural hazards will continue to occur. There will be an increasingly important process for all types of organizations to follow to prepare their infrastructures to weather these storms. Responsible organizations recognize that recovery from historical storms in the past is not just about getting back up and running—it is about rebuilding smarter to lessen the impact of future events.

15.2 Workforce Management and Emergency Response Planning

Dispatch protocols and the identification of priority assets and proximity response teams are key components of emergency response workforce management systems. By preemptively positioning and preparing response teams based on real-time storm or weather event information, utilities can significantly reduce the time to service restoration and increase crew member safety.

Mobile workforce management is also a key solution for utilities because hundreds of first responders and line workers are often deployed at once to assess and repair grid damage. Innovative technologies including augmented reality and the use of drones and unmanned aerial vehicles can add significantly to the productivity and safety of the utility storm response workforce. For both hardware and software, critical investments made by a utility or system operator prior to natural disasters or other asset failures will greatly affect grid resiliency and reliability when major events occur.

15.3 Equipment Relocating or Repositioning

Relocating transmission infrastructure is not feasible; however, stringing higher voltage lines and incorporating advanced sensors and control equipment will help identify and isolate problems faster, allowing utilities to expedite recovery.

Substation equipment is manufactured to meet standards, such as those developed by NEMA and the American National Standards Institute, and will perform in a wet environment but cannot be submerged. The key is keeping the energized parts separated from the non-energized parts. The substation needs to be protected from floodwaters either by barriers or being built high enough to withstand storm surge. Outfitting substations with automation, remote sensing, and control capabilities will enhance the substation's ability to adapt to and protect against outage conditions and mitigate future system failure by taking the appropriate protection and switching actions.

As a rule, higher voltage switches are mounted 10-feet off the ground, allowing switch operation if the station is still energized. Breakers, transformers, and metering inside the switch houses are also susceptible to flood damage. Utilities should consider if it is more cost-effective to build substations to withstand severe events or build them so they can be repaired or reenergized quickly. Taking distribution of power from overhead to underground is relevant for areas not prone to storm surge. An alternative investment strategy to lifting substations is to retrofit equipment with automation, protection, and control capabilities in an attempt to maintain operating through all but the most severe events and provide utilities with visibility in the event that the system does fail.

While it is costly to build underground infrastructure, it does eliminate the added costs for replacing poles, anchors, and hardware. Underground infrastructure is also more resilient to high wind conditions. The tradeoff is higher maintenance and repair costs. In areas where underground location is not a viable solution, more switching points and, in some areas, auto-restoration such as FLISR schemes can be added. This segments the system into more manageable sections, isolating damage and allowing service to be restored more quickly to smaller areas rather than waiting until much larger areas are repaired.

15.4 Recommendations

When implementing any recommendations for system hardening or storm preparation, it must be understood there is a direct correlation between average repair costs due to storms and the investment of building or relocating new infrastructure. Below are several recommendations that can help ensure utilities and communities are prepared for natural hazards and the disasters they can cause.

- **Create a national standard for equipment and structures in vulnerable areas.** Although there are standards that equipment and structures must meet to carry certain voltage levels, there is not a national rating standard for equipment in areas highly susceptible to storm damage. Products in these areas should be required to meet higher wind and flood standards to minimize outages and destruction to other equipment. Standards should also include the frequency in which products and poles/structures are inspected for damage or corrosion.

- **Work with other organizations and government offices to create a unified emergency storm response plan.** If access to roads is obstructed, line crew and other emergency responders cannot repair the damage to power lines. Therefore, it is necessary to communicate with appropriate departments to ensure a cohesive plan is in place for natural disasters, accounting for damaged or fallen communication lines.
- **Develop and present a positive business case.** Utilities are typically only permitted to recover on CAPEX with a clear and positive business case with demonstrable effects to their grids. Vendors must proactively help utilities formulate and display this business case to regulators, ratepayers, and stakeholders. Metrics for grid performance such as SAIDI, CAIFI, and others should be highlighted, as well as proposals for improved customer experience. Streamlining utility operations is a popular way that utilities seek to reduce operations and maintenance costs. Resiliency solutions often include automated data ingestion and storage, advanced analytics, and intelligent protection schemes to help utilities reduce costs. These can help utilities cut active grid management overhead and maintenance and repair costs.
- **Determine the cost-effectiveness of implementing changes to infrastructure.** In areas that see little or infrequent storm damage, it is not cost-effective to implement the same measures as in coastal or other vulnerable areas. The cost to end users to implement these changes can be vast. A simple comparison of recent storm damage costs versus the investment to upgrade equipment will help determine the areas of focus for repositioning equipment.
- **Work to harden systems and reposition equipment.** After the areas of most vulnerability are determined, consider all viable options to strengthen and reposition the existing equipment to better withstand damaging winds, floods, and ice. Consider elevating equipment above the 10-foot standard in areas susceptible to floods and areas below sea level. Reconfigure equipment on poles to better withstand large gusts of wind. When replacing poles, consider using ones larger in diameter that will have better resistance to wind. In areas with minimal flood damage, consider moving equipment and lines underground to prevent wind and ice damage to lines.

Section 16

Replacing or Upgrading Water-Damaged Electrical Equipment

16.1 Introduction

NEMA's *Evaluating Water-Damaged Electrical Equipment*,[12] published in September 2019, contains reference material to evaluate electrical equipment that has been exposed to water through flooding, firefighting activities, hurricanes, and other circumstances. The document provides a table summarizing recommended actions for various types of electrical equipment to determine whether they need to be replaced or reconditioned. New technological solutions have been developed that provide a third option: the core device (e.g., power circuit breaker, motor control center enclosure) is replaced with an upgraded device that matches the original equipment's mechanical and electrical interfaces. The upgraded device is consistent with new equipment standards and technological advancements without disturbing the primary enclosure, incoming and outgoing cable connections, or operating controls. In addition to the resiliency benefits brought on by the new upgraded device, the device will likely be equipped with onboard communications and the ability to relay information back to centralized software platforms.

16.2 Benefits of Upgrading versus Replacement for Water-Damaged Electrical Equipment

The benefits of upgrading versus the traditional replacement option are as follows:

- Costs for direct replacement upgrade devices are equal to or less than replacement equipment of the original design. The cost advantage is derived by the use of available manufactured components and devices versus tooling required to manufacture equipment that may have been in service for 10-20 years or longer.
- Delivery is faster because the direct replacement devices are in stock and the mechanical and electrical interfaces have been designed and stocked for common vintage equipment.
- New technology can be incorporated within existing structures at no added cost. Additional safety features can be included to better address arc-flash concerns and personnel safety.
- Speed of remediation is greatly increased because complete removal of the entire electrical structure is not required, cables are not disturbed, and

[12] NEMA, *Evaluating Water-Damaged Electrical Equipment*, , 2019 www.nema.org/Standards/Pages/Evaluating-Water-Damaged-Electrical-Equipment.aspx)).

equipment upgrades can be completed in intervals, allowing for selected power restoration during the remediation process. For power circuit breakers or motor control centers, individual devices can be installed as remediation progresses.

- Long-term reliability is improved by adding optional system improvements during the remediation period and includes monitoring of predictive failure modes such as humidity, temperature, dust, smoke, intrusion, vibration, floor water, power quality, or other parameters. For MV equipment, continuous partial discharge activity can also be monitored. These reliability improvements provide for audible alarms, messaging (text, voice, and email), and service dispatch depending on the needs of the customer.
    - Water damage from any body of water is usually defined as flood damage; therefore, an overhead steam or water leak can be defined as flood damage. Being notified of floor water or increasing humidity allows for immediate corrective actions, preventing subsequent electrical equipment failure.
- Life extension of existing capital investments is achieved because the critical core components and devices are being replaced with new devices.

For more examples of replacing or upgrading water-damaged equipment, including electrical distribution equipment, motor circuits, power equipment, transformers, wire, cable and flexible cords, wiring devices, ground-fault circuit interrupters and surge protectors, see NEMA's *Evaluating Water-Damaged Electrical Equipment* document.

Section 17
Disaster Recovery Planning

17.1 Introduction

The best time to plan for a disaster is before it arrives. However, for many victims of recent storms and natural disasters, this advice does not help in recovering from major damage. With today's energy management solutions and resiliency technologies, equipment can be installed and prepared before and after a catastrophic incident. By ensuring commercial facilities are retrofitted with the latest energy efficiency lighting and control systems, businesses and governments can ensure that vital operations data is preserved, and buildings and cities can come back online as soon as possible.

Smart systems, both industrial and commercial, return online and recover with little need for human intervention. As a result, businesses do not need to wait days or weeks for emergency rescue response to help mitigate damage and recover operations. Labor costs for maintenance and troubleshooting are also significantly reduced. Such reliability is essential to commercial businesses and institutions surviving a storm. For areas located in disaster zones, it is wise to install offsite backup for critical data and computing operations.

There are no one-size-fits-all templates for disaster planning. Various systems within a facility respond differently to power loss. After a disaster, power should be restored to the most critical services first, but the definition of critical changes depending on the duration of the outage. For example, freezers and refrigerated storage may be critical systems, but once the contents reach a critical temperature and the contents are lost, other loads within a facility may become more critical.

Attempting to sort out these priorities during the chaos that follows an event makes decision-making more difficult. If a disaster should occur, the consequences of electrical power loss can be minimized with established emergency procedures. Employees should be trained so they know what to do, and emergency preparedness needs to be made part of the culture of an organization.

The next sections outline three key stages of disaster management that should be addressed to ensure T&D networks remain online as much as possible. Utilities and grid operators must address each stage independently and as part of broad reliability and resiliency investments and grid modernization initiatives. Doing so helps ensure their electric grid remains reliable and resilient as global trends shift and natural events increase in frequency and scale. Utilities and grid operators should prioritize hardening in the first stage, mitigation in the second, and building a response plan for safe and swift post-storm recovery operations.

17.2 Predict, Prepare, and Protect

Utilities have invested heavily over the past several decades in storm hardening and resiliency. Much of this investment is specifically dedicated to natural disaster planning and includes the formation of strategic protocols, emergency response actions, and restoration guidelines. Utilities are working to reduce outages, improve overall safety and satisfaction, and mitigate the effect of disasters on their electric system. Lessening disaster effects is achieved through the strategic deployment of key grid hardening investment and resiliency technologies as well as the installation and maintenance of safe and secure critical infrastructure. As outages become less acceptable to regulators and more expensive to utility customers, these projects and investments are increasing in both number and size each year.

The best way for utilities and network providers to mitigate outages and operate a resilient grid is to proactively and preemptively invest in hardware and software technologies in preparation for weather and other outage events. Much of this investment will be significant and will likely involve regulators and other stakeholders, hampering the process and often delaying installation by years. However, the initial capital investment in these systems will be offset by the reduction in overall cost as each event occurs; utilities will further recover some of this cost through improvements in overall grid performance, especially with performance-based ratemaking structures.

The application of protective shielding or other hardening measure to existing grid assets increases the resistance of the asset to the effects of storms or natural event such as wind, rain, flooding, wildfires, or other natural disasters. Substations are commonly lifted 3-to 4-feet off the ground to protect against flooding, while many system electronics are often sealed in waterproof or fireproof casings or housings to minimize damage. The type of physical hardening applied to grid assets varies across regions and transmission versus distribution systems, and will align with the type of event experienced by the asset.

For software-based grid hardening and resilience, SCADA systems, ADMSs, OMSs, and other centralized and distributed software can be critical tools for utilities. These systems might be used to prepare for weather and other outage events and to assist or govern the restoration process, managing the flow of power across the network.

Actions utilities should take in the predict, prepare, and protect stage include the following:

- Obtain a qualified first response service provider with the breadth and depth of trained and experienced personnel for the facility’s equipment.

    - Spend the time to identify and meet with those resources that could be contacted for disaster support. Research provider capabilities. Make sure its personnel have toured the facility and have identified critical areas. Recognize that for widespread disasters like hurricanes, employees will be affected. Make sure the provider can source people and materials from out of the area as required.
- Perform a pre-crisis risk mitigation audit to estimate the potential impact of credible disaster scenarios and identify ways of minimizing vulnerability in the event of a disaster.
    - Perform a critical load audit to identify all loads that require backup power (may be more than what is actually backed up today).
    - Identify consequences of potential natural (e.g., flood, tornado, hurricane, earthquake) and human-made (e.g., terrorist, human error within organization) threats. This analysis should consider physical surroundings (e.g., proximity to rail, airports, ship ports, or highways) and includes financial impact resulting from the loss of that equipment.
    - Outline consequences of electricity loss (e.g., computer failure, loss of access, contamination, trapped persons, chemical release) with varying outage durations. Have a contingency plan to deal with each consequence (e.g., manual key entry backup to electronic locks). Pre-crisis audits provide the additional benefit of potentially identifying internal problems—not all problems are caused by external events—that could cause several issues including storage blocking equipment access/escape routes, missing breaker racking or lifting tools, missing drawings, etc.
- Conduct a safety audit and establish procedures to assure injury-free remediation.
- Confirm awareness of regulatory compliance.
- Identify all critical documentation and create a plan to store this information so that it can be accessed offsite in one or more safe locations. Do not assume that cloud communications will be available in all disaster scenarios.
- Consider adding local electrical power generation.
    - Permanent onsite local generation is high cost but eliminates the need to rely on a rental company having a generator when it is needed. However, this increases responsibility to ensure the system is functioning. A common solution is to contract out maintenance to a qualified engine dealer, typically the seller. Do not forget to contract with fuel providers for fuel delivery because normal fuel delivery will likely be affected after a problem strikes a wide area.

   - Add provisions for temporary power hookup. Opening and working on electrical equipment can only be done by trained, certified professionals, and this includes connecting an emergency generator. Remember, during times of emergency, trades people will be in high demand and short supply as the hard work of restoring power begins. Consider having provisions already installed to allow simply plugging in a backup generator.
   - Alternative energy sources, such as a solar energy system, are typically designed to operate when utility grid power is available and automatically shut down when utility power is lost; however, in times of emergency, having electrical power is highly desirable. Meet with a solar installation provider or a qualified engineering service provider to explore ways to configure local alternative energy sources into an island or a microgrid on an as-needed basis. This may involve adding protective devices or devices to automatically shed lower priority loads because alternative energy is rarely sized to power an entire building's load.
- Identify sources of equipment repair and replacement. These sources should be certified for the equipment installed. Because many facilities are older and may include electrical equipment from a variety of electrical vendors, look for sources that have the certification or other demonstrated proficiency to repair, renovate, and renew the electrical equipment installed at the facility.
- Make sure contracted support organizations have expertise in staging support equipment including generators, replacement electrical equipment, and satellite communication networks.
- Develop a plan for living and support accommodations for an in-house crisis response team and ensure that contracted support teams are similarly prepared. Food, water, and sleeping accommodations may be in short supply so make sure support teams can support themselves.
- With a radio communication system, confirm its operability following an electrical system failure. Typically this involves supplying power to chargers and repeaters.
- Document the equipment installed (brand, model, serial), device settings, and software (vendor-provided and user purchased). Update documentation when purchasing or changing equipment or settings. Make sure new staff members are trained on this procedure as previous staff leave. Have clear responsibilities as to who is responsible to keep the data updated.

17.3 Withstand and Mitigate

During a storm or other natural disaster, utilities are often limited in their capacities to safely deploy response crews to affected areas. Recovery work can rarely begin until a storm or wildfire has passed, especially if there are areas of dangerously exposed and destroyed equipment and electric infrastructure. As the effects of the disaster pile up, the consequences of utility investment (or lack thereof) in prediction, preparation, and protection strategies will directly and adversely affect its response actions during the withstand and mitigate phase.

If a utility or network operator has invested in appropriate systems and technologies with high levels of automation and remote monitoring and a strong software platform, it likely maintains a relatively uninterrupted picture of its overall network status. FLISR systems work autonomously, and real-time asset monitoring allows operators to control power flows in and across circuits throughout a major event. Response teams are assigned to critical dark assets for inspection and damage assessment, often held on standby, waiting for a safe opportunity to act. With advanced weather forecasts, utilities can strategically manage response teams to safely act during breaks in a storm. Once a major outage event strikes, however, most utilities immediately begin planning for response and recovery.

17.4 Respond and Recover

The storm is over, thousands of customers are likely without power, and it is time for a utility to restore its network. Safety is the utmost priority while utility response crews are dispatched far and wide to inspect, assess, and repair downed lines and poles, flooded substations, and other damaged T&D assets. The respond and recovery phase heavily relies on system visibility maintained by the utility throughout the event. With advanced remote monitoring and automation, a utility will know which key assets have been affected and will dispatch response crews or manually reroute power as needed.

Actions utilities should take in respond and recover stage include the following:

- Depending on how widespread the disaster, recognize that failure of communication systems may prevent contacting service providers. Consider prearranging with those providers to check-in following a wide area event.
- Execute disaster recovery plan. Mobilize disaster recovery team, each with assigned tasks.
    - Team will include internal company personnel and external contractors.
    - Use established team leaders to prioritize tasks. Consider outsourcing project management for specialty items such as electrical equipment repair or restoration.
- Flood waters conduct electricity. Entering a flooded building, especially rooms containing electrical equipment, is dangerous. Only trained personnel skilled in operating in this environment should enter such a facility.
- Once a disaster hits, do not panic. Choose electrical service providers carefully. While qualified service personnel may be in short supply following a wide area disaster, be careful in the rush to find support. Hire only qualified

service providers. Several manufacturers of electrical equipment have programs where electrical service providers are certified by the manufacturer. Review their recommendations by visiting manufacturers' websites. A listing of electrical equipment manufacturers is available at www.nema.org/mfgs.

- Once recovery from a disaster is complete, spend time reviewing what worked, what did not, and what could have been done differently or prevented. Update the plan as equipment is bought, upgraded, changed, or repaired.

17.5 Recommendations

Throughout each of the three critical stages of disaster management outlined above, it's critical that utilities, vendors, and communities take certain steps to ensure a swift, efficient, and safe recovery for the electrical system and the broader community. These steps and recommendations are outlined below.

- Develop a relationship with a proven service supplier.
- Review and understand critical power points within the operation.
- Analyze opportunities for alternative power and backup generation for critical power loads.
- Evaluate the EMS that is right for the facility. Lighting and energy solutions companies can evaluate the size of the facility, nature of business and operations, disaster threats (e.g., earthquakes or flooding), and other considerations to recommend and quote newer, smarter technologies suited to specific needs.
- When a new system is installed, ensure it is properly programmed for emergencies. If possible, connect the system to the building automation system's emergency protocols. Run diagnostic tests to ensure that lighting and data recovers in the event of emergencies.
- If the utility experienced storm damage, explore retrofit options. For example, energy harvesting wireless solutions are ideal for replacing and retrofitting damaged buildings. They can be placed and programmed in minutes, and do not require pulling wires. As a result, essential business functions can continue uninterrupted, expediting recovery.
- Investigate upgrades for existing systems. If the utility has already invested in a distributed control or centralized control system, investigate what options are available to upgrade to newer, smarter technologies with reliable recovery and constant data preservation. These improved technologies are safer with higher voltage ratings and much speedier, smoother recovery times after power interruptions.

Section 18
Wildfire Mitigation and Resiliency Technologies

18.1 Introduction

In addition to the ongoing threat of major storms such as hurricanes, the US is witnessing record-setting wildfires. Similar to storms and other outage events, wildfires bring significant risk to utilities and the electric grid. With much of the world's electric infrastructure built as overhead lines with wooden poles, the risk of major network destruction and wildfire-caused power outages is high. Utilities must be prepared to mitigate wildfire damage and enact a strong recovery plan for events in which damage occurs. Beyond mitigating wildfire damage should a fire occur, it is critical that utilities take actions and deploy technologies onto their networks to prevent wildfire ignition due to asset failure, vegetation-based outages, and other scenarios.

18.2 Wildfire Mitigation and Resiliency Technologies

Utilities can deploy a number of established technologies to prepare for the current and future impact of wildfires, as well as several key emerging technologies that will pave the way for further resiliency and recovery enhancements. The list below highlights these technologies.

- **FLISR:** A self-healing grid with strategically placed intelligent switches, relays, reclosers, and other devices to increase a utility's fault recognition speed to dispatch a crew for repairs. In the event of a network condition that causes an ignition risk, a FLISR system can ensure power is cut to at-risk locations and routed through safe, healthy networks.
- **Remote substation monitoring:** T&D substation monitors with asset health information and operating condition monitors and can detect outages and ignition conditions. Ambient temperature sensors may also determine if an asset is failing due to fire or if the asset temperature is high enough to promote ignition. With remotely monitored assets in substations and on T&D lines, utilities remain aware of their network status.
- **Line monitors and smart sensors:** Line monitors can detect outage conditions, line temperature spikes, and ignition risks. Some sensors can detect voltage fluctuations that may be indicative of outages or ignitions on other parts of the connected transmission or distribution networks. These sensors are equipped with communications capabilities and can stream real-time network condition data back to the utility, integrating with SCADA, ADMS, or other sensor data management system.
- **Microgrids:** Microgrids will become a key source of backup local generation for when centralized power goes out. Outages that result from wildfires can be

restored by connection to a microgrid, and preventative outages, such as the rolling blackouts conducted in California in the summer of 2020 to mitigate wildfire risk, can also be offset with microgrids and DG to maintain power through planned outage scenarios.

- **Smart meters:** smart meters can communicate over mesh or point-to-point networks to inform utilities about whether the power to a specific meter is on or off. During wildfires, this information can be used for firefighting operations and to ensure that power has been cut to at-risk locations. Newer smart meters can be equipped with transformer load monitoring and voltage-reading capabilities, which can detect small differences in voltage profiles that may signal an outage or ignition somewhere on the network.

  Connected reclosers and automated sectionalizers SCADA or ADMS-enabled and connected reclosers prevent lines from being reenergized after a fault. This prevents potentially dangerous ignition threats and notifies the utility of the condition in the specific network segment. Sectionalizers allow a grid to be divided up into smaller sections, isolating at-risk or faulted sections while maintaining flexibility across other sections.

- **ADMS, OMS, EMS, and SCADA:** These network management platforms allow utilities to monitor and manage the condition of their networks. Transmission substations and some distribution substations are equipped with SCADA, while ADMSs and DERMSs are growing into more popular options across microgrids, distributed energy systems, and distribution networks. For wildfire mitigation, a grid management platform can help utilities manage outages, manually or automatically reroute power, and cut power to areas of the system with high ignition risk. These system can pull in data from distributed sensors—for example, wind sensors out on transmission lines—and help utilities take the appropriate and safest action.
- **Drones and unmanned aerial vehicles:** With a fleet of unmanned aerial vehicles, utilities can routinely and cost-effectively inspect T&D lines and substations, capturing high resolution imagery at a fraction of the cost of using a helicopter for inspection. These images are then analyzed by image recognition analytics suites, and the utility is notified of any high risk assets. Drone inspections have proven to be more effective at identifying broken insulators, dusty bushings, and broken bolts on poles and towers than helicopters. Additionally, after a wildfire has occurred, utilities can deploy drones to inspect potentially unsafe or remote areas without putting workers or firefighters at risk and improving resiliency and network restoration operations.
- **Vegetation Management:** As much as 50% of utility-caused wildfires begin as a result of vegetation coming into contact with energized lines. Utilities can leverage advanced vegetation management schemes to drastically reduce wildfire ignition risk. Platforms such as GE's Visual Intelligence can

autonomously scan images, and using AI and machine learning, recognize network and asset characteristics indicative of high risk vegetation growth. Utilities that serve customers in high wind, dry, or other wildfire-prone areas must consider enhancing their vegetation management strategies to proactively mitigate vegetation-caused ignitions.

18.3 Roadmap Recommendations and Strategies

A cohesive and collaborative strategy involving some or all of the technologies above is key to reducing utility wildfire ignitions and rapidly restoring power in affected areas. Once a fire has begun to consume an asset, often little can be done to reduce damage to non-hardened assets (similar to a flooded area), but much can be done to prevent ignition and improve resiliency after the event. Several recommendations for wildfire mitigation and resiliency strategies are listed as follows:

- Identify the high risk sections of the network and prioritize mitigation and resiliency investment in those areas.
- Use high resolution predictive wind and weather forecasting platforms to predict when and where a wildfire may occur and take the appropriate action to mitigate if possible.
- Use a holistic portfolio of grid sensors, data collection devices, and condition monitors to maintain an accurate real-time snapshot of grid conditions at all times, especially before and during high risk dry and windy weather conditions.
- Automate T&D networks with connected automation schemes in all high risk areas and as many lower risk areas as possible to minimize the effect of wildfires across the network and to mitigate ignitions.
- Use an asset maintenance and replacement schedule that prevents asset failure, which can lead to ignition. Platforms that incorporate condition monitoring and connected automation schemes can produce predictive maintenance recommendations, further decreasing the likelihood of asset failure.
- Prepare a wildfire response action plan for power restoration and asset reconstruction if necessary. Supply repair and maintenance crews with drones and unmanned aerial vehicles for site surveillance and onsite operations. Prepare crew mobilization asset and maintenance schedules for affected areas.

Section 19

Prioritizing Strategic and Effective Investment and Necessary Upgrades – The Graceful Degradation Principle

19.1 Strategic and Cost-Efficient Investments for Present and Future

With a toolbox full of technologies, utilities and solutions providers must work collaboratively to produce and deploy systems and platforms to prepare for, withstand, and recover from storms and natural disasters while bolstering resiliency and reliability. This does not mean that investing and integrating in critical resiliency and outage mitigation technologies will be easy, as current cost-of-service recovery and spending models tightly govern utility capital expenses. Utilities must think ahead, be flexible, accept help, and constantly reevaluate options to ensure the operation of a hardened and resilient grid. This section outlines key strategies that should be considered by utilities seeking to address resiliency on their electric grids.

19.1.1 Thinking Ahead Ensures Preparedness

Storms, wildfires, natural disasters, and other major outage events are nearly guaranteed to occur every year and seemingly with more strength and scale each year. They will also be worse in some regions than others. The process for large capital expenses such as grid hardening projects involves regulatory case development, litigated proceedings, implementation, and often spans more than 3 years, sometimes resulting in a failed proposal.

Assuming the rate case and regulatory proceeding are successful, it is critical that utilities take a holistic view of their network's key weaknesses and issues that need to be addressed now and down the line, particularly when considering weather trends. Use of a proven but aging technology may be more likely to pass through regulators. However, if the technology immediately becomes obsolete or outdated, the utility has wasted time and money and likely will need to replace it again soon, especially in light of natural disasters increasing in frequency, cost, and damage. The grid is changing fast, and utilities need to think ahead to keep up. Grid investment and outages continue to get more expensive. When planning for current and future grid investment, utilities must weigh the costs and benefits of resiliency technologies versus the results of inaction.

19.1.2 Flexibility Enables Balanced Solutions

Historically, utilities and their regulators have been resistant to business model change or wholesale grid overhaul projects. In a monopolized market, utilities are urged to keep spending down and are often hesitant to adapt proven and more effective methods if they come at a cost. The market for resiliency and grid hardening technologies provides utilities with a wide range of options. Options include more affordable, targeted reliability improvement such as line sensors or more significant upgrades such as lifting substations by 3 feet to eliminate flooding issues or hardening a transmission network to prevent wildfires. Utilities need to have a flexible mindset when working toward achieving the ultimate goal of high reliability. Key grid areas may need to be prioritized. With flexible systems and a flexible mindset, grid performance will improve markedly, even in light of an increase in natural disasters.

19.1.3 Collaboration Breeds Innovation

In addition to flexibility and foresight, utilities must continue to allow vendors to supplement their in-house software and hardware development capabilities. Major software vendors have built dedicated and extremely complex asset management suites for data collection, analysis, and asset integration with storm management disaster response systems. Some major utilities insist on building their own system, a process that can take years and millions of dollars. In keeping with trends, an in-house software system is likely to be limited compared to some of the most advanced offerings in such a competitive market. Utilities and customers will always benefit from the integration of the best products available. With collaborative efforts on the part of both the utility and the solutions provider, innovation across and within segments and groups will provide utilities with more superior solutions than they may be able to purchase off the shelf or build themselves. The hardware retrofitting and upgrade process can be expensive, and utilities should allow vendors to supply them with the equipment they feel best suits the needs of their network and their customers.

19.1.4 Constant Reevaluation is Critical for Future-Proofing

As utilities plan for tomorrow, they must also keep watch over and address the demands of today. Weather events and natural disasters occur globally—sometimes with little-to-no warning. If a utility undertakes a DA integration, the full process may take 3 years or longer. In the meantime, the utility needs to evaluate its current system and approach every problem with a new, innovative, and efficient solution. It is critical that a utility understand the demands of its grid now and into the future while addressing risks and potential weaknesses with the best solutions available.

New, innovative grid hardening and resiliency technologies are brought onto the market all the time. Responsibility falls on both suppliers and their customers to ensure they are optimizing resources to maximize grid reliability throughout a future full of outage events. Utilities must not rest with current systems, technologies, protection schemes, or recovery efforts. Instead, they must continually improve all aspects of grid hardening and resiliency across the board. The technology is here, and it is up to utilities to use it.

19.2 What Should Guide Future Upgrades?

Utilities should strive to construct their grid as a well-thought-out system, something that improves and grows over time as weaknesses are addressed and strengths are added. Additionally, it is critical that the T&D grids are built out and improved over time, with marked advances over current systems, but without risking reliability.

In today's IT-driven world, this concept is called graceful degradation. In the context of upgrading the electric grid, it can be viewed as an approach for prioritizing necessary upgrades. It would work off a concentric network of normal configurations that successively decrease into circles of priority until reaching a central core that must operate at all times. This smallest circle would have the highest reliability requirements. Many could view this circular map as starting at the utility feeder, then defining microgrid areas, then limited campuses, and ending at individual buildings.

This concept calls for a paradigm shift away from standard interconnected designs to delivery models that do not primarily depend on a single source of energy. Restorative automation is one aspect of this design, but it extends further to a grid design that has layered levels of supply loss under emergency conditions.

19.3 A Smarter Grid

Before proceeding, an implementation of basic, cost-effective elements of a smarter grid needs to take place to ensure more resilience in the current system. Such elements include the following:

- Increased network redundancy supporting multiple supply paths
- DA reconnecting customers
- Remote SCADA monitoring and control to better assess the current conditions and manage safety
- Outage management to efficiently guide restoration
- Load and voltage restoration analysis to avoid restoration problems

A key concept at this phase is interoperability. Optimum effectiveness and efficiency will not be attained unless the OT and IT used for systems monitoring, controlling, analyzing, and managing key aspects of day-to-day and emergency operations is integrated. Systems today are more open and allow integration from existing systems into newer ones.

When building a portfolio of resiliency and grid modernization offerings, it is critical that vendors and OEMs provide utility customers with a variety of options to suit specific needs. In addition to specific and standalone equipment and products such as reclosers, switches, sensors, and others, vendors must provide integration options for software, communications, and cybersecurity solutions. Without these, utilities are likely to look elsewhere when selecting a partner.

Partners and vendors must offer flexible solutions that are interoperable with multiple platforms, communications networks, and utility personnel. It is unlikely that a utility will overhaul every grid software and communications platform as part of grid modernization initiative. A successful vendor will be one that can tailor its solutions to match the requirements and interoperability needs of the utility.

It would be beneficial for utilities with more than 50,000 connected customers to have a geospatial information system to locate assets, a DMS to visualize and control the network, and an OMS for automatic handling and response to trouble calls. This would speed assessment and response to issues in the network and facilitate communication with consumers.

19.3.1 Infrastructure: Working Toward Self-Sustaining Electrical Islands

Maintaining critical infrastructure such as hospitals, prisons, police and fire stations, and streetlights requires more than just backup generation for isolated buildings or systems; it requires self-sustaining power infrastructures such as embedded microgrids. Essentially, in a major storm or event, the availability of electric service should degrade gracefully into self-sustained areas according to layered priorities assigned to different load areas.

Local generation and storage allow sections of the power grid to operate independently in an intentional island mode during a major grid disturbance, such as the recent widespread outages caused by some of the strongest storms in history. Efficiency is increased by locating generation close to the consumption, which reduces costs and losses associated with transmission.

A microgrid will use DER (power generation) throughout its system to provide power when disconnected from the main grid. This typically includes a combination of thermal generation and renewable generation. Importantly, the microgrid can be scaled for different applications and implemented at military bases, critical care facilities, hospital complexes, assisted care campuses, and other designated high priority areas or cells, which essentially aggregate and coordinate load and supply in a defined area. When implementing these microgrids, designs should include important modernizing technologies including alternative generation sources, grid stabilization equipment, grid management software, energy storage, and a communications network. In areas where it is possible, utilities and microgrid operators should consider interconnecting several microgrids to create a self-sustaining and inherently flexible electric grid for emergency facilities and other key infrastructure components.

New microgrids will use multiple renewable and alternative fuel generation sources (wind, solar, fuel cells, and natural gas) that can provide power to multiple loads. These alternative power sources will not only allow redundancy but also reduce dependency on fossil fuel generation.

19.3.2 Gas-Insulated Switchgear: Protecting Power Sources from Water

MV switchgear, especially for electrical substations, is available in gas-insulated form. Gas-insulated switchgear is contained in a fully sealed vessel, which means that all electrical conductors and vacuum interrupters are protected from the environment. This type of containment makes MV switchgear conductors resistant to water contamination. Furthermore, the insulated cables that connect the gas-insulated switchgear use a type of connector resistant to temporary submersion. While gas-insulated switchgear is not normally designed to be operated in a submerged condition, it is likely that it would withstand a major interruption if temporarily immersed in water.

19.3.3 Reliability Enabled with Communications Capabilities

Advanced reliability improvement technologies offer protection for overhead radial lines. These technologies are capable of almost completely removing the effects of temporary fault currents on radial lines and, when applied with unique fault-clearing speed (one-half cycle), can also protect the fuse in the case of temporary faults. These technologies are usually designed to be installed in a series to the fuse. When the technology senses a fault current, it will open and stay open for a predetermined time (dead time). It will then close again and remain closed. If the fault is temporary, the radial line is reenergized. If the fault is permanent, the fuse will blow, protecting the system.

To minimize installation and operating costs, these advanced reliability improvement technologies are often offered as part of an integrated system of tools and accessories. One of the most important components is the communications module, which allows the crew to interface with the technology from the ground level using a laptop or handheld device. All of the different system components, when working together, permit easy installation, fast commissioning, and reliable operation in all conditions.

Many modern installations take this process one step further and enable distributed devices to communicate directly with a local substation and then further to a SCADA or ADMS for holistic network management. This brings additional resiliency and visibility benefits, as a utility can integrate radial feeder restoration plans into its consolidated disaster recovery plan.

19.3.4 Feeder Distribution Systems Locate, Isolate, and Restore

To be most effective immediately, DA solutions should be instantly implementable with a focus on being model-based according to existing national standards, including those of the DOE and the National Institute of Standards and Technology.

Automation controllers should easily mount in new or existing reclosers, switches, and substation circuit breakers. The purpose of these automation controllers is to detect and locate faults in the feeder circuit, isolate the faulted section, and restore power to the unfaulted sections up to the rated capacity of the alternate power source. Sensing is provided via current transformer and potential informer inputs. Automation controllers can be installed inside any manufacturers' switchgear and can be configured to work with the feeder's existing protection logic.

19.3.5 Quicker Restoration: Reliable Power via Modular Energy Storage

The power distribution market is shifting. The increasing use of DG and renewables leads to new challenges that result from the unpredictable generation capacity of renewable energy, especially during unforeseeable outages. Modular energy storage systems are a viable solution for a sustainable and reliable supply of power in the future, whether for the integration of fluctuating renewable energy sources in the grid, self-sufficient power for microgrids, or as reliable reserve during outages.

These systems combine cutting-edge power electronics for grid applications and the latest high performance lithium ion batteries. Their modular design enables power and capacity to be adapted to specific demands and ensures high availability and reliability.

Section 20
Acronym and Abbreviation List

ADA....Advanced Distribution Automation

ADMS....Advanced Distribution Management System

AI....Artificial Intelligence

AMI....Advanced Metering Infrastructure

C&I....Commercial and Industrial

CAIDI....Consumer Average Interruption Duration Index

CAIFI....Consumer Average Interruption Frequency Index

CAPEX....Capital Expenditure

CHP....Combined Heat and Power

COPS....Critical Operations Power Systems

CVR....Conservation Voltage Regulation

DA....Distribution Automation

DER....Distributed Energy Resources

DERMS....Distributed Energy Resources Management System

DG....Distributed Generation

DMS....Distribution Management System

DOE....Department of Energy (US)

DOTS....Distribution Operations Training Simulator

DR....Demand Response

DSO....Distribution Systems Operator

EIA....Energy Information Administration (US)

EMS....Energy Management System

EV....Electric Vehicle

FLISR .... Fault Location, Isolation, and Service Restoration

GIS .... Geographic Information System

GPS..Global Positioning System

HVAC ....Heating, Ventilation, and Air Conditioning

IEEE ....Institute of Electrical and Electronics Engineers

IT...Information Technology

IVVC... Integrated Vol/VAR Control

kV ....Kilovolt

kVA...Kilovolt-Ampere

kWh .... Kilowatt-Hour

MAIFI.. Momentary Average Interruption Frequency Index

MDMS .... Meter Data Management System

ms .... Millisecond

MV.. Medium Voltage

MW.. Megawatt

MWh.. Megawatt-Hour

NEC... National Electrical Code

OEM .... Original Equipment Manufacturer

OMS .... Outage Management System

OT .... Operational Technology

PMU .... Phasor Measurement Unit

PV .... Photovoltaic

R&D... Research and Development

ROI .... Return on Investment

SAIDI...System Average Interruption Duration Index

SAIFI .... System Average Interruption Frequency Index

SCADA ....Supervisory Control and Data Acquisition

T&D .... Transmission and Distribution

TPM... Trusted Platform Module

UK .... United Kingdom

US .... United States

V... Volt

VAR .... Volt-Ampere Reactive

VVO..Volt/VAR Optimization

W... Watt

XLPE ....Cross-Linked Polyethylene