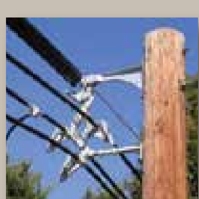
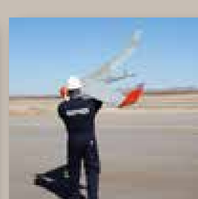
ELECTRIC POWER
RESEARCH INSTITUTE

# ENHANCING DISTRIBUTION RESILIENCY

## Opportunities for Applying Innovative Technologies





January 2013



## Summary

*Extreme weather and other natural disasters can threaten lives, disable communities, and devastate electric utilities' generation, transmission, and distribution systems. The majority of outages result from damage to the millions of miles of distribution lines. Utilities and their crews have continued to improve disaster response, focusing on upgraded equipment, advanced communications, rapid deployment of staged resources from their own and other utilities, and the systematic application of lessons learned. However, customers' expectations of service reliability have changed dramatically with the evolution of the 24/7, digitally connected society. Even with enhanced response and heroic efforts by crews, restoration that stretches to days, and in some cases weeks, is no longer acceptable. At the same time, consumers expect electricity to be affordable. The investment required to "harden" the distribution system to withstand the worst disasters must be regarded by all concerned as prudent and cost-effective.*

*This white paper reviews innovative technologies that EPRI and electricity sector stakeholders are developing to address this challenge and to serve as a basis for a multipronged approach to make the distribution system more resilient to storms and terrorist attacks. Collaboration between EPRI, electric utilities, and technology providers can accelerate the development, demonstration, and deployment of these technologies to meet consumers' expectations with respect to reliability and affordability while maintaining environmental sensitivity.*

## Background

According to a 2008 Edison Electric Institute (EEI) Reliability Report, 67% of electrical outage minutes were weather related, with contributing factors of lightning (6%), weather (31%), and vegetation (30%), typically due to wind, ice, or snow either directly affecting distribution assets or bringing vegetation into contact with utility lines, poles, and transformers.

Restoring service after storms can be costly. A survey of 14 U.S. electric utilities identified 81 major storms between 1994 and 2004, costing the utilities more than $2.7 billion (Johnson 2005). These direct costs represent only a fraction of a region's wider economic losses resulting from extended outages. Effects are exacerbated by the interdependence of the grid and other critical infrastructure such as telecom, natural gas and oil, water supply systems, banking and finance, and transportation.

A prominent recent example is the storm that struck the northeastern United States on October 29, 2011. Snowfall exceeding 12 inches (30.5 cm) in some areas stuck to the still leaf-laden trees, bringing down branches and trees. Damage was widespread to distribution lines and poles and some transmission lines, resulting in more than 800,000 Connecticut Light and Power customers being without power at some time during the 11-day outage. Many suffered multiple and extended outages. The duration of the power outage in some of the most heavily affected areas caused inconvenience and frustration among the public and among state and municipal officials (Witt 2011).

On average, U.S. electricity consumers can expect to lose power for more than 100 minutes annually due to outages from major storms. As with any average, individual consumers may never see an outage, while others could see outages of several days—despite the heroic efforts of utility workers in the field.

Consider this comment by Bill Federman in the *Times Union* when writing about life in Connecticut in October 2010 (*Times Union*, Albany, NY): "Being without heat, hot water, lights, a phone, an internet connection, and retail services of any kind was an adventure that we laughed off—*for about an hour*. (Emphasis added.) Then the seriousness of our predicament began to sink in. Absentmindedly flipping the light switch when we entered a room was no longer amusing."

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*This white paper was prepared by Mark McGranaghan, Matthew Olearczyk, and Clark Gellings*

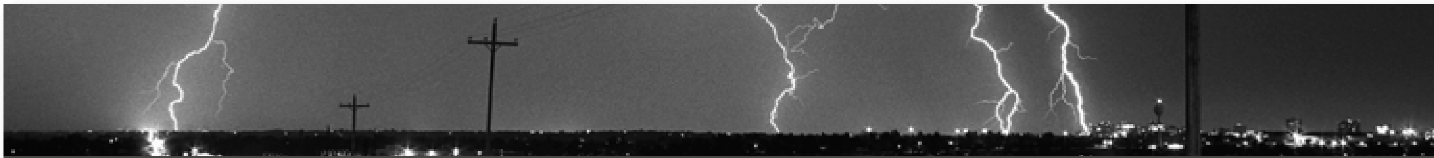




*Figure 1 – The 2008 Edison Electric Institute Reliability Report said that 67% of electric outage minutes were weather-related.*

Thus, beyond the average time of outages, the other average to be considered in this context is the average consumer's expectation. Even minor outages lasting a few hours can anger customers, elected officials, and regulators. In part, consumer sensitivity is fueled by customers' increasing dependence on the "web" of connectivity of digital devices. Interruptions in electric service lead to disruptions in connectivity, heightening customers' anxiety and dissatisfaction with service interruptions. To satisfy consumer service demands today, it is no longer enough to meet the standards set by regulatory agencies for restoration—consumers want fast restoration.

Increased use of computers and wireless communications also means heightened concerns about cyber security—an added complication in the resiliency equation. Distribution systems may be particularly vulnerable to cyber attack with the increased role of automation, as automation is one of the strategies to reduce the impact of other outage causes. Thousands of attempted breaches are launched by both amateur and professional hackers. To date, industry efforts have successfully minimized the impact of these incursions. Continued development of cyber defenses will be required as part of a program to enhance distribution system resiliency.

## Three Elements of Resilience

The resilience of the distribution system is based on three elements: **prevention**, **recovery**, and **survivability**. Damage *prevention* refers to the application of engineering designs and advanced technologies that harden the distribution system to limit damage. System *recovery* refers to the use of tools and techniques to quickly restore service to as many affected customers as practical. *Survivability* refers to the use of innovative technologies to aid consumers, communities, and institutions in continuing some level of normal function without complete access to the grid.

Improving the distribution system's resiliency requires advances in all three aspects. The most cost-effective approach will combine all three. The following sections highlight some opportunities for improvement using existing technology and materials, and some opportunities for accelerating the development and adoption of innovative technologies through collaboration with electric utilities and technology providers worldwide.

## Prevention

"Hardening" the distribution system to prevent damage will require changes in design standards, construction guidelines, maintenance routines, inspection procedures, and recovery practices and will include the use of innovative technologies. A utility's approach to all of these will be determined more specifically by its distribution system and work environment.

System planners have always had the option of configuring the system to maximize distribution service during major outages. Historically, however, the associated costs have not been viewed as prudent.

### *What Can Be Done Now?*

Several actions can be taken to prevent damage to the distribution system. These actions include:

***Vegetation Management*** –Tree trimming is a fundamental practice for mitigating local distribution outages. Vegetation management frequently must compete for budget dollars and often faces strong public opposition—at least until major storm-related outages occur. Recently, utilities have found it effective to use the results of storm damage and subsequent restoration as part of their assessment of their vegetation management and tree trimming programs. In particular, this application of storm data allows a critical review of damage and clearance standards and trim specifications, and it facilitates regulatory enforcement of tree trimming rights.

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=ENV&rId=220&pId=6931 Program 51 – T&D and ROW Environmental Issues

***Underground Installation*** – Installing distribution lines underground takes them out of harm's way of trees, cars, and most lightning strikes. However, the cost can be prohibitive—5 to 15 times more than overhead distribution—and does not ensure 100%

*Figure 2 – Utilities are using results from storm restoration in assessing their vegetation management and tree trimming programs.*

reliability. For example, severe storms may also bring flooding, and many underground devices, such as network protectors, are not designed to operate under water. For underground facilities, once the water recedes, troubleshooting and restoration may actually take longer than with overhead distribution systems.

An economical option may be to bury selected portions of the system. Such targeted undergrounding can be an effective hardening investment strategy. Since restoration time is related to accessibility, it may be most cost-effective to use undergrounding for portions of a circuit that are harder to access. Examples of this would include single-phase tap lines that serve remote areas and "rear-lot-line" circuits that are installed along the back of the property in residential neighborhoods. These circuits are difficult to access by vehicles and are more likely to be damaged by vegetation. Unlike traditional underground methodologies, selective undergrounding would address the common issue that, in many cases, tree damage in remote areas of a feeder can prevent energizing the entire feeder. This type of selective undergrounding sometimes goes against the grain of the public perception of undergrounding main trunk lines that are mostly visible. But, in storm conditions, if crews are able to concentrate on the three-phase lines along roadways, large blocks of customers will be restored quickly.

EPRI has initiated a project to evaluate targeted undergrounding and investment. For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236&pjSetId=7243
Project Set 180C – (Distribution) Cable Systems Management

*Figure 3 – An economical option for grid "hardening" may be to bury selected portions of the system.*

***Overhead Distribution Reinforcement*** – Some of the most effective actions are relatively simple and straightforward, such as adding structural reinforcement to existing distribution lines. Examples include adding guy wires or using steel poles to increase the strength of the lines to withstand higher wind loading. Some utilities now routinely make these improvements during system restoration. Another effective action is to reinforce some lines leading to a population center. An example would be to design two of four lines serving a population center to withstand higher winds.

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236&pjId=7265
Project Set 180I – Distribution Systems Practices

***Cyber Security*** – Utilities are increasingly susceptible to cyber security threats. No single permanent technical or operational solution exists to prevent cyber attacks, but development of a suite of technologies and tools is necessary to meet the evolving threats from cyber actions. The threat to cyber security is constant and must be considered as a potential terrorist weapon in conjunction with physical attacks. Cyber security is a heightened concern in situations in which a distribution system is already damaged or compromised by storms.

Many steps can be taken to improve a utility's ability to prepare and mitigate cyber attacks. Some of these steps include identifying attack scenarios and failure scenarios, using modeling techniques to assess the system's ability to withstand attacks, and developing a "play-book" to identify how the utility will respond when an attack happens. EPRI is developing guidelines and models that are helpful to utilities in preparing for future incidents.

For information on EPRI's Cyber Security Program, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=237&pId=7280
Program 183 – Cyber Security & Privacy

## *Where Can Innovation Be Employed?*

***Pole and Line Design*** – Certain pole and line design configurations are less susceptible than others to damage from trees and falling limbs. Although hardening of the system is the intuitive solution, significant interest exists in better understanding the way that overhead systems fail and developing new technologies to ensure that the systems fail in a manner that minimizes the restoration effort. Research is under way to assess overhead components and crossarms, pole treatment options, and the effect of third-party components (telephone, cable television, etc.).

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236&pjId=7265
Project Set 180I – Distribution Systems Practices

*Figure 4 – Significant interest exists in developing and deploying pole and line configurations that can help minimize restoration efforts.*

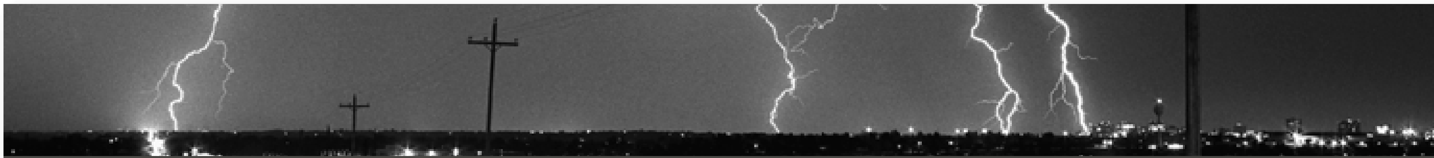




*Figure 5 – Hydrophobic coatings help components shed precipitation, mitigating water damage and facilitating ice removal.*

***Hydrophobic Coatings*** – Hydrophobic coatings are now being applied to various components in the transmission and distribution system. By helping components shed precipitation, these coatings mitigate water damage on non-ceramic insulators and can facilitate ice removal. Projects are under way at EPRI to assess the performance, reliability, and application of these coatings.

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=233&pId=7298&suId=7318
Supplemental Project 1025805: *Application of Nano-Technology Coatings to Transmission Components*

***Dynamic Circuit Reconfiguration*** – This operational design offers the opportunity to combine advances in information technology, communications, and sensors with innovations in restoration practices.

Many utilities have successfully deployed Distribution Automation with Optimal Network Reconfiguration. These systems involve the deployment of automated distribution switches/sectionalizers/reclosers, sensors, communications, control systems, and data analytics to automatically reconfigure circuit connections in order to maximize service restoration. Once deployed, these systems serve two roles. First, they limit the number of customers affected by faults on the feeder mains by directly tripping (reclosers) or sectionalizing (switches or sectionalizers). Second, once the fault is isolated to one section of the feeder, the systems enable restoration of service to unaffected sections from adjacent feeders. Additional research is needed to ensure compatibility with new technologies such as distributed resources (photovoltaics, storage, microgrids, etc.).

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236
PS180A Distribution Planning, Design, and Analysis

## Recovery

Proper resiliency planning must provide for rapid damage assessment and crew deployment. To enhance the ability to respond and recover quickly, the U.S. electric industry has developed effective mutual assistance programs, in which transmission and distribution utilities call in crews from across a region to help restore downed lines, poles, and transformers. The host utility needs to provide logistical support in the form of lodging, food, and fuel; must have on hand the necessary spare parts; and must have the capability to efficiently dispatch crews to the affected areas.

Recovery requires prompt damage assessment, access to damaged assets, and readily available replacement components. In the recent storms in the northeastern United States, pinpointing affected areas was problematic, as was routing crews through streets that were not blocked by fallen trees. As a result, crews were sometimes idled because they could not reach affected areas.

## What Can Be Done Now?

***Load Reduction*** – During outages, an established industry practice is to use load reduction programs to reduce demand on the system from customers who still have service. This practice may be necessary when transmission outages occur and when reconfiguration of distribution circuits is needed. Although this practice may reduce demand only 5%–15%, it can be useful in some situations to aid recovery. Options include:

- Media appeals – using both conventional and social media
- Voluntary load-reduction programs
- Interruptible tariffs
- Demand-response programs such as direct load control, time-of-use rates, etc.
- Conservation voltage reduction (CVR) through distribution automation

***Restoration Management*** – Utility restoration management practices include procedures and systems to shift from centralized to decentralized restoration management.

These practices must be tailored to events of different magnitudes and to differing types of disruption (wind, flood, tsunami, earthquake, and terrorist or cyber attacks, etc.).

***Damage Prediction and Response*** – Current- and next-generation numerical weather prediction models can provide high-resolution predictions of wind speed, wind direction, rainfall amounts and type, and other important meteorological parameters known to be associated with weather-related electrical outages. Laboratory and field studies of the mechanisms under which key electric infrastructures fail can also be conducted, particularly after large events such as hurricanes, winter storms, and severe local storms. Better understanding of failure mechanisms can be combined with improved predictions of related meteorological variables to create decision-support tools that can aid utility emergency operations managers in pre-positioning physical and human assets, prioritizing key infrastructures for efficient restoration of service, and reducing response time and cost.

## Where Can Innovation Be Employed?

***Airborne Damage Assessment*** – EPRI recently completed preliminary tests showing that both small piloted aircraft and unmanned aerial vehicles (UAV) or *drones* equipped with high-resolution cameras, global positioning systems, and sensors can be valuable tools for damage assessment. UAVs equipped with EPRI's Airborne Damage Assessment Module (ADAM) can be small and light enough to be handled by a technician, and can quickly survey devastated areas that are difficult to reach by roads blocked with downed trees or other obstacles. The use of ADAM-equipped aircraft could

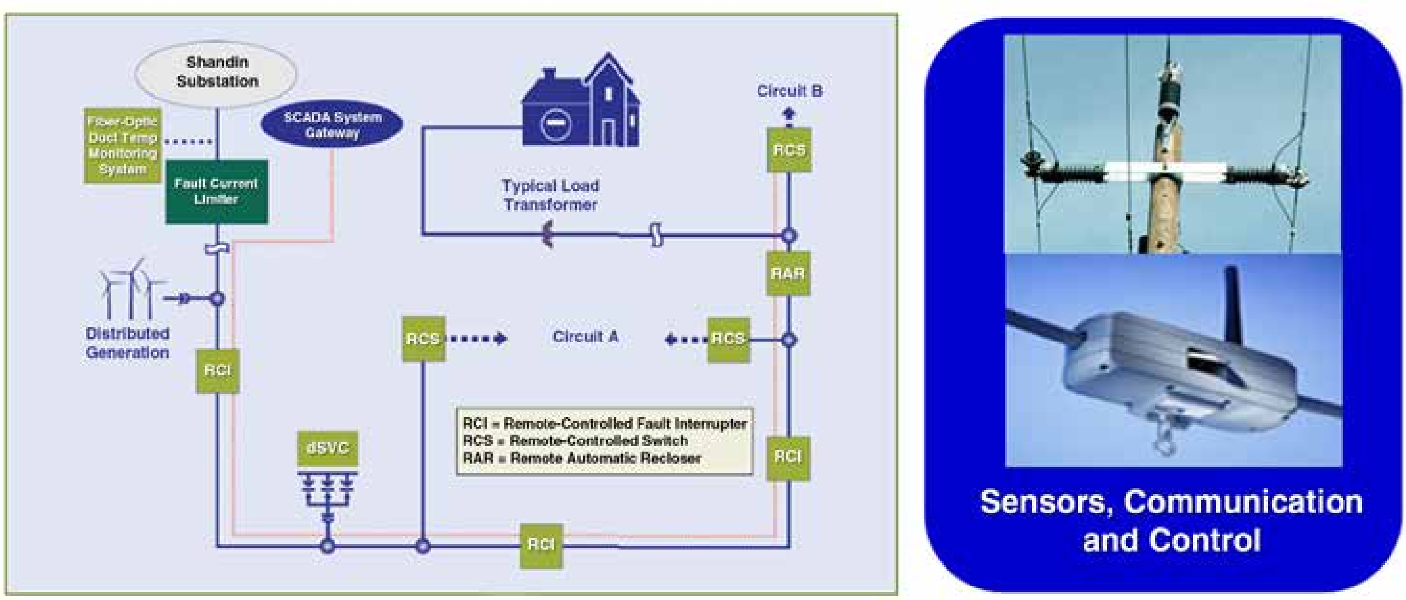



*Figure 6 – Circuit auto-reconfiguring allows for restoring portions of a damaged system to minimize the spread of an outage.*

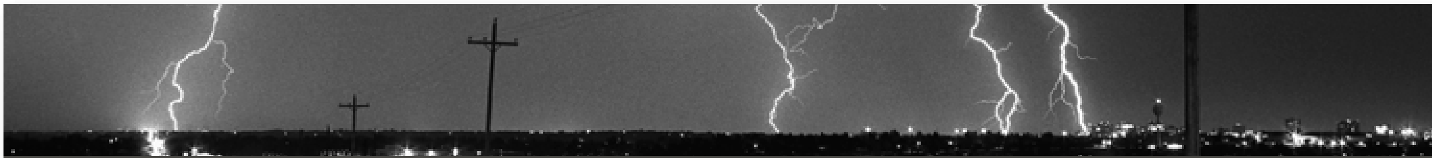




*Figure 7 – Preliminary tests indicate the potential for unmanned aerial vehicles to reduce costs and speed up restoration.*

substantially reduce costs and cut the response time by hours, if not days. It could also aid in assessing system conditions in normal situations. EPRI research will also assess the accuracy of the sensors and cameras to determine if it is sufficient to assess equipment such as insulators.

Implementing ADAM requires integration with three key distribution operations backend systems: the outage management system (OMS), the geographical information system (GIS), and the asset management system. These systems are important for enabling incident command operations to understand and access situational information in real time. They also support overall distribution management.

- ***Outage management system (OMS):*** At the heart of any storm response and damage assessment is the outage management system, which gathers outage information from a variety of sources and helps to predict outage locations and direct restoration efforts. An OMS enables a focused response, allowing utilities to prioritize restoration efforts, re-energize restored feeders, give customers and the public estimates of restoration time, and coordinate with governmental organizations.
- ***Geographical information system (GIS):*** GIS is rapidly becoming the foundation of distribution system documentation because the map-based database is suited perfectly to tracking assets and monitoring the state of geographically dispersed assets.
- ***Asset management system:*** As with any industry, keeping track of assets is crucial for utilities because this management provides an interface between the engineering and the accounting sides of the business. An asset register allows utilities to maintain a database of what assets they own, their predicted lifecycle, and their technical specifications.

For information on this set of projects, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236
PS180B Distribution Inspection, Maintenance, Asset Planning, and click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=233&pId=7330
P37.111 Risk-Based Substation Equipment Asset Management

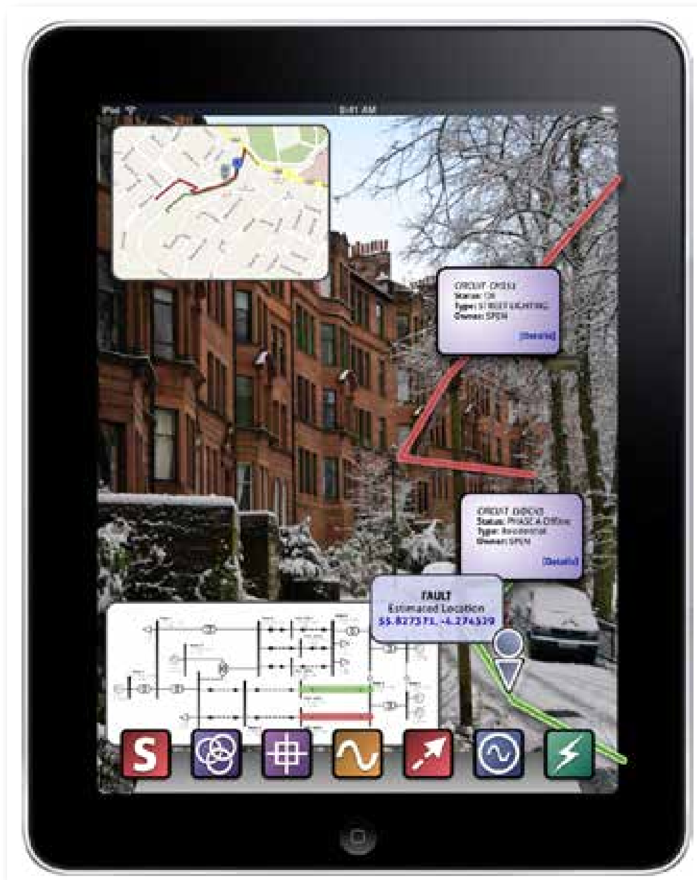
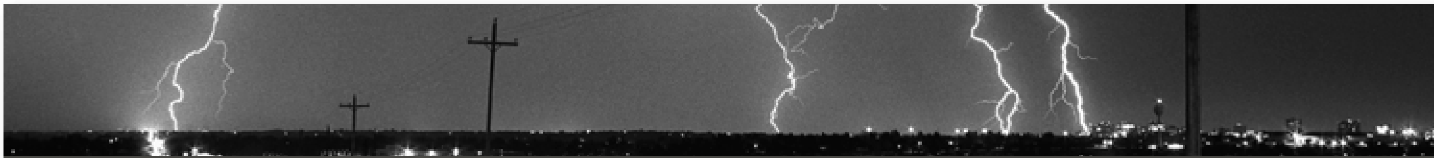



*Figure 8 – Tablet computers and smart phones will enable real-time, interconnected capabilities for field operations and disaster response.*





EPRI plans to work with utility members to conduct test flights with manned and unmanned aircraft to clarify how the module should be configured and deployed to handle different terrains and weather conditions as well as meet other requirements. This project will also look at different cost models to determine the level of value for investment in ADAM and aircraft.

For information on the ADAM project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=235&pId=7236&suId=7509
Supplemental Project 1023304 – *Airborne Damage Assessment Module*

***Field Force Data Visualization*** – EPRI is developing data visualization technology for utility engineering and field operations. Using computer tablet and smart phone technologies, these systems would allow real-time data retrieval when a user points the mobile device at a distribution pole or at transmission and distribution conductors. As an example of this application, a field technician would aim the hand-held device camera at a pole structure, while the screen displays the camera image, with the one-line circuit drawing overlaid, and all of the pertinent asset data available from the GIS. Recovery crews can use such tools to retrieve detailed information on assets in the field and to determine quickly which components should be dispatched for repair and replacement.

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=237&pId=7139&suId=7487
Supplemental Project 1024667 – Field Force Data Visualization

***Recovery Transformer*** – A collaboration of the U.S. Department of Homeland Security (DHS) Science & Technology Directorate (S&T), the transformer manufacturing company ABB Inc., CenterPoint Energy Inc., and EPRI has developed a prototype transformer that could be deployed to replace a damaged or destroyed transformer in about a week, instead of several months, and thereby prevent sustained power outages. Known as a "recovery transformer", the prototype is being demonstrated at a CenterPoint Energy substation. A large substation transformer can be disabled by disasters such as earthquakes or tornados or by geomagnetic disturbances, internal failure, or terrorist acts. If successful, this project will validate the concept of modular transformer design to enable rapid deployment of replacements necessary for recovery operations, particularly for simultaneous loss of multiple transformers.

*Figure 9 – Rapid deployment of "recovery transformers" could prevent sustained outages to large numbers of customers. (Photo: DHS S&T)*

## Survivability

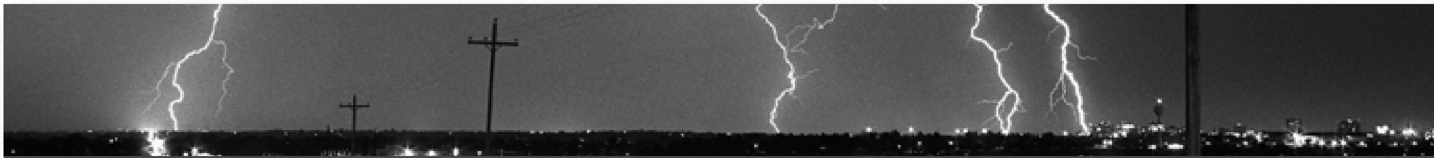
*Survivability* refers to the ability to maintain some basic level of electrical functionality to individual consumers or communities in the event of a complete loss of electrical service from the distribution system. The key elements of survivability include communicating with customers; using resilient technologies to supply critical infrastructures such as traffic signals, prisons, hospitals, and cell phones; and equipping and enabling consumers to use distributed generation.

For distribution utilities, survivability is a new function—and one that will require new business models and innovation.

### *What Can Be Done Now?*

The concept of assisting customers with survivability features is relatively new to the electric industry. Historically, many customers such as hospitals, banks, and data centers have assumed responsibility for their own survivability, relying on generators, uninterruptible power supplies (UPS), and occasionally alternative distribution feeds (custom service coordinated with the electric utility). Given the relatively rapid evolution of customer expectations, now is an opportune time for utilities to reassess their role in maintaining power to essential services such as traffic lights, prisons, and hospitals and in providing customers uninterrupted access to communications and modern conveniences.

As highlighted in reports regarding the October 2011 storms in Connecticut, customer frustration was exacerbated by not knowing an estimated time of restoration. (Customers consistently cite the importance of knowing the estimated time of restoration.) Utilities likewise were frustrated by a lack of accurate information as to





which customers or groups of customers were without service.

*Communicating with Customers* – Utilities are beginning to use both the Internet and smart phones to enhance the targeting and speed of their communications. For example, Commonwealth Edison Company (ComEd) is among a growing number of utilities that facilitate externally facing outage reporting and communication. ComEd offers an interactive outage map on ComEd.com that customers can use to determine the location and scope of outages and to get estimated times of restoration. ComEd also offers a mobile application for iPhone® and Android™ devices that enable customers to:

- Report an outage and check restoration status
- View their account summary and history
- Manage payments, including budget billing, automatic payments, and one-time payments
- Report a meter reading
- Find a location to make an in-person payment

*Community Energy Storage* – In the future, the electricity enterprise may benefit from cost-effective and reliable bulk energy storage to help balance and optimize supply and demand of bulk power resources. Distribution-level energy storage offers potential advantages, such as enhanced reliability and support of self-sufficiency. EPRI is examining the functional requirements and storage technology capabilities for mitigating the effects of variable renewable generation, improving reliability, and facilitating service when the distribution system is damaged. Certain battery technologies may be approaching a stage of development at which they can be considered for distributed storage applications at a community—or even individual customer—scale.

For information on this project, click here or see http://portfolio.epri.com/ProgramTab.aspx?sId=PDU&rId=237&pId=7366&suId=7516
Supplemental Project 1025118 – *Battery Storage Systems and Applications Demonstration*

## Where Can Innovation Be Employed?

*Using PEVs as a Power Source* – Plug-in electric vehicles (PEVs), both all-electric and hybrid, could be used to supply energy to a home during an outage. Hybrid electric vehicles also could operate

*Figure 10 – Plug-in electric vehicles may become an alternative power source during outages. (Photo: Nissan)*

as a gasoline-fueled generator to provide additional standby power. Automakers are interested in the concept, but the technologies require further development.

Nissan Motor Co., Ltd. recently unveiled a system that enables the Nissan Leaf to connect with a residential distribution panel to supply a residence with electricity from its lithium-ion batteries. The batteries can provide up to 24 kWh of electricity, sufficient to power a household's critical needs for up to two days.

*Using Photovoltaic (PV) Systems as a Backup* – Increasingly, consumers are installing rooftop PV systems to augment grid-supplied electricity. Usually limited by roof area and sized to meet an economically viable portion of the building's electrical needs, these systems cannot supply 100% of a residence's typical demand, nor do the systems, as currently configured, allow for operation as independent microgrids to supply part of a residence's needs. EPRI assessments have identified inverter and control designs that could convert PV systems into self-sufficient technologies, but few inverter manufacturers have stepped forward to serve this need.

In 2011, two U.S. Department of Energy (DOE) projects demonstrated inverter products that can operate while tied to the grid or "islanded." Princeton Power, Inc. (Princeton) demonstrated a 100-kW demand response inverter with two dc terminals and two ac terminals. Princeton is also introducing a 10-kW version specifically for the residential and small commercial markets. Petra Solar demonstrated a micro-inverter-based PV system capable of operating in grid-tied or islanded mode. Both companies report that they have demonstrated seamless transition between these modes.

*Figure 11 – Solar photovoltaic installations can play a role in providing backup power and supporting self-sufficiency.*

Other companies report development of similar products. With a proper transfer switch (perhaps controlled by the utility), these products could provide backup power to residences or a community during an outage.

*Matching Consumer Load to PV Capabilities* – The existing controls associated with PV arrays are not sufficiently functional to match the electrical demand of a residence without the presence of grid supply or local storage. Companies are developing residential circuit breaker panels that allow the control of individual circuits and appliances. Control devices could be developed to weave these breaker panels into the PV system, so that when grid power is lost, load is automatically curtailed to balance supply and load for the residential microgrid. These systems also could manage the "ramps" that occur as the sun rises and sets or as clouds block sunlight.

*Providing Urgent Services* – An opportunity exists to identify innovative technologies that can provide limited services or "urgent services" to critical aspects of community infrastructure. Only a few of these technologies have been identified, and fewer still have been researched. EPRI proposes to launch research to address this opportunity (see Appendix E, "EPRI Distribution System Resiliency Research Workshops"). Examples include:

- *Cell Phones* – During a prolonged power outage, even if cell phone towers are energized, the cell phones themselves will eventually run dry. Cell phone users whose automobiles have gas or electric storage and patch cords can charge their phones. A few consumers have solar chargers. A resiliency plan would encourage and instruct citizens to have solar chargers. Utilities could consider making them available through various channels and at various prices or at no cost.
- *Conventional Vehicles* – If appropriate cables and connectors

*Figure 12 – Smart power distribution panels could help curtail a customer's power use to match supply and load for a self-sufficient "microgrid" if grid service is interrupted. (Photo: Eaton)*



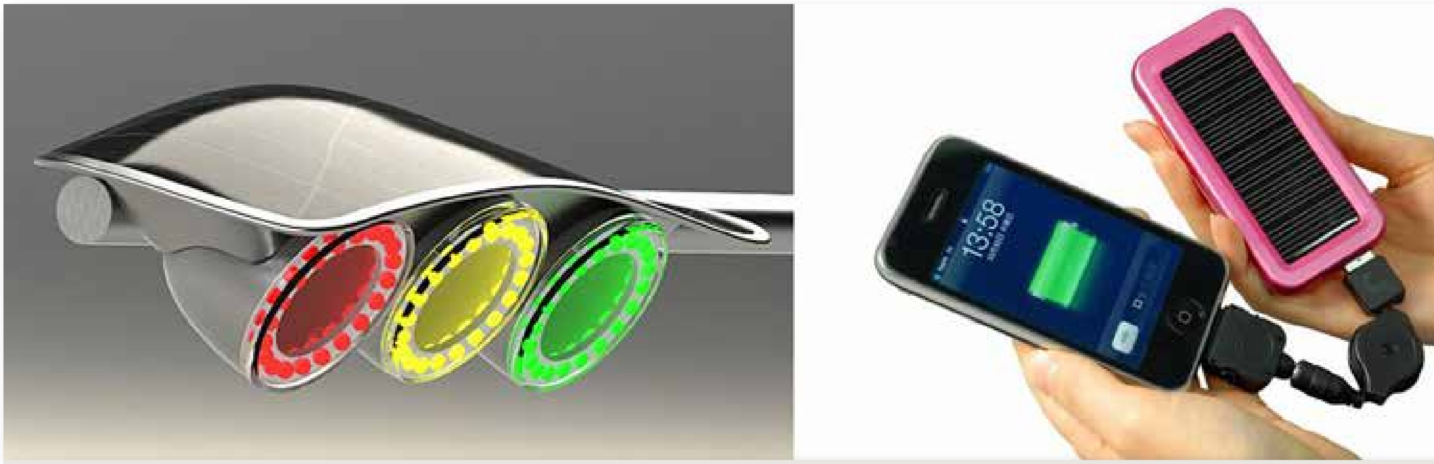



*Figure 13 – Self-sufficient traffic signals and solar cell phone chargers are among the many adaptations that society could choose to enhance survivability during major power interruptions. (Courtesy of Carnegie Mellon University)*

were available, conventional internal combustion engine- (ICE-) powered vehicles could be used to energize devices such as cell phone chargers, flashlight battery chargers, and critical medical devices.

- ***Traffic Lights*** – During rolling blackouts in South Africa in 2007, a major cause of traffic accidents was the loss of functional signals. A self-sufficient traffic light system might be designed with LEDs and battery backup (or solar PV backup) to operate during an outage.

## New Planning and Analysis to Support Resiliency

New opportunities are emerging with respect to planning and analysis, and these opportunities point to the need for expanded demonstrations.

***Prioritizing Resiliency Investments*** – EPRI is undertaking research to provide a decision-support tool to identify investments that are optimal for hardening the distribution system against extreme weather and other unusual conditions. Such tools could help utilities improve system reliability and aid utilities in working with stakeholders, such as customers and regulators, to develop prudent investment strategies.

The goal is to provide information that utilities can apply to make their distribution systems more resilient to major weather events. To achieve this goal, it will be necessary to understand outage causes, determine suitable options to mitigate or greatly reduce outages, vet outage reduction options to define effectiveness, and build a decision-support tool for applying grid resiliency programs.

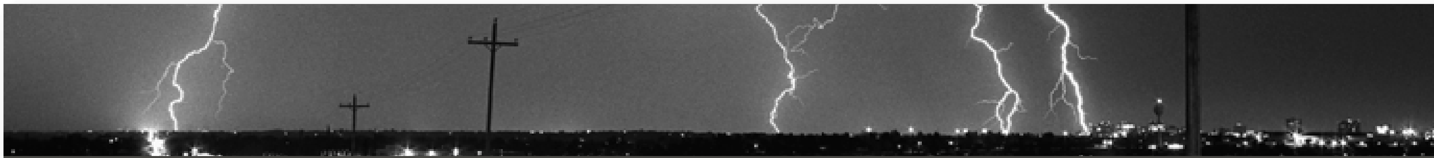
The project scope will include:

1. Identification of leading practices for storm response
2. Assessment and evaluation of infrastructure damage
3. Identification of leading or alternative vegetation management practices
4. Identification, testing, and modeling of options for overhead distribution system hardening
5. Analysis of underground distribution costing, with a focus on options for making "undergrounding" more viable
6. Analysis of grid modernization impacts on system resiliency
7. Prioritization of hardening and storm-response investments

For information on this project, click here or see http://my.epri.com/portal/server.pt?Product_id=000000000001025704
Supplemental Project 1025704 – *Distribution Grid Resiliency*

***Modernizing Distribution*** – EPRI is launching the Distribution Modernization Demonstration project to develop and demonstrate data management and analytics that will support distribution operations, planning, and asset management related to hardening the distribution system. To meet its goals, the project will employ "learning by doing"—employing field demonstrations to determine the effectiveness of analytical applications.

Distribution sensors, devices, and systems are already producing vast amounts of data, outpacing utilities' ability to process, analyze, and





use the data for advanced applications that benefit the distribution system and improve its resiliency. Advanced metering infrastructure (AMI) systems represent a significant source of new data. Going from one "meter read" per month to hourly reads totaling 720 per month represents a 71,900% increase in data. Some advanced meters can also provide data such as volts and VARs that may be beneficial for distribution operations, planning, and asset management.

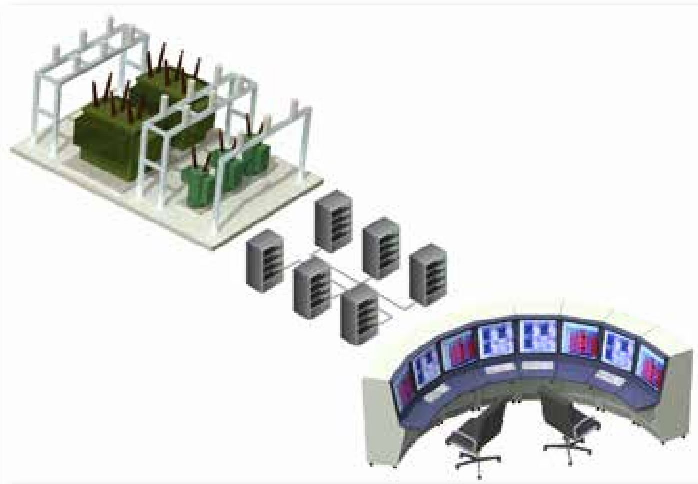


*Figure 14 – Modern distribution management systems could achieve new levels of resiliency and enhance recovery efforts.*

The Distribution Modernization Demonstration objectives include identifying new and existing distribution applications that have value to utilities, developing functional specifications for these applications, and assessing the applications in the lab and in utility demonstrations. Examples include applications to identify incipient faults, increase accuracy of outage locations, and on-line validation of GIS maps. The specifications will define the detailed functional requirements for each application along with the data management and integration requirements associated with the application. These demonstrations would also allow the use of the smart grid and its components to be assessed during and after storms.

For information on this project, click here or see http://my.epri.com/portal/server.pt?Product_id=000000000001025705 Supplemental Project 1025705 – *Distribution Modernization Demonstration*

## Conclusions

Accelerating the development of innovative technologies to improve distribution resiliency will require a global collaboration of research organizations, electric utilities, and technology providers. EPRI has initiated collaborations cited in this document, proposing technology development that could help improve key aspects of distribution resiliency. The industry must ensure that these options can be reliably and cost-effectively adopted by distributors and by consumers, recognizing that no single entity can accomplish this objective.

This white paper documents a menu of innovative technologies and methodologies that EPRI and its electricity sector collaborators are developing to make the distribution system more resilient to disasters. A collaborative approach that brings together the experts from EPRI, electric utilities, and technology providers can expedite the development of the technologies necessary to meet the changing technological landscape and expectations of consumers.

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## Appendix A: Assessing Survivability Options

Technologies described in this section are only a few of those that are available now or that have the potential to be developed, demonstrated, and assessed. EPRI is initiating a collaborative project to identify and assess potential solutions to the survivability issue. The preliminary scope includes:

- Identify areas to improve survivability through "urgent services" such as chargers for cell phones, storage for traffic lights, home generators, microgrids, etc.
- Scan and identify currently available technologies that can improve customer survivability in these areas.
- Screen the state of technology including cost, benefit, performance, application, and maturity of these technologies.
- Create a knowledge base of what consumers can do now and what requires additional R&D to help accelerate the development and deployment of these technologies.

## Appendix B: The Electric Ecosystem

By viewing the electric system as an "electric ecosystem," its stakeholders can approach reliability in terms of the central mission of an electric system, not just in terms of preventing blackouts (Talukdar et al. 2003). This concept infers increased use of the distribution system to bolster reliability, without relying on the extra-high-voltage and high-voltage transmission grid.

A system geared to survivability is built on a system of sub-units (Farrell et al. 2002). One example involves traffic signals. Traffic signals are typically supplied from the same distribution circuit as other customers in an area. Outages can render traffic lights inoperative, causing traffic accidents. Power system engineers have known for some time that systems using large central-station power plants tied together with a grid is inherently vulnerable. The use of smaller, distributed generators could markedly increase reliability, and if these generators are installed as part of a resiliency plan, they could make the power system more resilient to severe weather or even terrorist attacks. Such a system could configure microgrids with distributed generation, electric and thermal energy storage, and an array of energy management and control systems.

To reconfigure the distribution system for microgrids and survivability and to prepare for changes in consumer demand and related technology, utilities need to assess the barriers and incompatibilities associated with integrating distributed resources (for example, local storage, demand response, distributed generation, and renewable resources) and fully apply them in practice (EPRI 2009). Such assessments can support a variety of distribution system improvements:

- Developing smart grid project plans
- Evaluating smart grid proposals
- Reviewing and assessing smart grid projects
- Assisting in the final assessment of smart grid projects

Research is under way to develop a methodology and quantitative metrics for evaluating smart grid projects related to integrating distributed energy resources into the grid and market operations, including distributed generation, storage, demand response, and renewables. This methodology includes a smart grid project assessment spreadsheet that identifies the important characteristics of smart grid projects to achieve integration of distributed resources, that is, those characteristics that indicate the extent to which these projects can fulfill smart grid objectives.

The microgrid is a natural evolution of distributed resources used in areas where conventional power systems could not reliably serve customers. Microgrids can also provide support to conventional power systems that are constrained in meeting demand. When used to enhance resiliency, microgrids can be configured to operate in tandem with the bulk supply system during normal conditions, but disconnect and operate as an independent island in the event of a bulk supply failure or emergency (EPRI 2001).

In this configuration, not only must the generators all work together to control voltage, frequency, VARs, and other parameters, they must also do so in an environment in which the microgrid may be periodically reconfiguring itself by attaching itself to adjacent microgrids or breaking apart into smaller microgrids. This capability requires the highest level of communication among generation devices and the adaptive grid command and control that can shift from one controller to the next as the system changes state. The generator protection schemes and operating setpoints will have to adapt each time that the system changes state. To be implemented effectively, this approach needs considerable research. Such systems could be augmented by the installation of energy storage by the customer.

The concept of allowing electric energy storage to receive benefits from several value streams is still unresolved. A debate is ongoing regarding the best ways to account for value and benefits accruing from energy storage. If consumers could own and operate (automatically) local storage and receive compensation for its use both by distribution utilities and wholesale market participants, while having the asset available for responding to pricing signals, then the storage asset could be available to ensure survivability as well.

## Appendix C: Extreme Weather Events

Concern is growing regarding the electric infrastructure's vulnerability to widespread blackouts and power outages resulting from extreme weather and other natural disasters. Recent trends are illustrated in Figures 15 and 16, and recent examples include Hurricane Katrina, the October 2011 storms in the northeastern United States, and the Fukushima Daiichi nuclear disaster in Japan. In each case, the electric infrastructure suffered considerable damage and left citizens without power and often without clean water, food, and fuel for heating or transportation. As an additional consequence of the digital age, the stop-gap communication now often provided by cell phone technology failed as well because many cell towers were without power, and cell phone users were largely without power to charge their phones (except for a few with solar chargers).

These seemingly random occurrences appear to be increasing in frequency. As shown in Figure 15, the number of natural disasters totaled 247 in 2010.

The impact of extreme weather events is further evidenced by examining power outages in North America. According to the North

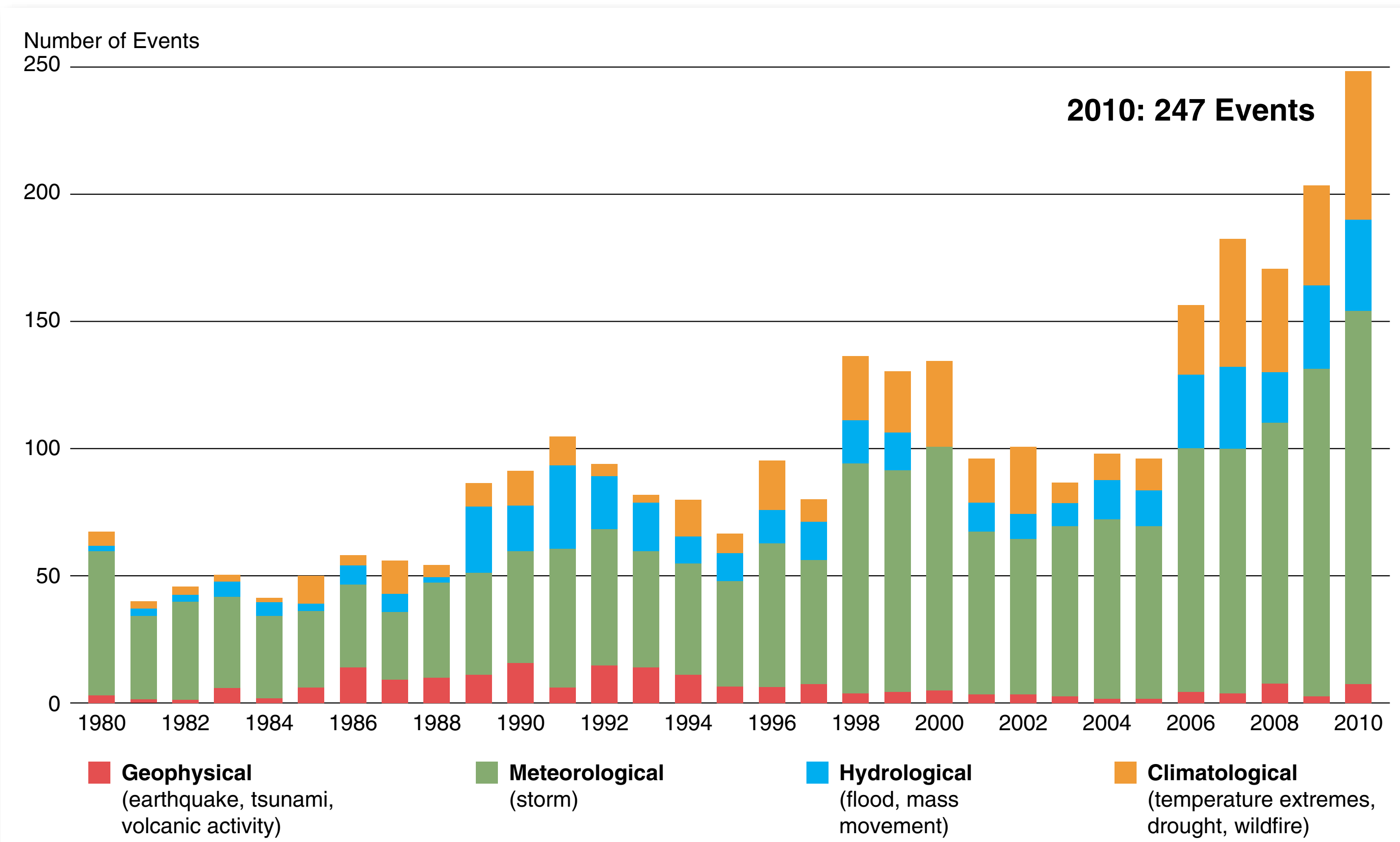


*Figure 15 – Natural Disasters in the United States, 1980–2010. (Source: http://www.riholtz.com/blog)*

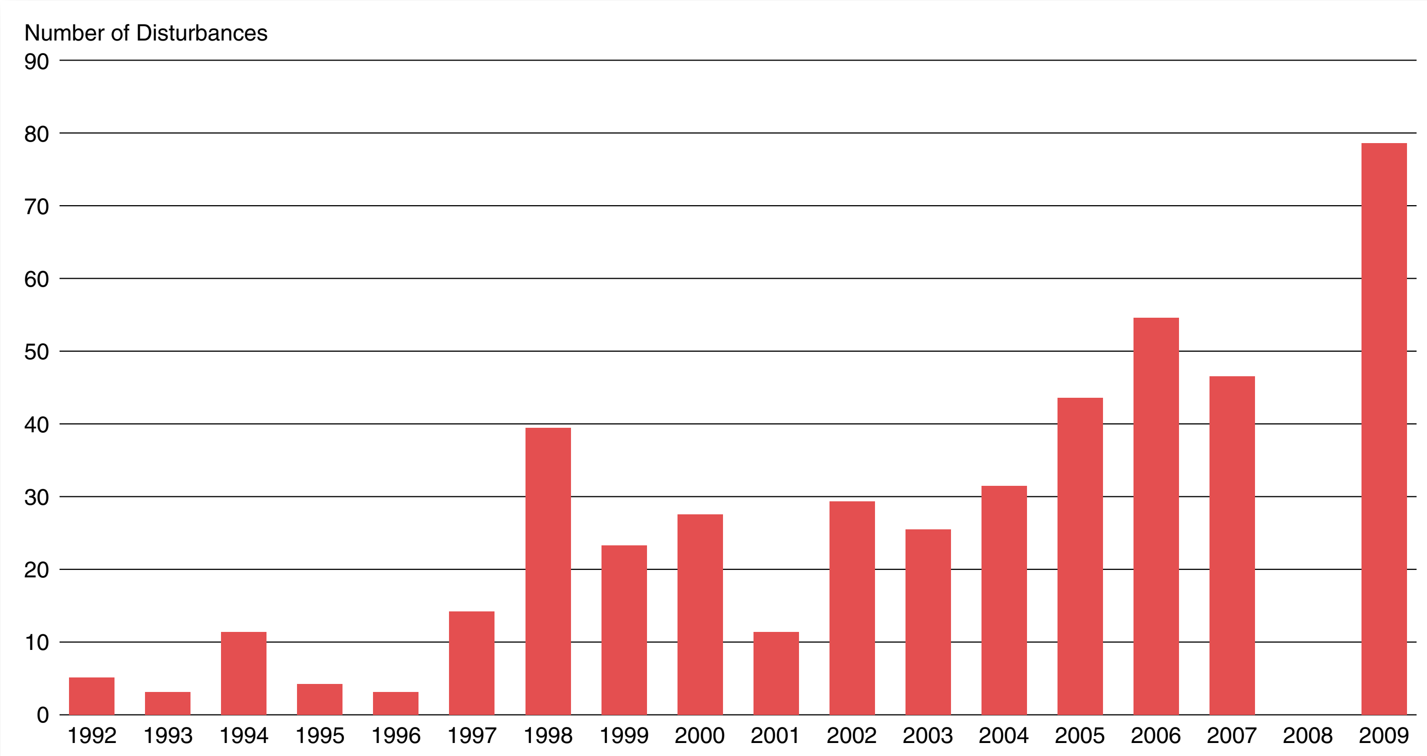


*Figure 16 – North American Electrical Disturbances Caused by Weather. (Source: NERC)*

American Electric Reliability Corporation (NERC), the number of so-called major disturbances increased dramatically from 1992 to 2009. Refer to Figure 16.

Note: This information is taken from the PDFs found here: http://www.nerc.com/page.php?cid=5166, which is NERC Event Analysis: System Disturbance Reports. The data in the graph display the number of disturbances recorded in the pdfs that were weather related (if the word "weather" was in the cause of the blackout) sorted by year. The graph shows number of disturbances caused by weather per year.

## Appendix D: Has Anything Changed?

Even as the industry maintains its focus on providing affordable, reliable, and environmentally responsible electricity, the industry must now also broaden that focus to include facilitating the survival of consumers and communities when the lights go out. The basics of this area of activity may include the need to inform and engage stakeholders and regulators in endorsing the use of resources to prepare consumers and communities to survive long-term outages. In the recent blackouts in India, the use of local generation and uninterruptible power supplies prevalent in that developing country allowed it to recover more easily from power outages than many Western countries.

## Appendix E: Distribution System Resiliency Research Workshops

When hurricanes, ice storms, and other significant weather events occur, the electric distribution system is vulnerable to extensive damage and outages. The impacts and costs of these storms can be substantial, given the critical nature of electric power systems, and its interdependency with other vital infrastructure, such as natural gas and oil, water supply, banking and finance, and transportation.

With the frequency and severity of recent storms, considerable industry attention has been centered on hardening the distribution system so that it will experience less damage during such events. Hardening can address design standards, construction guidelines, maintenance and inspection procedures, and restoration practices. A given utility will base its approach on its particular distribution



system and working environment. A significant challenge is to determine which of the optimal investments to employ for improving durability and resiliency.

In response to this challenge, EPRI is launching a multiyear research initiative to provide utilities with meaningful, actionable information with which to make optimal investments in hardening the distribution system and improving its resiliency.

For information on this project, click here or see http://my.epri.com/portal/server.pt?Product_id=000000000001025704
Supplemental Project 1025704 – *Distribution Grid Resiliency*

To better understand the issues associated with system hardening and storm management and to ensure that the proposed project scope is aimed at the most critical needs, EPRI conducted four workshops around the country to gather input and feedback from utility experts. The workshops were hosted by Long Island Power Authority (LIPA), Long Island, NY; Exelon, Chicago, IL; Duke Energy, Charlotte, NC; and Southern California Edison (SCE), Pomona, CA. More than 70 representatives from 21 different companies attended. EPRI experts provided ideas for the project scope, followed by working sessions with participants to define specific industry needs and the scope of potential project tasks to address those needs.

The goal is to provide information that utilities can apply to make their distribution systems more resilient to major weather events. To achieve this goal, the following research objectives must be realized:

1. Understand outage causes.
2. Determine suitable options to mitigate or greatly reduce outages.
3. Vet outage reduction options to define effectiveness.
4. Build a decision support tool for applying grid resiliency programs.

First, the research must determine precisely how and why distribution system outages occur during major weather events. Once the outage mechanisms are understood fully, options for addressing these mechanisms can be identified and vetted for applicability and effectiveness. The final step: Create a tool to help utilities prioritize and apply the options for improving grid resiliency for their system's parameters and weather characteristics.

The project scope will include:

1. Identify leading practices for storm response.
2. Assess and evaluate infrastructure damage.
3. Identify leading or alternative vegetation management practices.
4. Identify, test, and model options for overhead distribution system hardening.
5. Analyze underground distribution costing, with a focus on options for making "undergrounding" more viable.
6. Analyze grid modernization impacts on system resiliency.
7. Prioritize hardening and storm-response investments.

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**The Electric Power Research Institute, Inc.** (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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