Consensus Study Report

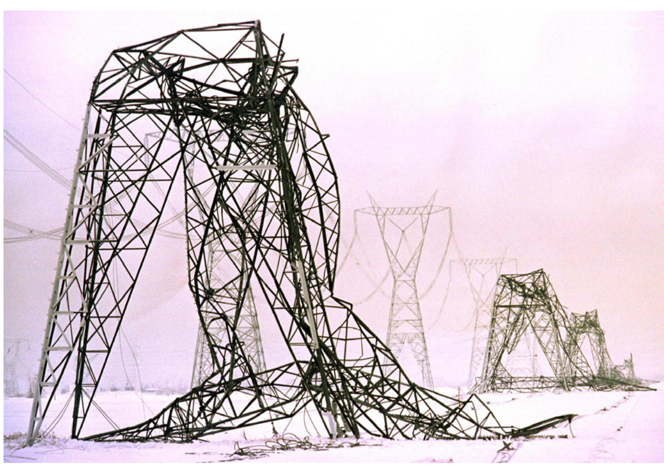
July 2017

HIGHLIGHTS

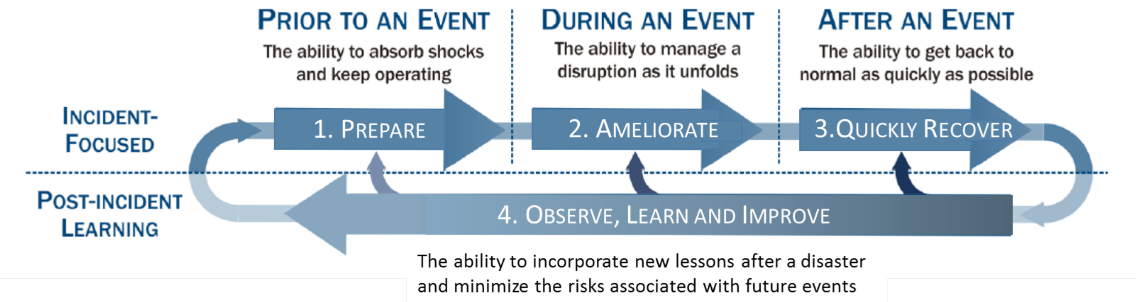
Enhancing the Resilience of the Nation's Electricity System

Electricity is fundamental to our nation's health, safety, and economic productivity. The electric grid powers our homes, essential services such as hospitals and emergency responders, and critical infrastructures ranging from communications to natural gas delivery. Nonetheless, our electricity system is vulnerable to diverse threats that can potentially cause extensive damage and result in large-area outages that take a long time to recover from. These events range from familiar natural disasters such as hurricanes, earthquakes, and ice storms, to low-probability events such as solar storms, to malicious human actions including cyber or physical attacks. When major outages happen, everyday tasks become difficult, economic damages can add up to billions, and lives can be lost.

In its 2014 appropriations for the Department of Energy, Congress requested that the National Academies of Sciences, Engineering, and Medicine organize a study to identify technologies, policies, and organizational strategies to increase the resilience and reliability of the U.S. electricity system. The study focuses largely on reducing the nation's vulnerability to large-area long-duration outages—those that span several service areas or even states and last three days or longer. Much can be done to make both large and small outages less likely, but they cannot be totally eliminated no matter how much money or effort is invested. To increase the resilience of the grid, the nation must not only work to prevent and minimize the size of



Massive damage to transmission infrastructure in southeastern Canada following the 1998 ice storm, which disrupted service to millions of people and required more than one month to recover from. SOURCE: Robert Laberge/AFP/Getty Images



A framework for critical infrastructure resilience. SOURCE: Modified from NIAC (National Infrastructure Advisory Council), 2010.

outages, it must also develop strategies to cope with outages when they happen, recover rapidly afterward, and incorporate lessons learned into future planning and response efforts.

THE ELECTRIC GRID IS ESSENTIAL, CHANGING, AND HETEROGENEOUS

Despite the changing technology, economic, and regulatory environment, the report finds that the majority of people will continue to depend on the organized, interconnected power system to provide resilient electric service for at least the next two decades. The grid is a complex, cyber-physical system composed of millions of physical, computing, and networked components that are spread across the continent. Most electricity is generated in large, centralized power plants, transmitted long distances at high voltages, and distributed to residential, commercial, and industrial consumers at lower voltages. The network of generators and high-voltage transmission lines—called the bulk power system—is subject to numerous operational, physical, and cyber security standards developed by the North American Electric Reliability Council with authority from the Federal Energy Regulatory Commission. High-voltage electricity from the bulk power system is converted to lower voltage at substations, and sent into thousands of electric distribution systems across the U.S. Distribution systems are regulated by state and local authorities or by oversight boards, and they exhibit tremendous heterogeneity in their resources, technological sophistication, ownership structure, and oversight mechanisms. The grid—composed of both the bulk power system and local distribution networks—is a system governed by many independent decisions and without a single organization in charge.

No single entity is responsible for, or has the authority to implement, a comprehensive approach for ensuring the resilience of the nation's electricity system. Because most organizations involved in operating and regulating the grid are preoccupied with short-term issues, they neither have the time to think systematically about what could happen in the event of a large-scale outage, nor do they adequately consider the potential consequences in their operations, planning, or research and development priorities. The U.S. needs a process to help all parties better prepare for and take action to mitigate the consequences of major outages. While the study's specific recommendations detailed below will incrementally advance the resilience of the nation's electricity system, these alone will not be sufficient unless the nation is able to adopt a more integrated perspective. Thus, the report recommends the creation of multiple resilience assessment groups to envision grid vulnerabilities and systemic impacts of large-area long-duration outages, provide guidance and support to decision-makers working to improve grid resilience, and coordinate across federal, state, and local levels.

STRATEGIES TO PREVENT OUTAGES AND MAKE THEM SMALLER

Resilience begins with preparative and preventative actions to make outages less likely. While the report focuses predominantly on large-scale outages, many of the approaches described may also reduce occurrences of small routine outages and increase utility performance on common reliability metrics. The report describes and recommends multiple strategies to make outages less frequent or smaller in scale, including:

- Improving the health and reliability of individual grid components, for example through preventative maintenance
- Designing the system's cyber-physical architecture to reduce critical dependence on individual components
- Rapidly providing better information and control strategies to operators through increased deployment of sensors and advanced data analyses

- Ensuring fuel diversity and avoiding over-reliance on any single fuel source, particularly natural gas

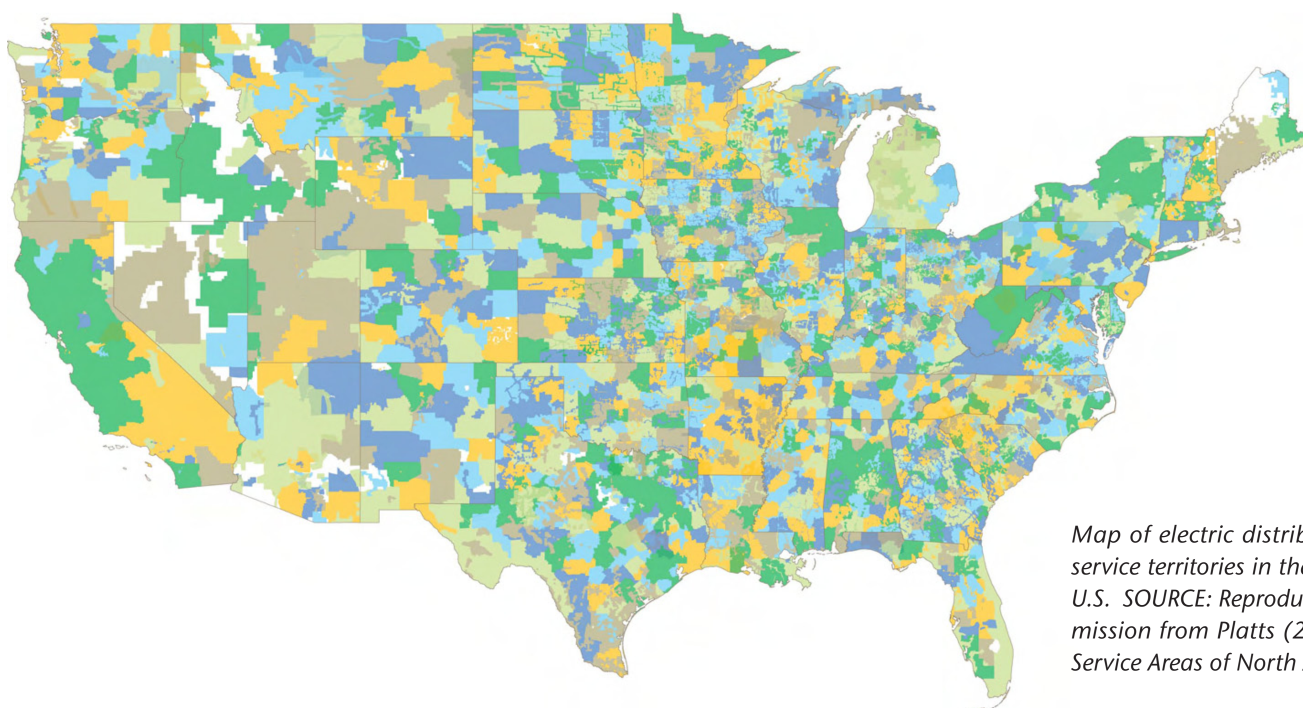
Many of these strategies focus on the bulk power system of large generators and high-voltage transmission lines, but the rapid pace of technological change for distribution systems in some regions is bringing additional opportunities to light. Distributed energy resources (DERs) and advanced controls on local distribution systems could play a larger role in preventing or limiting the spread of outages, for example through automatic reconfiguration of circuits to isolate broken components or using DERs to maintain power quality (e.g., keeping voltage and frequency within specified limits). A critical challenge in implementing any of these strategies on a meaningful scale is navigating the complex economic, institutional, and regulatory structures that oversee the grid.

STRATEGIES TO COPE WITH OUTAGES WHEN THEY OCCUR

The second stage in the resilience framework is to ameliorate the impacts of outages when they happen. While large-scale outages are rare, some will occur and restoration may take a long time. It is essential that utilities, public agencies, and society more broadly prepare for prolonged periods of electricity loss and the subsequent loss of vital public services including heating and cooling, water and sewage pumping, traffic control, financial systems, healthcare, and emergency response. The effects of power outages vary depending on the weather, the types and locations of customers affected, and the duration of the outage. A central theme of this report is the need to improve how different elements of society imagine the diverse consequences of prolonged power outages. The report recommends several strategies to help prepare for such scenarios, including:

- Improving the reliability of customer-purchased backup power equipment through more systematic testing and upkeep
- Re-evaluating government stockpiles and contracts for provisions of emergency power equipment and fuel during disasters
- Encouraging critical facility operators to pre-register information about their emergency power needs in a centralized and accessible database
- Exploring the potential for dynamic and selective provisioning of power to specific circuits or even individual meters on a circuit

Advanced distribution technologies including DERs, microgrids that can separate from the larger grid and maintain small pockets of power, and smart controls in substations and on individual distribution lines could provide partial service to critical facilities. The report recommends that state regulatory bodies and distribution system operators evaluate the legal,



Map of electric distribution utility service territories in the continental U.S. SOURCE: Reproduced with permission from Platts (2014), "Utility Service Areas of North America".

financial, and technical challenges associated with using customer-owned generation assets to provide partial service during major outages.

STRATEGIES TO EXPEDITE RECOVERY AND IMPROVE LEARNING AFTER OUTAGES

The last stages in the resilience framework involve recovery and learning from an outage. Effective restoration begins well before the disaster through preparatory activities including drills and stockpiling of key equipment. In the chaotic period after a large-scale power outage, utilities, first responders, and public agencies must work together to restore power quickly. In general, recovery entails an iterative process of assessing damage, coordinated activity to reconfigure, repair, and replace physical components, and a variety of activities to rebuild the cyber monitoring and control systems. However, in practice restoration processes are different depending on the event and the type of damage caused, such as whether the cyber monitoring and control system is functioning and able to aid in damage assessment. The report recommends several strategies to improve restoration activities for different damage scenarios, including:

- Developing standards for utility cyber control systems so that personnel on loan from other organizations can effectively participate in cyber mutual-assistance agreements
- Continuing research and demonstration into advanced power transformers that can provide greater operational flexibility
- Running restoration drills that engage key stakeholders from other critical infrastructure sectors such as communications, natural gas, and transportation
- Improving post-incident investigation practices to better learn from major outages and improve recovery processes for future outages

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