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Ensuring a Reliable and Resilient Electrical Grid

EXECUTIVE SUMMARY

In addition to being affordable, reliable, and sustainable, the United States electricity system must be *resilient* – able to avoid, and rapidly recover from, events that may compromise power delivery. The 2021 cold weather-related events in Texas and region-wide heat waves in California demonstrated the vulnerability of our electrical grid to increasingly common extreme weather events. Major factors threatening the reliable and resilient operation of the grid include: aging infrastructure; potential consequences due to climate change; cyber and physical attacks; unavailability of electricity supply due to intermittency of some renewable generation coupled with the decreasing availability of dispatchable power; and deficiencies in the integration of electric grid operating systems from wide-spread geographical regions with differing power generation technologies.

Recommendations to improve the operation, reliability, and resiliency of the electric grid include:

- accelerating the replacement of aging infrastructure;
- shortening supply chains to reduce replacement times for key components;
- hardening the power supply at the national level against threats from weather and cyber/physical attacks;
- deploying new technologies;
- encouraging diverse clean energy technologies;
- supporting deployment of energy storage; and
- updating the operating systems for the electric grid.

These recommendations should be carefully weighed when making policy and investment decisions regarding the electricity power generation sector.

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INTRODUCTION

The goal of the U.S. electricity system, including production, transmission, and distribution, is to be affordable, reliable, and sustainable. For the electricity system to provide dependable power, it must be both reliable and resilient. Reliability and resiliency are complementary objectives that are often grouped together, but they have separate meanings and must be evaluated independently.

Reliability is the ability of the electrical system to avoid failure, due to the loss of individual components, weather related events, or external events. *Resiliency* is the ability of a system to minimize the consequences of, and to recover rapidly from, a failure. In a complex system, steps taken to improve reliability may impair the resilience of the system, and vice versa.
An example of this trade-off is the networks of sensors and electronic controls often referred to as smart-grid technology. Smart grids can allow the grid to recover much more quickly from failure, improving the resiliency. If the smart grid is not engineered with cybersecurity in mind, the grid will be more vulnerable to cyber-attack, potentially harming its reliability. At the same time, however, the smart grid may improve the reliability of the system in other ways, such as allowing isolation of individual components before they fail and cause larger, widespread disruptions. These trade-offs between reliability and resiliency, and between various aspects of reliability and resiliency, must be considered at the policy, business, and technological level.

This document provides recommendations for policymakers to improve U.S. energy reliability and resiliency. Recent large-scale disruptions to the U.S. grid will be discussed, as well as threats that could lead to future disruptions. Both technological changes and policies that may mitigate this threat will be discussed.

OVERVIEW OF RECENT U.S. POWER DISRUPTION EVENTS

Events in the two most populous states, California, and Texas, in the past two years have shown how vulnerable our current power system is to disruption. A series of additional events in the past 20 years shows that these two power systems are not alone in being vulnerable to disruption.

Texas: The February 2021 statewide power outages in Texas[i] were triggered by three severe winter storms that dropped temperatures to as low as -2◦F in Dallas with 140 continuous hours below freezing. On an average day during the first week of February 2021, ERCOT was historically able to supply the electrical needs of the area but, with low temperatures combined with the winter storms all types of generation technologies failed. Certain power plants within each category of technologies (natural gas-fired power plants, coal power plants, nuclear reactors, wind generation, and solar generation facilities) failed to operate at their expected electricity generation output levels.

Power plants listed a wide variety of reasons for going offline throughout the event. Three reasons for power plant failures include "weather-related" issues (30,000 MW, ~167 units), "equipment issues" (5,600 MW, 146 units), "fuel limitations" (6,700 MW, 131 units), "transmission and substation outages" (1,900 MW, 18 units), and "frequency issues" (1,800 MW, 8 units)[ii].

While it is possible to weatherize electrical generation and natural gas systems and partially weatherize renewables, much of Texas ERCOT system was not weatherized. As a result, gas well heads shut down, moisture in pipelines froze, windmills froze, and electrical pumps failed due to loss of electric supply (power outage lasted about 2.5 days). The official death toll was 246 dead,[iii] along with at least $130 B in direct damages[iv]. The results of the Feb 2021 outage were not confined to Texas. Peaks in the spot price of natural gas in Minnesota[v] caused by supply disruptions from Texas suppliers, for example, appear to have led to $800M in increased costs for consumers[vi].

The Texas's regulatory approach left it uniquely vulnerable to this disaster. ERCOT is outside of the North American Reliability Council regulatory structure by choice and is minimally interconnected to the national electrical grid which caused them to be unable to be assisted by the interconnecting grid.

Notably, El Paso, which is outside of ERCOT and is part of the Southwest Power Pool transmission organization, is connected to the greater national transmission system and operates under national power standards, did not lose power. Systems in El Paso have enhanced winterization, additional crews, and a diverse portfolio of electric generation options. ERCOT operators were handicapped by earlier decisions to not winterize despite recommendations issued after a 2011 winter storm with similar effects.[vii]

California: The 2020 California blackouts were triggered by a region-wide heat wave that led to increased demand for electricity for air conditioning. Elevated temperatures can also lead to reduced power output. After a 1,000 MW wind and a 470 MW natural gas generating unit tripped offline, the California Independent System Operator (CAISO) issued a Stage 3 Electrical Emergency and directed utilities, particularly PG&E, to begin load shedding[viii]. By implementing rolling blackouts that impacted 200,000-250,000 customers per hour, overall grid reliability was maintained. About 2 million customers suffered a loss of power. The causes were ballooning demand, inadequate transmission, an overreliance on intermittent forms of renewable energy and natural gas plant challenges during hot weather. However, unlike Texas, the balance of the overall electric system remained operational.

Puerto Rico: The above two events are simply the most recent large-scale blackouts in the United States. Other events in the past 20 years show that these are not isolated events. The 2017 Puerto Rico blackouts and the 2021 New Orleans blackouts show the vulnerabilities of critical infrastructure. Hurricane Maria damaged or destroyed much of Puerto Rico's already fragile infrastructure, including 80 percent of the island's power lines. Power was not fully restored for 11 months, making this the largest power outage in US history and the 2nd largest in the world, after the 2013 blackout in the Philippines caused by Typhoon Haiyan. The Puerto Rico outages affected both humanitarian relief and Puerto Rico's economic recovery. Because relief funds are targeted at repairs instead of upgrades, Puerto Rico still lacks a resilient power grid.

Louisiana: The extended blackout in southern Louisiana after Hurricane Ida in 2021 shows the consequences of failure to upgrade equipment. 18 deaths were attributed to lack of air conditioning and carbon monoxide poisoning due to improper generator usage. A failure to upgrade transmission capabilities after Hurricanes Katrina (2005) and Gustav (2008) is widely held to be responsible for the length and severity of these blackouts.

Northeastern United States: While severe weather events are the most notable cause of recent blackouts, they can also be caused by human error, deferred maintenance, and other issues. The 2003 Northeastern Blackout was caused by overgrown trees contacting power lines. Within 3 minutes, this failure cascaded, shutting down 21 power plants and affecting 50 million people in Ohio, Michigan, New York, Pennsylvania, New Jersey, Connecticut, Massachusetts, and Ontario[ix]. Due to poor tree maintenance and a relatively small, localized, failure cascaded across the region. While the blackout was resolved within four days, the damages in New York City alone were more than $500 million.

Florida: Over twenty years ago Jacksonville, Florida had a severe winter storm with temperatures down to 11F that essentially shut down the JEA power plants due to water and fuel pipes freezing throughout the plant infrastructure. Based on that freeze, money was expended to winterize the water and fuel piping. Pipes were either insulated due to size or had heat tracing installed. The winterization efforts greatly improved the power plant response to winter storms as well as hurricanes in the area.

THREATS TO THE ENERGY SYSTEM

There are multiple threats to the energy system. Some of these, such as aging equipment, have led to failures of the electrical grid. Others, such as cyberattacks, have led to failures of the electrical grid outside of the United States, and to related energy systems in the United States.

Aging Infrastructure: Multiple power plants and transmission components that are part of the United States electrical system are past their licensed design lives. Some US operating fossil fuel plants were constructed in the 1950s and 60’s, while the nuclear plants operating in the United States were built in the 1970s through 1990’s. Renewable energy plants are generally newer, but there are wind farms dating to the 1970s and solar farms dating to the 1980s. The electric transmission infrastructure that supports the older electrical generation facilities, including portions of the coal and natural gas supply chains, are equally dated.

There are similar challenges in the 640,000 miles of high-voltage transmission lines in the lower 48 states, many of which were built in the 1950s and 1960s, with an expected design life of 50 years. The average age of installed large power transformers (LPT) in the United States is approximately 38 to 40 years, with 70 percent of LPTs being 25 years or older. The electrical distribution system is not only aging but, the components have long lead-times, and most have imported replacement components. These systems were designed for smaller populations, different usage (less use of electronics and cooling needs) and different electrical sources.

Climate Change: The consequences of a changing climate for the United States energy system are still a subject of considerable discussion. There is a growing consensus that while it is difficult to attribute any individual severe weather event to climate change, severe weather events are growing in intensity and frequency. These can include events such as hurricanes and tornadoes that cause physical damage to power generation and distribution equipment. Extreme temperatures can also lead to increased demand for heating and cooling power. Finally, the interactions of the power system with the changing environment can generate risks not only to the power system, but to the environment, as demonstrated by California wildfires[x] caused by electrical equipment sparking the dry grass and forests

More subtle effects from climate change are possible - it may change renewable energy resource availability and locations while higher temperatures reduce the efficiency of thermal energy generation. Major concerns include (1) determining how severely, and how rapidly, climate change will affect power systems, and (2) substantial portions of the United States power system were not built to account for changing climates.

Cyber- and Physical Attacks: The Federal Power Act (FPA) requires the Electric Reliability Organization (ERO) to develop and enforce mandatory and enforceable reliability standards; the Federal Energy Regulatory Commission (FERC) certifies the standards (Section 215 to FPA). FERC approved an initial set of mandatory cybersecurity standards that have been frequently updated and reviewed since 2008[xi]. While no US electrical grid has been shut down due to cyber-attacks, the recent 2021 ransomware attack on the Colonial pipeline system, leading to fuel shortages in the eastern United States, showed that US infrastructure is vulnerable. The Colonial attack also showed additional aspects of how infrastructure is vulnerable: the attack targeted the billing and data management systems and took advantage of the lack of two-factor authentication.

The electrical system is heterogenous, and in many cases, the systems were not designed with physical sabotage or cybersecurity in mind. The possible sources of security attackers include state actors, hackers and individuals acting with or without state protection, and terrorist groups. Physical security is a related concern; the US power transmission systems are spread out in remote areas of the system often with minimal security protections that are not technically feasible and economically reasonable to protect.

New Technologies: Managing the integration of emerging technologies, including renewable energy, electric vehicles, storage, and smart / microgrids, presents a new set of challenges. These challenges will grow with increasing decarbonization: The International Energy Agency (IEA) has stated that only 50% of the technologies required to meet the 2050 decarbonization goals are now commercially available[xii]. Each of these technologies introduce new vulnerabilities, even as they may ameliorate existing vulnerabilities. Electric vehicles create new electric load demands and change the patterns of electricity use. Storage has the potential to make the grid more reliable and resilient, but its failure modes are not well understood. Finally, smart grids may improve the reliability and resilience of the electrical system but may introduce new cyber vulnerabilities. Understanding the benefits and drawbacks of new technologies is key to integrating them into a reliable and resilient system.

TECHNOLOGY BASED RECOMMENDATIONS

Appropriate technical decisions, which require significant planning and commitment of resources, will improve the reliability and resiliency of the electrical grid. This will necessitate effective use of existing technologies, and an integration of new technologies into the grid. Recommendations for Technology strategies to promote energy reliability and resilience are discussed below.

Accelerate the Replacement of Aging Infrastructure**:** As noted above, large parts of the United States electrical system are either past their design life or operating under load conditions that they were not designed to operate under. Replacing aging infrastructure in a systematic manner will improve both the reliability and efficiency of the electrical system. Cost recovery/allocation will be critical and may require further FERC oversight and regulatory reform.

Harden the Power Supply at the National Level**:** The technology existed to prevent the Texas power outages. Natural gas lines, fossil fuel power plants, wind turbines, and electrical distribution systems all operate reliably in other states that experience more severe temperatures than those experienced in Texas in February of 2021. Incorporating appropriate levels of hardening to severe weather events should be accelerated. The range of conditions that systems should be prepared to operate under should be expanded in recognition of both uncertainties in the existing climate record and anticipated future changes in climate. This can be done as aging infrastructure is replaced, and/or retrofitted to extend the existing infrastructure design life.

Cyber and Physical Security: Effective cybersecurity is not only vital to preventing cyberattacks, but also necessary for smart grids and expanded energy storage. Maintaining the cyber-security of the grid will require effective cyber-security measures to be implemented across the entire electrical system, even systems not under FERC authority. All levels of government, utilities, the public and related organizations will need to coordinate and cooperate. between.

Secure the Energy Supply Chain / Shorten the Replacement Time of Key Components**:** In many cases, critical components such as electrical transformers have lead times on the order of years and many of the manufacturers are overseas. Developing shared reserves of critical components will allow component failures to be addressed quickly. Other efforts to reduce the lead time through effective supply chain management and domestic manufacturing should also be encouraged.

Effective Deployment of Electrical Storage: While storage is often thought of as a back-up when electrical generation capability is lost, storage can also be used to prevent the loss of electrical generation capability. Effective use of stored energy for frequency control can prevent failure of a grid. It can also be used to accelerate the restart of electrical facilities, including “black starts” without external power. Finally, by allowing the grid to respond more efficiently to both changes in demand from users and changes in generation from intermittent renewables, storage can improve the overall reliability of the electrical grid.

Encourage Diverse Clean Energy Resources and Standby Electrical Generation Capability: Policies have encouraged renewable energy generation and natural gas generation but have been most supportive of wind and solar resources. Other stable resources such as hydro, geothermal, and biomass-based electricity should receive equitable incentives and support. Deep decarbonization requires all types of resources which will create a more reliable and resilient electric infrastructure.

Increasing the amount of dispatchable electrical generation capability in a standby role could improve the reliability and resilience of the system but could also cause greater carbon emissions. In the case of ERCOT, standby generation should also take into account the low connectivity of the local grid to the national grid. Dispatchable electrical generation should be available to fill gaps created by the intermittency of solar and wind resources. Bio-based fuels could be a solution to help source dispatchable electricity generation, such as renewable diesel or bio-based natural gas. Present laws and regulations discourage the use of biofuels for electricity generation. A more fungible system for biofuels could help with reliability.

Use of Smart Grids: A smart self-healing grid uses secure digital components and real-time communications technologies installed throughout a grid to monitor the grid's electrical characteristics at all times and constantly tune itself so that it operates at a reliable, secure and optimum state. It has the intelligence to constantly look for potential problems caused by storms, catastrophes, human error or even sabotage. The smart grid isolates problems immediately as they occur, before they cascade into major blackouts, reorganizes the grid and reroutes electricity transmission so that services continue for all customers while the problem is physically repaired by line crews, if needed.

A smart grid can provide a number of benefits that lead to a more stable and efficient system. Three of its primary functions include:

- Real-time monitoring and reaction, which allows the system to constantly tune itself to an optimal state;
- Anticipation, which enables the system to automatically look for problems that could trigger larger disturbances; and
- Rapid isolation, which allows the system to isolate parts of the network that experience failure from the rest of the system to avoid the spread of disruption and enables a more rapid restoration.

Beyond, managing power disturbances, a smart grid system efficiently integrates/manages distributed energy resources (DERs), and provides much-needed local and system flexibility. The ideal smart grid system consists of microgrids, which are small, mostly self-sufficient power systems, and a stronger, smarter high-voltage power grid, which serves as the backbone to the overall system.

CLOSING SUMMARY

Maintaining a reliable and resilient grid faces the challenges of an aging infrastructure, climate change, cyber and physical attacks, and disruptive new technologies. Technological solutions exist for creating a reliable and resilient electrical grid that are compatible with other energy goals such as affordability and sustainability.

Weather related events can cause major electric disruptions. History has proven that these events will continue to occur, and experience has shown that many utilities were not prepared when it had happened again. Reliability requires that the electricity infrastructure be hardened for weather related events.

Future policy decisions for the US electrical system need to:

- Encourage an accelerated replacement of aging infrastructure that incorporates cyber and physical security;
- Develop shared reserves of critical components;
- Effectively coordinate supply chain management and domestic manufacturing;
- Diversify energy resources and storage along with standby/dispatchable electric generation; and,
- Greater implementation of smart grid systems.

POST SCRIPT

As this report was finalized in February 2022, Texas was hit by a severe winter storm that initially raised concerns of a power outage similar to 2021. No large power outage was experienced. An EIA analysis attributed this to a combination of increased preparations and a far less severe storm, thus straining the power system less than in the 2021 incident. Increased preparations included inspection and enforcement of weatherization and readiness requirements, increased operational reserves, requirements for on-site fuel supply, and increased testing. The decreased strain included less loss of power, and less demand for electricity for heat, as compared to both initial predictions and the 2021 storm.[xiii] Experts remain concerned about the ability of the Texas power system to remain functional in a storm as severe as that experienced in 2021.

This statement represents the views of the Energy Public Policy Task Force of the ASME Committee on Government Relations and not necessarily the views of ASME as a whole.

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[i] https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Witness%20Testimony_Robb_OI_2021.03.24.pdf

[ii] https://energy.utexas.edu/ercot-blackout-2021

[iii] https://www.dshs.texas.gov/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf

[iv] "A Debrief of the Texas Power Outages & The Financial & Policy Implications" by Mike Nasi April 27, 2021

[v] https://www.kare11.com/article/money/natural-gas-price-hikes-passed-to-customers/89-0f6e40b4-7534-4550-8fb4-7a0e7536318d.

[vi] https://www.minnpost.com/greater-minnesota/2021/03/minnesota-lawmakers-look-to-help-customers-deal-with-natural-gas-price-spike/.

[vii] https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf.

[viii] ERCOT's electricity suppliers provided 308 GW-hrs of electricity from wind generation, 34 GW-hrs from solar, 765 GW-hrs from natural gas, 255 GW-hrs from coal, and 123 GW-hrs per from nuclear power each day. As the temperatures plunged, electricity demand increased. At the same time, electricity generated from wind dropped to a daily average of 113 GW-hrs, generation from solar dropped to 17 GW-hrs, generation from coal remained relatively steady at 212 GW-hrs, while electricity from nuclear power dropped to 101 GW-hrs.

[ix] https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1165.pdf.

[x] https://energysafety.ca.gov/wp-content/uploads/docs/strategic-roadmap/final_report_wildfiremitigationstrategy_wsd.pdf

[xi] https://www.gao.gov/assets/gao-21-81.pdf.

[xii] https://www.iea.org/reports/net-zero-by-2050

[xiii] https://www.eia.gov/todayinenergy/detail.php?id=51278&src=email