National Electricity Emergency Response Capabilities

Prepared by:

Risk and Infrastructure Science Center

Global Security Sciences Division

Argonne National Laboratory

Prepared for:

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Acronyms and Abbreviations

ANSI	American National Standards Institute
BLS	U.S. Bureau of Labor Statistics
CFZ	Cascadia Subduction Zone
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DOE-OE	U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability
EAAC	Energy Emergency Assurance Coordinators
EIA	Energy Information Administration
EEI	Edison Electric Institute
ESF	Emergency Support Function
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FRCC	Florida Reliability Coordinating Council
kW	kilowatt(s)
kV	kilovolt(s)
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MW	megawatt(s)
MRO	Midwest Reliability Organization
NERC	North American Electric Reliability Corporation
NPCC	Northeast Power Coordinating Council
NRE	National Response Event
PG&E	Pacific Gas and Electric
RFC	Reliability First Corporation
RMAG	Regional Mutual Assistance Groups
RRAP	Regional Resiliency Assessment Program
SCADA	supervisory control and data acquisition system
SERC	SERC Reliability Corporation
SPP	Southwest Power Pool
STEP	Spare Transformer Equipment Program

TRE	Texas Reliability Entity
U.S.	United States
WECC	Western Electricity Coordinating Council

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Executive Summary

An electric industry-wide National Response Event (NRE) is a natural or man-made event that is forecasted to cause or that causes widespread power outages impacting a significant population or several regions across the United States and requires resources from multiple Regional Mutual Assistance Groups (RMAGs).[1] The NRE designation is reserved only for the most significant events, such as a major hurricane, earthquake, an act of war, or other occurrence that results in widespread power outages.[2]

NREs affect not only the electrical infrastructure in communities, but also many other infrastructure sectors, which are all interdependent with the electrical system (e.g., communications, financial, and health care), and often span several states and/or regions. Thus, individual electric utilities cannot adequately plan for a NRE and the necessary related infrastructure restoration efforts. Planning for, and responding to, an event of this magnitude requires coordination and collaboration at the federal, regional, state, and local levels to address the breadth and inter-related nature of these potential impacts. Policies and regulations that facilitate collective action are also vital.[3]

This report will describe the existing electricity emergency response and recovery capabilities within the context of the known and potential hazards based on historical data and modeling studies, as well as identify opportunities to improve national electricity emergency response and recovery capabilities through technology, policy, operational, and organizational means. In the context of this analysis, emergency response activities are those efforts immediately following an event such as assessing system status; damage to generation, transmission, substations; distribution; and crew availability. Recovery activities are efforts to restore the system and return to normal operations.

Gaps were identified in relationship to effectiveness in responding to known and expected NREs. Data was collected on the availability of critical response materials such as wooden poles, cross arms, and spare transformers whose availability can be a limiting recovery factor during an NRE.[4] This information indicates that there are approximately 3,000 spare transformers in the United States. Reliability First Corporation (RFC) has the largest number (822, approximately 28% of the total). The North American Electric Reliability Corporation (NERC) regions with

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[1] Edison Electric Institute (EEI), undated, "Overview of the Electric Power Industry's Mutual Assistance Process during a National Response Event (NRE)," available at http://www.eei.org/meetings/meeting_documents/deric.pdf, accessed July 28, 2016.

[2] EEl, 2016, *Understanding the Electric Power Industry's Response and Restoration Process*, available at http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/documents/ma_101final.pdf, accessed July 28, 2016.

[3] Gridwise Alliance, 2013, *Improving Grid Reliability and Resilience: Lessons Learned from Superstorm Sandy and Other Extreme Events, Workshop Summary and Key Recommendations*, available at https://www.naseo.org/Data/Sites/1/documents/committees/energysecurity/documents/gridwise-superstorm-sandy-workshop-report.pdf, accessed July 27, 2016.

[4] Superstorm Sandy is an example NRE in which contracting enough work crews and maintaining a steady supply of utility poles to the impacted areas were limiting issues during electric restoration, see URL: http://www.usatoday.com/story/news/nation/2012/11/10/sandy-utility-pole-shortage/1696385/.

the lowest number of Federal Energy Regulatory Commission (FERC)-reported spare transformers are Texas Reliability Entity (TRE) (36, approximately 1% of the total) and Florida Reliability Coordinating Council (FRCC) (68, approximately 2% of the total), which may make these regions more-vulnerable to an extended power outages resulting from transformer damage. Alaska is reported to only have one spare medium-voltage transformer.

The data also indicates that the Northeast Power Coordinating Council (NPCC) does not appear to have any wooden pole manufacturers, which agrees with the restoration experience after Superstorm Sandy, during which a lack of utility poles impeded utility restoration activities.[5] However, there appears to be a number of Canadian wooden pole manufacturers that may be available to supply the Northeast. SERC has the majority of utility pole and cross arm producers, which is a benefit when a Gulf Coast hurricane occurs (due to shorter shipping distances). WECC has a number of wooden pole manufacturers located in Oregon and Washington, with only one manufacturer in California.

Data from the Bureau of Labor Statistics indicates that as of May 2015, the electric industry employed a total of 133,218 electric linemen and 18,430 electrical engineers. The ratio of the number of linemen per customers is lowest in WECC which is not unexpected, given that it is geographically the largest NERC region serving an area of nearly 1.8 million square miles and approximately 81 million people. Southwest Power Pool (SPP) has the highest ratio, which may reflect the frequency of severe weather such as ice storms in the region. The largest number of electrical engineers per customer occurs in NPCC (a ratio of 0.22), while FRCC has the least (a ratio of 0.06).

A tipping point analysis was performed that uses the information on number of customers that lost power and the number of mutual assistance workers needed for restoration to estimate external restoration resources needed for a potential future NRE. U.S. Department of Energy (DOE) Form OE-417 data was collected from 2000 to 2014, to determine those historical events for which a national-level response was required based upon whether the event caused widespread power outages impacting a significant population or several regions across the United States and required resources from RMAGs. A total of 13 events were identified, that included hurricanes, ice storms, and other severe weather incidents.

Data collection and analysis were performed to determine which future events or combination of future events could result in exceeding the national capability to respond and recover based on type and extent of each hazard. Eight potential future events were identified which are projected to require a number of linemen greater than that available in a given NERC region and require critical materials in excess of regional capabilities.

Section 7 provides a list of recommendations that are meant to ensure effective management resources to a national-level event. Enhancements in Emergency Support Function (ESF)-12 capabilities are discussed to respond to catastrophic events and improve electricity system

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[5] Jervis, R., 2012, “Suppliers struggle to keep up with utility pole demand,” *USA Today*, November 12, available at http://www.usatoday.com/story/news/nation/2012/11/10/sandy-utility-pole-shortage/1696385/, accessed June 30, 2016.

resilience through improvements to technologies, policies, operational procedures, and/or organizational practices.

1 Introduction

An electric industry-wide National Response Event (NRE) is a natural or man-made event that is forecasted to cause or that causes widespread power outages impacting a significant population or several regions across the United States and requires resources from multiple Regional Mutual Assistance Groups (RMAGs).[6] The NRE designation is reserved only for the most significant events, such as a major hurricane, earthquake, an act of war, or other occurrence, that result in widespread power outages.[7]

NREs affect not only the electrical infrastructure in communities but also many other infrastructure sectors, which are all interdependent with the electrical system (e.g., communications, financial, and health care), and they often span several states and/or regions. Thus, individual electric utilities cannot adequately plan for a NRE and the necessary related infrastructure restoration efforts. Planning for, and responding to, an event of this magnitude requires coordination and collaboration at the federal, regional, state, and local levels to address the breadth and inter-related nature of these potential impacts. Policies and regulations that facilitate collective action are also vital.[8]

This report describes the existing electricity emergency response and recovery capabilities within the context of the known and potential hazards based on historical data and modeling studies, as well as identifies opportunities to improve national electricity emergency response and recovery capabilities through technology, policy, operational, and organizational means. In the context of this analysis, emergency response activities are those efforts immediately following an event such as assessing system status; damage to generation, transmission, substations; distribution; and crew availability. Recovery activities are efforts to restore the system and return to normal operations.

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[6] Edison Electric Institute (EEI), undated, "Overview of the Electric Power Industry's Mutual Assistance Process during a National Response Event (NRE)," available at http://www.eei.org/meetings/meeting_documents/deric.pdf, accessed July 28, 2016.

[7] EEI, 2016a, *Understanding the Electric Power Industry's Response and Restoration Process*, available at http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/documents/ma_101final.pdf, accessed July 28, 2016.

[8] Gridwise Alliance, 2013, *Improving Grid Reliability and Resilience: Lessons Learned from Superstorm Sandy and Other Extreme Events, Workshop Summary and Key Recommendations*, available at https://www.naseo.org/Data/Sites/1/documents/committees/energysecurity/documents/gridwise-superstorm-sandy-workshop-report.pdf, accessed July 27, 2016.

2 Information and Data Sources

A number of sources of information are involved in the response and recovery of electric power system disruptions. Table 1 lists selected data sources used in the preparation of this report.

Table 1 Data Sources and Role in Analysis

Data Source	Role in Analysis
FEMA	Historic event response
NERC	Transmission system data
FERC	Transformer data
DOE	Electric utility/distribution system data – DOE Form 417
BLS	Labor statistics
EEI	National response and restoration
Eaton	Electric utility/distribution system incident data

3 Emergency Response and Recovery Overview

Government at all levels is involved in responding to disasters, attacks, and other incidents that affect the nation's electricity supply. The electric power providers, however, are responsible for repairing damaged infrastructure and restoring services. Federal agencies and state and local government play important roles in coordinating the response, gathering and sharing of information, and communicating with key stakeholders and the public. Government's primary role in responding to energy crises or emergencies is one of coordination and communication. In severe emergencies, Government plays additional roles such as providing logistical support—for example, location and transportation of repair crews and equipment; assisting in damage assessments with experienced trained personnel; regulatory relief such as driver hour/weight/pollution control waivers; security forces; police and fire protection; and/or escort of materials, equipment, and personnel.

Electric utilities respond daily to events that lead to power outages. This study analyzed hazards, infrastructure damage impact, and restoration resources in an attempt to answer questions regarding our nation's response capabilities. At what point do events indicate that the extent of damage to the electric infrastructure exceeds their ability to respond with internal resources? What recourse do utilities have? In general, the utility objective is to restore power most efficiently—typically measured by restoring power to the most customers in the least time in a safe manner. How can government facilitate the restoration process? The electric network is subject to natural and man-made events that could lead to infrastructure damage and subsequent power outages. The extent of damage to the infrastructure determines the amount of resources that will be required to restore operations. Figure 1 visually displays this relationship, and, in

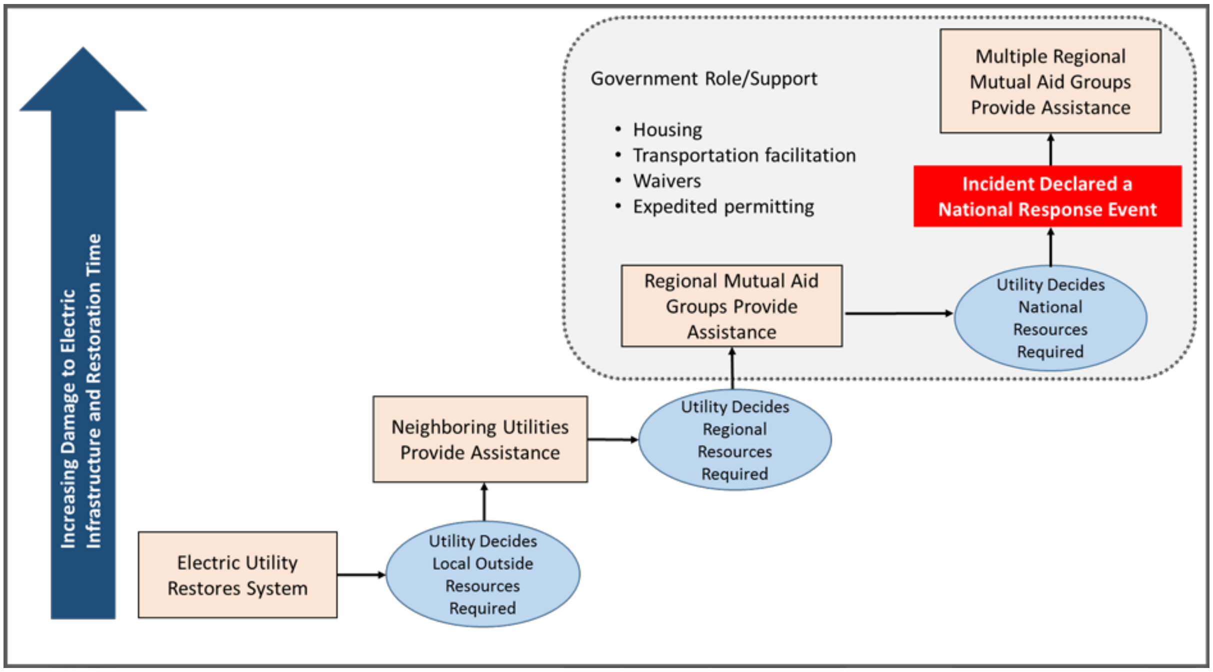

Figure 1 Restoration Resource Process

addition, indicates that there is a “tipping point” at which external resources will be needed by utility providers to address increased damage to the infrastructure and potentially trigger a national-level response.

Figure 2 illustrates grid performance—pre-, during-, and post-event. During the pre-event steady-state phase, prior to any disruptive event, the grid is operating normally within the standard N-1/N-2 tolerances. During the *Prevent/Prepare* phase, the system can be designed and operated to be more resilient should a disruption occur. Once a disruption to the grid occurs and is detected, which could be either natural or man-made, operators and automated processes will undertake a range of measures to *Mitigate* the impacts of the event. During this phase, performance of the grid may be degraded as the configuration of grid assets and the availability of resources have changed compared to pre-event, and as operators attempt to maintain reduced functionality with available resources. Grid performance following the event is shown toward the right end of the spectrum as operators and response personnel exercise immediate response and recovery actions to stabilize the grid, reconnect loads, and return to full functionality as quickly as possible. *Response* activities to stabilize the grid and mitigate cascading failures to grid components and impacts on end users occur immediately following and during the event. Actions that improve the response and reaction to immediate consequences following an incident focus on the ability to contain the impact of a particular all-hazards event. Improved response planning, communications, analysis, and mitigation contribute to effective consequence management following an event. During the *Recovery* phase, operators reconstitute system components and return to normal operations.

Historical data are analyzed to provide insight into the most common threats and hazards, the availability of resources, and identity the point where external assistance is required. The analysis is conducted at the regional level using the eight continental U.S. regions defined by the North American Electric Reliability Corporation (NERC). Figure 3 shows these NERC regional designations.

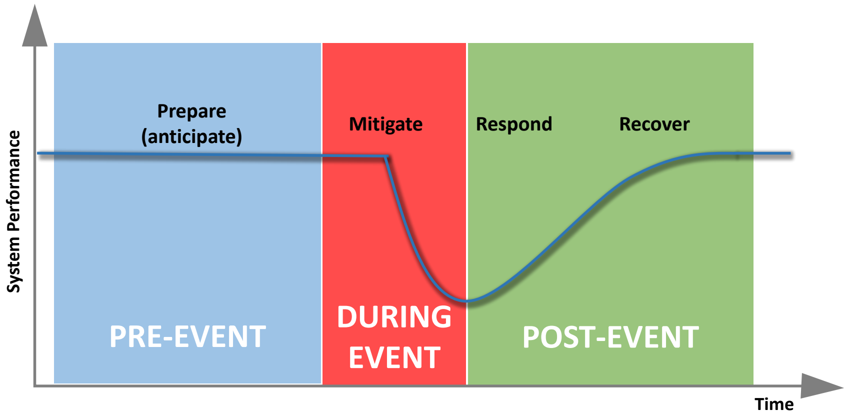

Figure 2 Grid Performance and Incident Phases

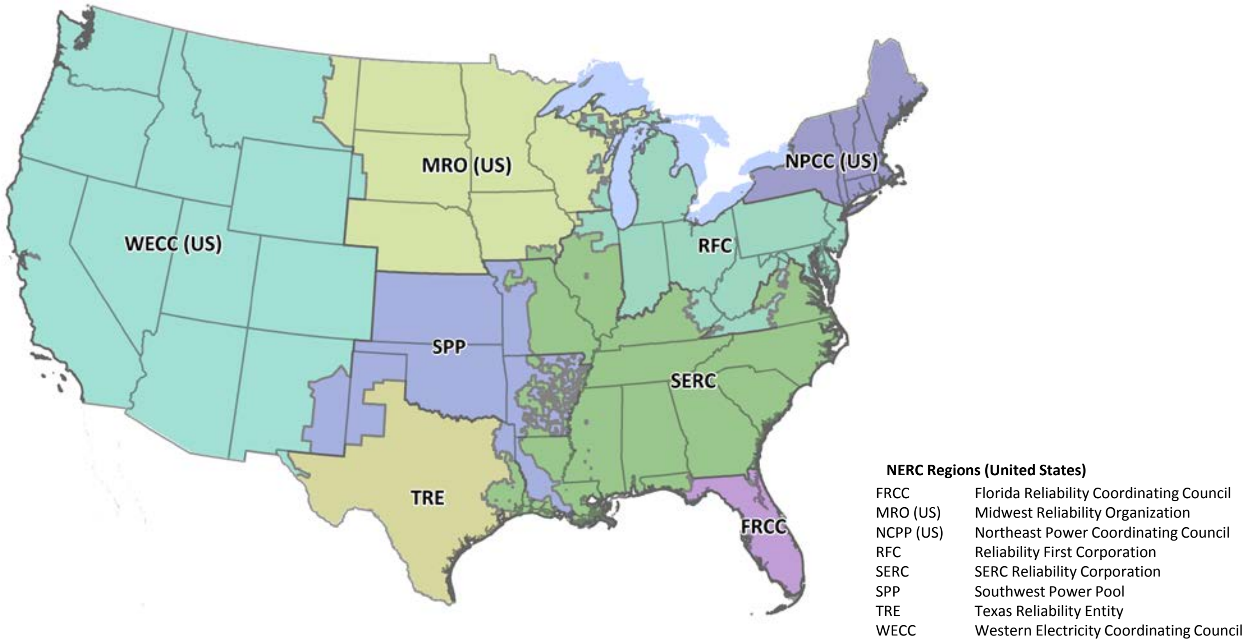

Figure 3 NERC Regions

3.1 ESF-12 Role

The federal government and many state governments organize response resources and capabilities under the National Response Framework's Emergency Support Function (ESF) construct. U.S. Department of Energy (DOE) is the designated coordinator for ESF-12. Restoration of normal operations at energy facilities is the responsibility of facility owners. ESF-12 is intended to:

- Facilitate the restoration of damaged energy systems for incidents requiring a coordinated federal response;

- Collect, evaluate, and share information on energy system damage and estimations on the impact of energy system outages within affected areas;

- Provide information concerning the energy restoration process such as projected schedules, percentage completion of restoration, and geographic information on the restoration;

- Facilitate the restoration of energy systems through legal authorities such as fire and police department support and waivers; and

- Provide technical expertise to the utilities, conduct field assessments, and assist government and private-sector stakeholders to overcome challenges in restoring the energy system.[9]

The private sector utility owners and operators take the lead in the restoration of electric services after an incident occurs. ESF-12 assesses the impact of the incident, coordinates information and requests for assistance with electric sector owners and operators, and facilitates the overall information sharing and restoration process.

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[9] DOE, 2008, "Emergency Support Function #12 – Energy Annex," available at http://www.fema.gov/media-library-data/20130726-1825-25045-9530/emergency_support_function_12_energy_annex_2008.pdf.

4 Hazard Analysis

4.1 Typical Emergency Events

A hazard is a natural or man-made source or cause of harm. Although natural hazards occur largely on a regional basis, man-made threats and hazards are not regionally based. A hazard differs from a threat in that a threat is an intentional act of an adversary directed at an entity, asset, system, network, or geographic area, while a hazard is not directed. The physical vulnerabilities of the electric power system vary among infrastructure components and geographic location. In general, threats and hazards can be categorized as natural and human and or man-made. Historically, weather-related disturbances are the leading source of grid outages. Severe weather is the single leading cause of power outages in the United States. Natural hazards, including hurricanes, winter storms and ice, earthquakes, tornadoes, wildfires, and floods present a significant and varied risk to the grid. Human or man-made threats are intentional, directed attacks on an asset or system; examples include insider threat and malicious physical or cyberattacks.

Threats and Hazards

- *Natural disasters:*
  - *hurricanes*
- *Severe weather*
  - *Thunderstorms*
  - *Extreme high temperatures*
  - *Extreme winter weather*
  - *Ice storms*
- *Equipment failures*
- *Improper response to operating conditions*

Man-made hazards encompass technological failures resulting in accidents, equipment/materials degradation or failures, or improper response to operating conditions (e.g., equipment misoperation as a result of improper or little formal training programs). Technological failures may be attributed to any number of causes, including communication failure among operators, equipment malfunction, material failures, inherent design weaknesses, poor or improper maintenance and operating practices, minimal training programs, or aging infrastructure. As advancements in grid automation increase, (e.g., smart grid, advanced meter applications, and advanced controls in distribution and transmission systems), a heavy reliance on communications further increases the potential for cyber-related threats that may impact grid operations.

The analysis of threats and hazards impacting the electric sector is conducted on a national level as well as on a regional level using NERC regional entities. Note that the analysis can be scaled to any entity of interest such as state, county, city; FEMA region; or system. As with any analysis and assessment paradigm, the depth and breadth of collected data characterizing the entity of interest largely sets the scope and expectations of follow-on analysis and assessment efforts. Other factors like data accessibility and availability, extent of modeling capabilities, and completeness of assessment methodologies and capabilities also come into play. It is with these factors in mind that a regional perspective was chosen to illustrate the framework. Publicly available data and information at the NERC regional level provide adequate information to set the groundwork for individual regional characterizations and cross-cutting regional comparisons. In essence, the NERC regional perspective provides an acceptable level of data availability and aggregation for analysis of hazards to the electric system.

Data collected by NERC on electric power incidents can be analyzed at the national level to determine the frequency of different hazards affecting the bulk power system as a whole. There were 1,717 incidents between 2000 and 2014. The data in Figure 4 shows that severe weather is the single leading cause of power outages to the bulk power system in the United States. Incidents as a result of severe weather such as thunderstorms, high winds, and winter and ice storms accounted for 44% of outages and caused more than 8 million customer outages. The malicious attack category includes acts of vandalism and other physical attack.

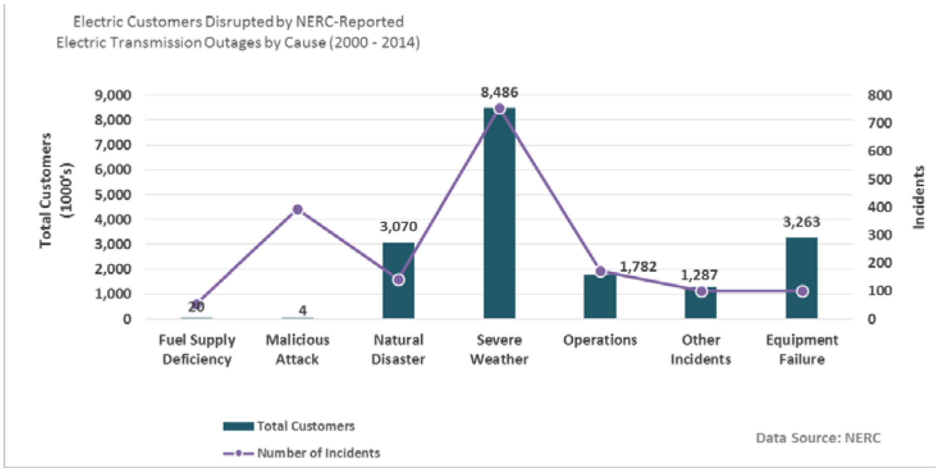

Figure 4 Electric Transmission Incidents 2000–2014

Threats and hazards vary regionally; for example, in Florida, 56% of the outages reported by the Florida Reliability Coordinating Council (FRCC) were due to natural disasters/tropical storms. Severe weather is the single leading cause of power outages in the United States. Transmission outages caused by severe weather such as thunderstorms, hurricanes, and blizzards accounted for 50% of outages reported between 2001 and 2014.

A review of Table 2 indicates that each NERC region appears to be vulnerable to different hazards. The greatest impact on FRCC, Southwest Power Pool (SPP), and Texas Reliability Entity (TRE) is due to hurricanes, reflecting the severe substation flooding and massive damage to transmission systems caused by the high winds and storm surge associated with hurricanes. A primary hardening strategy for transmission subject to hurricanes usually involves upgrading aluminum structures to galvanized steel lattice or concrete.[10]

Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), Reliability First Corporation (RFC), and SERC Reliability Corporation (SERC) are subject to extreme weather such as storms and high winds which can lead to trees falling on power lines or branches coming in contact with power lines. Dead and decaying trees are more likely to cause problems during storms and high winds. The August 2003 blackout that disrupted service to many portions of the Northeast was traced in part to tree limbs coming into contact

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[10] White House, 2013, *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*, available at http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf, accessed June 30, 2016.

Table 2 Statistics for the Top Five Transmission System Incidents by Event Type and NERC Region

Rank	Event Type	Annual Frequency (per year)	Average Loss (MW)	Average Number of Affected Customers	Average Restoration Time (hours)	Maximum Restoration Time (hours)
Florida Reliability Coordinating Council (FRCC)						
1	Natural Disaster – Hurricane/Tropical Storm	1.67	1,060	452,663	109	407.7
2	Equipment Failure	0.40	721	149,934	4	23.5
3	Severe Weather – Thunderstorm	0.20	152	105,333	8	24.4
4	Shed Firm Load	0.27	187	45,359	6	23.1
5	Protection System Misoperation	0.07	283	42,124	0	0.2
Midwest Reliability Organization (MRO)						
1	Severe Weather – Thunderstorm	0.60	310	373,923	70	287.6
2	Severe Weather – Ice Storm	0.47	159	239,714	137	216.5
3	Severe Weather – High Winds	0.33	130	104,400	48	144.2
4	Fuel Supply Deficiency	0.47	379	20,000	154	624.3
5	Natural Disaster – Hurricane/Tropical Storm	0.07	0	107,000	96	96.3
Northeast Power Coordinating Council (NPCC)						
1	Severe Weather – Thunderstorm	2.20	59	137,929	52	216.0
2	Unknown Cause	0.27	9,159	991,372	42	95.3
3	Natural Disaster – Hurricane/Tropical Storm	0.73	9	237,521	108	351.0
4	Severe Weather – Winter Storm	1.13	96	120,877	69	263.3
5	Severe Weather – Ice Storm	0.47	36	256,590	99	240.0
Reliability First Corporation (RFC)						
1	Severe Weather – Thunderstorm	15.07	113	153,347	46	216.5
2	Severe Weather – High Winds	2.73	60	146,092	61	192.0
3	Severe Weather – Winter Storm	2.60	121	137,848	67	384.2
4	Natural Disaster – Hurricane/Tropical Storm	1.67	138	193,919	86	300.0
5	Severe Weather – Ice Storm	1.20	168	105,006	80	384.0
SERC Reliability Corporation (SERC)						
1	Severe Weather – Thunderstorm	7.53	290	119,474	28	191.8
2	Natural Disaster – Hurricane/Tropical Storm	2.13	798	277,897	62	336.2
3	Severe Weather – Winter Storm	2.07	269	116,801	36	72.3
4	Severe Weather – Ice Storm	1.13	558	129,547	78	192.5
5	Reduced Voltage	0.20	7944	451,905	0	0.2
Southwest Power Pool (SPP)						
1	Natural Disaster – Hurricane/Tropical Storm	0.67	65	324,071	77	312.1
2	Severe Weather – Ice Storm	0.47	184	373,500	134	264.2
3	Reduced Voltage	0.07	0	2,000,000	24	24.5
4	Severe Weather – Thunderstorm	0.60	97	60,057	59	215.8
5	Severe Weather – Winter Storm	0.20	0	98,503	24	239.8

Table 2 (Cont.)

Rank	Event Type	Annual Frequency (per year)	Average Loss (MW)	Average Number of Affected Customers	Average Restoration Time (hours)	Maximum Restoration Time (hours)
Texas Reliability Entity (TRE)						
1	Natural Disaster – Hurricane/Tropical Storm	0.60	1,049	616,700	171	456.2
2	Severe Weather – Thunderstorm	2.00	143	123,102	23	119.8
3	Severe Weather – Winter Storm	0.27	100	360,250	60	120.4
4	Major Generation Inadequacy	0.13	2,200	577,872	24	24.2
5	Severe Weather – Other	0.13	147	131,000	12	24.3
Western Electricity Coordinating Council (WECC)						
1	Severe Weather – Lightning	0.27	291	2,651,000	6	23.5
2	Severe Weather – Thunderstorm	1.53	259	278,901	59	239.9
3	Severe Weather – Winter Storm	1.13	239	347,803	61	240.5
4	Protection System Misoperation	1.40	246	274,000	0	0.6
5	Severe Weather – High Winds	2.00	166	154,070	63	408.2

Source: DOE, 2016, "Electric Disturbance Events (OE-417)," available at http://www.oe.netl.doe.gov/oe417.aspx, accessed June 30, 2016.

with transmission lines in Ohio. One strategy to reduce transmission outages is adequate vegetation management programs which can help prevent damage to the transmission infrastructure.[11]

The Western Electricity Coordinating Council (WECC) is unique in that lightning appears to be the primary cause of transmission outages in its region. A lightning arrester is a device used on electrical power systems to protect the insulation and conductors of the system from the damaging effects of lightning. If protection fails or is absent, lightning that strikes the electrical system introduces thousands of kilovolts that may damage the transmission lines and can also cause severe damage to transformers and other electrical or electronic devices.

It was not possible to determine whether the number of transmission incidents is increasing with time, due, for example, to changes in incident reporting. However, it should be noted that a report by the National Governors Association found that 70% of the nation's transmission lines and transformers are at least 25 years old, and 60% of circuit breakers are at least 30 years old. The report indicated that much of the infrastructure was designed in the 1950s, making the system "vulnerable to disruption."[12]

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[11] New York State Electric & Gas Corp (NYSEG), 2016, "Transmission Lines, Trees and Vegetation," available at https://www.nyseg.com/UsageAndSafety/electricalsafety/transmissionlinesandtrees.html, accessed June 30, 2016.

[12] National Governors Association (NGA), 2014, *Governors' Guide to Modernizing the Electric Power Grid*, available at http://www.nga.org/files/live/sites/NGA/files/pdf/2014/1403GovernorsGuideModernizingElectricPowerGrid.pdf, accessed June 30, 2016.

Electric power transmission and distribution systems are vulnerable to the same set of hazards, but the risks associated with each impact may differ for the two types of systems. Differences in risk or risk management strategies arise from the purpose of the equipment, technological differences, geographic location, and from regulatory aspects (e.g., state versus federal compliance standards for vegetation management) for transmission and distribution systems.

One of the primary differences between transmission and distribution systems is that problems on transmissions systems can cause large-scale blackouts over many states, while problems on distribution systems are usually more localized in nature, impacting generally fewer people. Transmission systems are also designed as a network with multiple paths between different substations to minimize the impacts caused by the loss of a single component. Distribution systems are often operated radially such that only one single path delivers the electricity to any given customer. This causes outages downstream from any point of failure in the distribution system.

Incident data was compiled for distribution systems. As with transmission systems, Figure 5 shows that electric utilities nationally experienced the highest number of outages from weather-related (33%) events followed by equipment failure (28%).

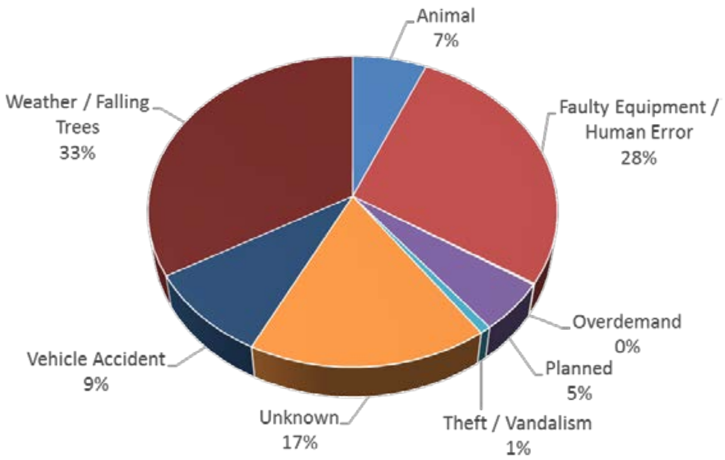

Figure 5 Electric Distribution Outages 2008–2014[13]

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[13] Eaton, 2016, “Blackout and Power Outage Tracker,” available at http://powerquality.eaton.com/blackouttracker/default.asp?wtredirect=www.eaton.com/blackouttracker, accessed June 30, 2016.

Data indicates that 90% of customer outage-minutes are due to events that affect local distribution systems.[13] The top-five causes of distribution system outages vary by NERC region, as shown in Table 3, with weather events predominating for all NERC regions except for WECC. Generally, most power outages are caused by damage from trees and tree limbs falling on local electricity distribution lines and poles.

Table 3 Number of Distribution System Incidents by Cause and NERC Region (2008–2014)

Cause	FRCC	MRO	NPCC	RFC	SERC	SPP	TRE	WECC	Total
Animal	32	76	100	269	231	244	57	331	1,340
Faulty Equipment/ Human Error	149	281	433	1,070	735	895	225	1,966	5,754
Over-demand	1	0	1	5	7	5	2	9	30
Planned	17	57	63	165	192	144	29	420	1,087
Theft/Vandalism	5	2	10	42	30	19	10	48	166
Unknown	112	135	289	726	428	604	158	1,156	3,608
Vehicle Accident	54	74	147	394	323	283	95	572	1,942
Weather/Falling Trees	183	297	731	1,407	1,274	1,322	288	1,425	6,927
Total	553	922	1,774	4,078	3,220	3,516	864	5,927	20,854

Source: Eaton, 2016, "Blackout and Power Outage Tracker," available at http://powerquality.eaton.com/blackouttracker/default.asp?wtredirect=www.eaton.com/blackouttracker, accessed June 30, 2016.

Faulty equipment/human error tops the list for WECC. Examples of faulty equipment include substation fires, transformer fault and potential subsequent explosion, distribution line failure, and arc flashing across air-insulated switchgear.[14] An example of a faulty equipment incident in WECC was a substation fire on July 4, 2004, which posed a blackout threat in Phoenix, Arizona. During the event, five transformers at the substation were damaged and had to be replaced prior to peak summer loads.[15]

"Unknown" events include those with "multiple initiating" causes. Outages are also caused by vehicles driving into components of the electric system such as power poles. Approximately 7% of power outages are caused by animals. According to the Braintree Electric Department, by installing wildlife guards on the distribution equipment most affected, animal-caused outages were reduced by approximately 80%.[16]

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[14] ABB, 2012, "*Overcoming urban power distribution challenges with technology innovations*," available at https://library.e.abb.com/public/4252c34d661764a185257a9300723ff2/ABB-456-WPO_urban-substations_FINAL.pdf, accessed June 30, 2016.

[15] Peoriatimes.com, 2005, "Westwing substation back to full strength," available at http://www.peoriatimes.com/news/article_dba93a4f-e423-5320-a62b-41f2ca1a8e50.html, accessed June 30, 2016.

[16] Gatehouse Media, Inc., 2010, "Braintree battles suicidal rodents with squirrel pads, tree trimming," available at http://braintree.wickedlocal.com/article/20100629/NEWS/306299505, accessed June 30, 2016.

Table 4 provides information on incidents affecting the NERC regions, as a function of year. Comparing the results of Tables 2 and 4 shows that the average number of affected customers is much lower for distribution compared to transmission incidents, although there are many more distribution incidents compared to transmission. Data indicates that 90% of customer outage-minutes are due to events that affect local distribution systems.

Table 4 Overall Statistics for Distribution System Incidents by Year and NERC Region

Year	Annual Frequency (per year)	Average Number of Affected Customers	Average Duration of Outage (hours)
Florida Reliability Coordinating Council (FRCC)			
2008	74	82,657	1.6
2009	98	2,887	1.1
2010	111	2,623	0.8
2011	67	3,786	0.2
2012	54	6,208	0.3
2013	68	5,590	0.5
2014	69	2,656	0.3
Midwest Reliability Organization (MRO)			
2008	144	4,682	2.4
2009	178	2,376	0.9
2010	214	3,577	1.0
2011	150	12,851	1.7
2012	138	3,005	0.7
2013	194	4,255	0.6
2014	207	2,784	0.7
Northeast Power Coordinating Council (NPCC)			
2008	329	9,760	2.6
2009	357	3,614	0.9
2010	504	9,654	0.6
2011	505	33,161	0.4
2012	387	17,449	0.4
2013	396	4,886	0.6
2014	414	4,842	0.7
Reliability First Corporation (RFC)			
2008	329	9,760	2.6
2009	357	3,614	0.9
2010	504	9,654	0.6
2011	505	33,161	0.4
2012	387	17,449	0.4
2013	396	4,886	0.6
2014	414	4,842	0.7

Table 4 (Cont.)

Year	Annual Frequency (per year)	Average Number of Affected Customers	Average Duration of Outage (hours)
SERC Reliability Corporation (SERC)			
2008	517	9,198	4.4
2009	595	7,150	1.1
2010	772	5,373	0.7
2011	776	10,524	0.8
2012	666	14,342	0.4
2013	768	4,740	0.5
2014	846	5,521	0.6
Southwest Power Pool (SPP)			
2008	371	10,075	2.6
2009	519	4,638	0.9
2010	552	3,416	0.9
2011	499	10,986	0.3
2012	415	8,311	0.4
2013	539	3,502	0.5
2014	630	3,853	0.8
Texas Reliability Entity (TRE)			
2008	90	9,133	1.8
2009	138	3,884	0.8
2010	141	4,976	0.6
2011	116	4,673	0.3
2012	120	5,613	0.3
2013	130	4,373	0.3
2014	196	2,133	0.8
Western Electricity Coordinating Council (WECC)			
2008	88	36,108	3.3
2009	121	5,570	1.1
2010	124	6,049	1.4
2011	131	5,254	0.2
2012	112	5,547	0.2
2013	136	6,808	0.5
2014	153	4,590	0.2

Figure 6 shows how the average number of distribution incidents vary as a function of month and NERC region, based on data from 2008 to 2014. It can be seen that the greatest number of affected electric customers occurs during the summer months, which highlights the effect of severe weather such as thunderstorms and tropical cyclones. WECC has the highest number of incidents, in part, because this NERC region occupies the largest land area in the United States. FRCC experienced the least number of distribution incidents.

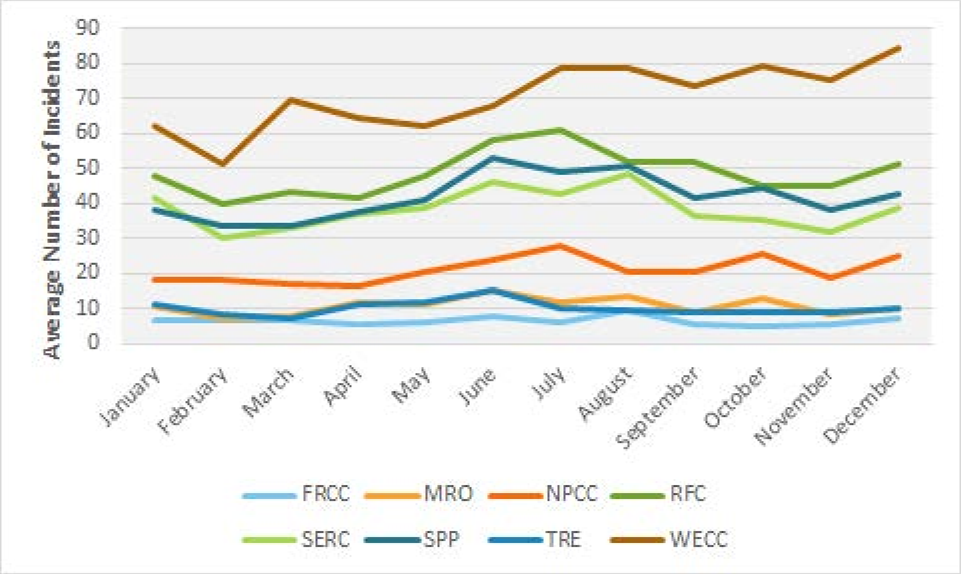

Figure 6 Electric Distribution Incidents as a Function of Month

4.2 Catastrophic Events

The power grid system is vulnerable to multiple serious threats, such as cyber-attacks, electromagnetic pulse (EMP) release, and natural hazards like hurricanes or solar geomagnetic storms. Concern has been expressed that private power utilities are not truly prepared to handle a catastrophic loss of electric power event, and that the effects of such an event would be profound on the entire national grid system.[17] One issue was the amount of damage that could occur as a result of a catastrophic event and the ability to find and install replacement equipment such as utility poles and transformers.

Data is available concerning the quantity of restoration resources for recent hurricanes, as shown in Table 5.[18] The energy infrastructure and supply disruptions caused by the 2008 hurricanes were similar but not as severe as those caused by Hurricanes Katrina, Rita, and Wilma in 2005. Although worst-day outages between both hurricane seasons were comparable, Hurricanes Katrina and Rita were more powerful and caused more lasting damage to energy infrastructure than Hurricanes Gustav and Ike. It can be seen in Table 5 that Hurricane Katrina resulted in the greatest damage to the electric distribution sector in the Gulf Coast, but that Hurricane Rita had a greater impact on electric transmission.

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[17] McClelland, J., 2012, "Protecting Electric Grid from Cyber Attacks," FDCH Congressional Testimony, July 17, 2012, available at https://www.gpo.gov/fdsys/pkg/CHRG-112shrg75809/html/CHRG-112shrg75809.htm, accessed June 30, 2016.

[18] DOE, 2009, *Comparing the Impacts of the 2005 and 2008 Hurricanes on U.S. Energy Infrastructure*, available at http://energy.gov/sites/prod/files/Comparing%20the%20Energy%20Infrastructure%20Impacts%20of%20the%202005%20and%202008%20Hurricanes%20-%20February%202009.pdf, accessed June 30, 2016.

The hurricanes listed in Table 5 had a lasting impact on the electric sector. In areas where the damage was the most extensive or where access was the most difficult, it took several weeks before necessary repairs were completed. In addition, thousands of mutual assistance linemen from multiple states and Canada were required to help the restoration efforts in the Gulf Coast.

Table 5 Restoration Resources Required for Major Hurricanes

Infrastructure Impacted	2005			2008	
	Katrina	Rita	Wilma	Gustav	Ike
Utility Poles Destroyed	72,447	14,817	~14,000	11,478	10,300
Transformers Damaged	8,281	3,580	NA	4,349	2,900
Transmission Structures Damaged	1,515	3,550	NA	241	238
Substations Off-Line	300	508	241	368	383

Other examples of how severe weather can damage distribution electric equipment include the following:

- Electric cooperatives in Mississippi reported that more than 50,000 utility distribution poles were destroyed by Hurricane Katrina.
- One Louisiana cooperative indicated that an estimated 3,500 miles of its power lines and poles were blown to the ground after Hurricane Katrina.
- After Hurricane Katrina, a total of 92,000 wood poles and 90,000 wood cross arms were delivered within four weeks of the storm's passing.[19]
- In the wake of Super Storm Sandy, the wood pole manufacturing industry provided a total of 65,100 wood poles and 103,500 cross arms.[20]
- The January 2009 North American Ice Storm resulted in more than 30,000 utility poles being downed throughout Arkansas.
- The January 28–30, 2002, winter storm in Oklahoma destroyed more than 31,000 utility poles.
- The December 10–11, 2007, winter storm damaged 2,000 utility poles in Kansas, and around 5,400 lines and transformers required refusing.

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[19] Woodpoles.org, 2014, "Ten Features Often Overlooked about the Extraordinary Wood Pole," North American Wood Pole Council, available at http://woodpoles.org/portals/2/documents/Ten_features.pdf, accessed June 30, 2016.

[20] Little, A., 2014, "Protecting Utility Poles from Extreme Weather," Alden Systems, Inc., available at http://info.aldensys.com/bid/331018/Protecting-Utility-Poles-From-Extreme-Weather, accessed June 30, 2016.

- It can be seen that severe weather events can cause widespread damage and require repair and replacement of thousands of transmission and distribution elements such as utility poles, cross arms, and transmission structures.

5 Response Resource Capabilities

Electric utilities' power restoration and business continuity planning includes year-round preparation for all types of emergencies, including storms and other weather-related events, as well as cyber and physical infrastructure attacks. A speedy restoration process requires significant logistical expertise, along with skilled/trained certified workers and specialized equipment. Utility restoration workers involved in mutual assistance typically travel many miles from different geographic areas to help the requesting utility to rebuild power lines, replace poles, and restore power to customers.[21]

Electric utilities respond alone to minor power outages. More severe emergencies engender greater involvement by others, culminating in federal response in the case of a major disaster. During an emergency, an electric utility requires trucks, tools, equipment, and supplies to restore the grid. They need these materials in greater number, and more quickly, than during business as usual. Utilities rely on their own inventories or on their normal contract suppliers to meet their emergency needs. In the event these options fail, utilities can "borrow" from other utilities, as most electric industry materials are relatively standardized. Poles from one utility might not meet another utility's construction standards, but can still be used in an emergency. Wires, fuses, and other supplies are often equally interchangeable.[22]

Even though every disaster is different, there are planned measures that can be proactively taken to reduce power interruptions during disaster restoration. Utility stock levels on key materials can be increased for key restoration materials required for immediate restoration of a utility's electrical power system backbone:[23] Another option for companies is to have contracts with multiple suppliers who can ramp up production and increase supply of critical materials such as the following in emergency situations:

- Utility poles and cross arms,
- Pole-mounted single-phase transformers,
- Pad-mounted and substation single- and three-phase transformers,
- Molded rubber cable connector products,
- Distribution surge and lightning arresters,
- Fuses and fuse links,
- Cutouts,
- Disconnect switches,
- Tools and connectors, and
- Line reclosers.

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[21] EEI, 2016a.

[22] City of Buffalo, undated, "City of Buffalo Municipal Electric Utility Energy Emergency Response," available at http://www.ci.buffalo.mn.us/wp-content/uploads/2014/05/BMUElectricPreparedness.pdf.

[23] Eaton, 2013, "Storm Season Rapid Response," available at http://www.cooperindustries.com/content/dam/public/powersystems/resources/library/100_Promotional/B10009050.pdf.

This analysis focuses on the availability of a number of these key materials, which are utility poles, cross arms, and substation transformers. These materials are an important key during a recovery event because limitations on their availability are likely to increase the restoration timeline.

5.1 Capability Analysis—Equipment

5.1.1 Transformers

Transmission systems are typically designed with significant redundancy to avoid congestion problems and limit the effect of disturbances. High-voltage transmission lines are used to transfer power over long distances. This reduces losses but has significant implications for system restoration—larger more sophisticated transformers are required that are difficult to acquire and have longer lead time.

Distribution systems characteristics such as voltage, feeder length, exposure to natural elements (i.e., overhead or underground conductor routing), sectionalizing capability, redundancy, conductor type/age, and number of customers on each feeder play a significant role in vulnerability to events and system restoration. The majority of electric outages result from damage to the millions of miles of distribution lines.

The most common distribution voltage in use throughout North America is 12.47 kV, although anywhere from 4.2 kV to 34.5 kV is widely used.[24] Worldwide, there are primary distribution voltages as low as 1.1 kV and as high as 66 kV. Some distribution systems use several primary voltages—for example, 23.9 kV and 13.8 kV, and 4.16 kV. Table 6 provides the highest distribution voltage in each NERC region, which indicates that the most-frequent distribution voltage in the United States occurs between 6.9 and 13.8 kV (43%) and 23 kV and 34.5 kV (32%). Only the SPP and WECC have maximum distribution voltages from 0.1 kV to 2.4 kV.

Table 6 Breakdown by NERC Region of Highest Distribution Voltage by Number of Electric Utilities (2014 data)

NERC Region	0.1–2.4 kV	2.4–6.9 kV	6.9–13.8 kV	13.8–23 kV	23–34.5 kV	34.5–69 kV
FRCC	0	0	11	3	14	2
MRO	0	1	59	11	16	8
NPCC	0	1	6	4	10	7
RFC	0	0	82	13	25	16
SERC	0	0	86	30	101	21
SPP	1	2	79	40	55	18
TRE	0	0	14	5	18	8
WECC	2	0	55	16	52	16
Total	3	4	392	122	291	96

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[24] Csanyi, E., 2015, “Primary Distribution Voltage Levels,” Electrical Engineering Portal, available at http://electrical-engineering-portal.com/primary-distribution-voltage-levels.

Transmission-level voltage is generally considered to be 100 kV and above. There were 416,261 circuit-miles of transmission lines in the United States at the end of 2012 ranging from low-voltage transmission lines of 138 kV to extra-high voltage of 765 kV. The configuration and voltage of the transmission system are largely a function of the evolution of load and generation. Nearly 22,000 additional circuit-miles are planned to be in service by 2023. While the main driver for transmission investments varies by region, the primary reasons include addressing reliability concerns, integration of renewable generation, and alleviation of congestion.

American National Standards Institute (ANSI) Standard C84.1-1989 divides system voltages into “voltage classes.” Voltages 600 V and below are referred to as “low voltage,” voltages between 600 V and 69 kV are referred to as “medium voltage,” voltages from 69 kV to 230 kV are referred to as “high voltage,” and voltages 230 kV to 1,100 kV are referred to as “extra high voltage,” with 1,100 kV also referred to as “ultra-high voltage.” The emphasis of this guide is on low- and medium-voltage distribution systems.

Figure 7 illustrates the geographic dispersion of transmission system voltages by voltage class, which has implications for potential sharing of equipment to replace damaged components. The issue of replacement parts and equipment sharing is especially relevant for the higher voltage transmission networks where component failures can have a more widespread impact and require long lead times to obtain replacements, such as large transformers, circuit breakers, and other specialized electrical equipment. This risk can be mitigated through Memoranda of Understanding (MOUs) and Memoranda of Agreements (MOAs) with neighboring entities. The ability to share power and equipment across the NERC regions increases grid resilience; however, the systems would need the same voltage level in order to do that. There is limited sharing potential at the 765-kV level as there are relatively few 765-kV (extra-high voltage) lines.

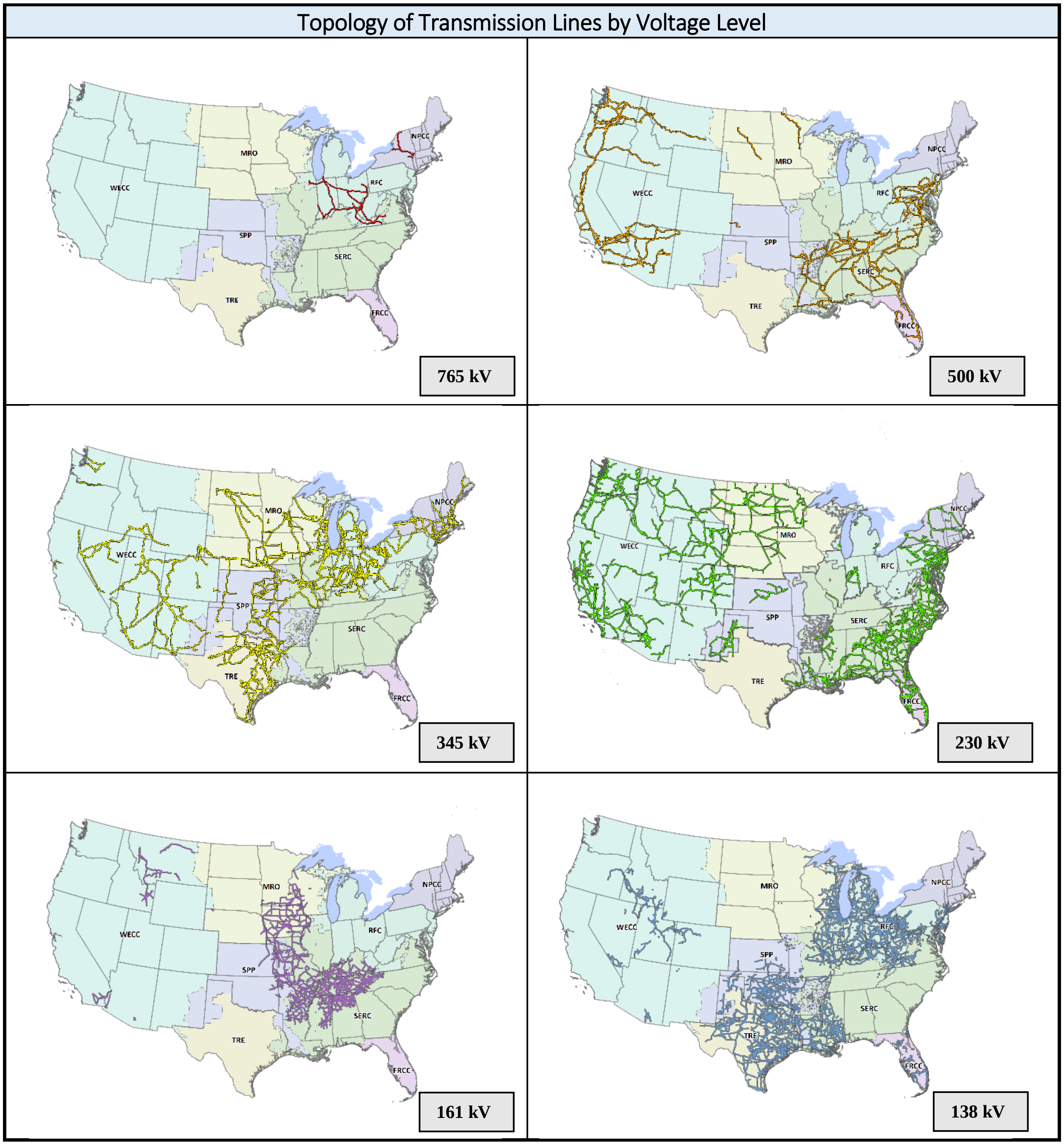
Topology of Transmission Lines by Voltage Level

Figure 7 Transmission and High-Voltage Distribution Line Network by NERC Region and State (Source: Platts)

FERC Form 1, Electric Utility Annual Report, is a comprehensive financial and operating report submitted for Electric Rate regulation and financial audits.[25] It requires respondents to provide information on their substations, substation voltages (primary, secondary, and tertiary), overall substation capacity, the number of transformers in service, and the number of spare transformers. This information was collected for all utilities submitting a FERC Form 1 in 2014 and collated by NERC region and voltage class, as shown in Table 7.

Table 7 Breakdown of Spare Transformers by Voltage Class and NERC Region (2014 data)

NERC Region	Number of Spare Transformers				
	Low (< 0.6 kV)	Medium (2.4 kV–69 kV)	High (115 kV–230 kV)	Extra-High (>345 kV)	Total
Alaska	0	1	0	0	1
FRCC	10	40	6	12	68
MRO	177	86	66	6	335
NPCC	33	121	70	18	242
RFC	183	334	236	69	822
SERC	7	241	321	77	646
SPP	75	106	42	16	239
TRE	0	26	8	2	36
WECC	87	256	188	54	585
Total	572	1,211	937	254	2,974

Table 7 indicates that there are approximately 3,000 spare transformers in the United States. RFC has the largest number of spare transformers in United States (822, approximately 28% of the total), followed by SERC (646, approximately 22% of the total), and WECC (585, approximately 20% of the total). The NERC regions with the lowest number of FERC-reported spare transformers are TRE (36, approximately 1% of the total) and FRCC (68, approximately 2% of the total), which may make these regions more-vulnerable to an extended power outage resulting from transformer damage. Alaska is reported to only have one spare medium-voltage transformer.

The data in Table 7 also indicates that the majority (1,211, approximately 41% of the total) of the spare transformers in the United States have primary voltages between 2.4 kV and 69 kV, and that they would be used as replacements in the distribution power network. There are only 254 spare transformers (approximately 9% of the total) for the bulk electric system (BES), and their replacement has been noted as a potential issue for critical infrastructure resilience in the United States.

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[25] FERC, 2016, "Form 1 - Electric Utility Annual Report," available at https://ferc.gov/docs-filing/forms/form-1/elec-subm-soft.asp, accessed June 30, 2016.

Maintaining an inventory of spare components and equipment-sharing policies established with MOUs and MOAs helps utilities mitigate the risk of long-term outages as a result of damage to large power transformers. For example, access to long-lead time equipment is facilitated by the following entities:

- Spare Equipment Database (NERC)—tool to facilitate coordination and communications between those entities needing long lead-time equipment and those who may be able to share existing equipment being held as spares.

- Spare Transformer Equipment Program (STEP; Edison Electric Institute)—increases the inventory of spare transformers and streamlines the process of transferring those transformers to utilities in need of equipment damaged by a terrorist attack or other event. As of August 1, 2015, more than 50 electric utilities are members of STEP. These companies directly serve over 98 million customers (about 67% of U.S. electricity customers).[26]

- SpareConnect Program (Edison Electric Institute)—establishes a confidential, unified platform for the entire electric industry to communicate equipment needs, such as transformers and related equipment, including bushings, fans, and auxiliary components in the event of an emergency or other non-routine failure. More than 120 utilities (investor-owned, municipal, and cooperative) participate in SpareConnect.[27]

- Grid Assurance—a collaborative effort of utilities and energy companies to provide improved responses to major events affecting the electric transmission grid by giving transmission-owning entities access to domestically stored long lead-time critical equipment, including large power transformers and related items such as bushings and circuits. Grid Assurance will own and provide subscribers with timely access to an inventory of emergency spare transmission equipment that can otherwise take months to acquire.

- Recovery Transformer (RecX)—a collaboration among the U.S. Department of Homeland Security (DHS), S&T, Electric Power Research Institute (EPRI), and ABB Inc. resulted in the successful design, transportation, installation, and energization of a prototype transformer to replace a failed extra-high voltage transformer. Ninety percent of utility power uses this type of transformer. In operational testing, the prototype transformer was transported, commissioned, and energized in less than a week as compared to several months.

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[26] Edison Electric Institute, National Rural Electric Cooperative Association, and American Public Power Association, 2015, “Comments on a National Power Transformer Reserve Program,” available at http://www.energy.gov/sites/prod/files/2015/09/f26/EEI-APPA-NRECA_Submission_RFI_Transformer%20Reserve.PDF, accessed June 30, 2016.

[27] Ibid.

The manufacture and use of interchangeable parts and standardized designs can help reduce the long lead time for specialized equipment. Ongoing research is looking at the potential of standardizing physical connectors and interfaces as well as interoperable control systems.

5.1.2 Wooden Poles and Cross Arms[28]

While no central database exists, the utility and wood pole industries estimate that there are about 130 million wood utility poles in use across North America—about 40% are owned by investor held utilities, 27% are owned by rural electricity associations, 28% by telephone companies, and 6% are owned by railroad companies [29] More than 99% of all distribution lines and a significant portion of lower-voltage transmission lines are and continue to be built with wood.[30,31] Available supply, cost, ease of handling, and installation are all factors in this. A study by the utility industry concluded that "The bottom line is that treated wood offers the most energy-efficient, functional, cost-effective and practical material for use by electric utilities in providing electrical service to the public." They are the backbone of overhead line construction, and most of these poles are pressure treated with some type of preservative. The most prevalent wood preservative utilized for poles in service is pentachlorophenol (penta). Approximately 63% of poles are treated with this preservative, followed by chromated copper arsenate (16%), creosote (16%), copper naphthenate (3%), and ammoniacal copper arsenate or ammoniacal copper zinc arsenate (1%). An estimated 4.2 million poles are treated each year.

Under the requirements of the National Electrical Safety Code (NESC), overhead lines are designed to withstand the expected loads of a defined weather event in terms of a specified wind velocity or a specified ice thickness and concurrent wind velocity and are geographic or region/area specific. If an actual weather event does not impose loads greater than those estimated in the design, only minimal failures would be expected. However, if the actual loads exceed the design load as typically occurs during extreme weather events such as hurricanes and tornados, or ice storms (combined ice and wind conditions), failures are expected, and the failure rate will be a function of the degree to which the design load is exceeded. While the primary cause of outages in ice storm events is ice-covered trees falling on the utility lines, in extreme wind events, most failures are caused by secondary damage effects such as falling trees or windblown debris.

One of the proven advantages of wood poles is the ability of the industry to respond quickly to the need for large numbers of poles after natural disasters strike. Some facilities can produce more than 400 poles a day. For example, after Hurricane Katrina, some 92,000 wood poles and 90,000 wood cross arms were delivered within 4 weeks of the storm's passing. In the wake of

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[28] Woodpoles.org., undated, "Preservative-Treated Wood Poles," North American Wood Pole Council, available at http://woodpoles.org/Home.aspx, accessed June 26, 2016.

[29] The Environmental Literacy Council, 2015, available at http://enviroliteracy.org/environment-society/life-cycle-analysis/wood-utility-pole-life-cycle/.

[30] Woodpoles.org, undated.

[31] Maloney, D., 2016, "A Field Guide to the North American Utility Pole," Hackaday.com, available at http://hackaday.com/2016/02/22/a-field-guide-to-the-north-american-utility-pole/, accessed July 27, 2016.

Super Storm Sandy on the East Coast, the industry provided a total of 65,100 wood poles and 103,500 cross arms to return power to the region.

Data on wooden pole and cross arm manufacturers was collected from multiple sources, including the North American Wood Pole Council,[32,33] American Wood Protection Association,[34] National Rural Electric Cooperative Association (NRECA),[35] and Internet searches. Appendix A provides the characteristics of the wooden pole and cross arm manufacturers. (Information on the manufacturing capacity of the wooden pole and cross arm companies in Appendix A is not publicly available and is generally considered to be business-sensitive information.) The manufacturers were then grouped by NERC region; Table 8 provides this information.

Table 8 Number of Manufacturers of Electric Utility Poles and Cross Arms by NERC Region

NERC Region	Number of Manufacturers	
	Utility Poles	Cross Arms
FRCC	3	0
MRO	2	1
NPCC	0	0
RFC	3	0
SERC	35	9
SPP	1	0
TRE	2	0
WECC	11	7
Total	57	17

The data in Table 8 indicates that NPCC does not appear to have any wooden pole manufacturers, which is somewhat unusual given the amount of wood-related industries in Maine and New Hampshire. However, the lack of local manufacturers in NPCC agrees with the restoration experience after Superstorm Sandy, during which a lack of utility poles retarded utility restoration activities.[36] A pole supplier to utilities in Northeast received orders for poles prior to Sandy making landfall however, the damage to poles was more extensive than estimated

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[32] Woodpoles.org, 2016a, "Wood Pole Producers and Suppliers in North America," North American Wood Pole Council, available at http://woodpoles.org/Supply/PoleSuppliers.aspx, accessed June 30, 2016.

[33] Woodpoles.org, 2016b, "Crossarm Producers and Suppliers in North America," North American Wood Pole Council, available at http://woodpoles.org/Supply/CrossarmSuppliers.aspx, accessed June 30, 2016.

[34] American Wood Protection Association (AWPA), undated, "Suppliers & Sources: Utility Products," available at http://www.awpa.com/suppliers/utilityproducts.asp, accessed June 30, 2016.

[35] National Rural Electric Cooperative Association (NRECA), 2016, "Approved Plant List," available at http://www.nreca.coop/what-we-do/wood-quality-control/approved-plant-list/, accessed June 30, 2016.

[36] Jervis, R., 2012, "Suppliers struggle to keep up with utility pole demand," available at http://www.usatoday.com/story/news/nation/2012/11/10/sandy-utility-pole-shortage/1696385/, accessed June 30, 2016.

and depleted the available supply. [37] In addition, there appears to be a number of Canadian wooden pole manufacturers, which may be available to supply the Northeast. SERC has the majority of utility pole and cross arm producers, which is a benefit when a Gulf Coast hurricane occurs (due to shorter shipping distances). WECC has a number of wooden pole manufacturers located in Oregon and Washington, with only one manufacturer in California (Conrad Forest Products in Arbuckle, California).

The information in Table 8 indicates that there are NERC regions with limited local resources for production of wooden poles and cross arms, which will have negative implications in the event of a catastrophic disaster affecting the distribution sector. These spare parts would have to be trucked long distances from SERC to complete the restoration process. This analysis did not take into account the inventory of wooden poles and cross arms situated in each NERC region, but experience from Hurricane Sandy has shown that these resources are quickly depleted by a widespread disaster.

5.2 Capability Analysis—Labor

Electrical power-line installers and repairers install or repair cables or wires used in electrical power or distribution systems, and may erect poles and light or heavy-duty transmission towers. Information on their employment as a function of state is available from the U.S. Bureau of Labor Statistics (BLS).[38] The state-level data on employment of electrical power-line installers and repairers (called "linemen" in the electric industry) was then grouped as a function of NERC region and shown in Table 9.

Table 9 Average Number of Lineman per Customer Available for Restoration

NERC Region	Number of Customers (1,000s)	Total Number of Lineman	Number of Lineman per 1,000 Customers
FRCC	10,091	7,330	0.726
MRO	9,125	9,540	1.045
NPCC	13,274	11,670	0.879
RFC	24,446	22,210	0.909
SERC	27,104	28,250	1.042
SPP	6,592	7,450	1.130
TRE	11,673	10,940	0.937
WECC	30,914	17,080	0.553
Total	133,218	114,470	0.859

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[37] Merritt, J., 2012, "Waiting for power? It could be a matter of poles," available at http://news.trust.org//item/20121103005400-bowpv?view=print, accessed August 6, 2016.

[38] BLS, 2016a, "Occupational Employment and Wages, May 2015, 49-9051 Electrical Power-Line Installers and Repairers," available at http://www.bls.gov/oes/current/oes499051.htm, accessed June 30, 2016.

The ratio of the number of linemen per customers is lowest in WECC, which is not unexpected given it is geographically the largest NERC region, serving an area of nearly 1.8 million square miles and approximately 81 million people. SPP has the highest ratio, which may reflect the frequency of severe weather such as ice storms in the region.

The issue of availability of electric linemen has been stated as a concern. Years of cost cutting by the utility industry have reduced worker training programs and thereby the number of experienced linemen. Since deregulation came to the electric industry more than 10 years ago, utilities have reduced their line staff by 25 or 30%. Because the job of utility linemen is varied and complex, it takes 5 years to train a lineman to a journeyman level, and most in the industry acknowledge that it takes 10 years to become a well-rounded lineman.[39] Another issue with availability of lineman is that they are highly mobile and transient.

As of May 2015, the electric industry employed a total of 18,430 electrical engineers.[40] Table 10 shows the distribution of the electrical engineer employment as a function of NERC region. (It should be noted that Alaska and Hawaii employ about 40 and 90 electrical engineers, respectively; added to the total of 18,300 in Table 10 results in a national total of 18,430.)

Table 10 Average Number of Electric Engineers per Customer

NERC Region	Number of Customers (1,000s)	Total Number of Electrical Engineers	Number of Engineers per 1,000 Customers
FRCC	10,091	590	0.06
MRO	9,125	880	0.10
NPCC	13,274	2,860	0.22
RFC	24,446	3,960	0.16
SERC	27,104	3,350	0.12
SPP	6,592	700	0.11
TRE	11,673	1,250	0.11
WECC	30,914	4,710	0.15
Total	133,218	18,300	0.14

The largest number of electrical engineers per customer occurs in NPCC (a ratio of 0.22), while FRCC has the least (a ratio of 0.06), which will require some research to explain (TBD).

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[39] International Brotherhood of Electrical Workers, undated, “Worker Schedule Threatens Utility,” available at http://www.ibew.org/articles/05journal/0504/p12_shortage.htm, accessed June 30, 2016.

[40] BLS, 2016b, “Occupational Employment and Wages, May 2015, 17-2071 Electrical Engineers,” available at http://www.bls.gov/oes/current/oes172071.htm, accessed June 30, 2016.

5.3 Situational Awareness and Common Operating Picture

Typically, there will be two-way communications between DOE and state energy agencies with responsibilities as defined by state energy assurance plans and state emergency management plans. Information from DOE and state assessments will flow from the appropriate state energy agencies to the emergency management agency. Information on the impacts on other sectors affected by the energy disruption will flow from the state emergency management agency to the responsible state. Many states use WebEOC (an online crisis management system) to manage incident reporting and information flows. DOE Office of Electricity Delivery and Energy Reliability (DOE-OE) currently hosts a restricted website which provides the database of the Energy Emergency Assurance Coordinators (EEAC) contacts, and which both DOE-OE and states can access. This restricted website, together with the Energy Information Administration's (EIA's) public websites and email communications, are the primary tools for EEAC coordination.[41]

A recent example of government's role in emergency response is Superstorm Sandy. During Sandy, FEMA employed WebEOC to coordinate and support response operations. Using a single online platform facilitated information sharing and ensured that those involved in the emergency response effort shared a common operating picture enabling a unified federal response. In addition, WebEOC facilitated a common operating picture on the status of all resource requests through a live resource tracking board that consolidated information on all resources shipped to support Hurricane Sandy. Sandy also showed areas where the platform can expand to provide a clearer federal common operating picture, including enhancements of real-time feeds, integration with other situational awareness products, and linking to the information of other whole community partners.[42]

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[41] FEMA, 2013, *Hurricane Sandy FEMA After-Action Report*, July 1, available at https://www.fema.gov/media-library-data/20130726-1923-25045-7442/sandy_fema_aar.pdf, accessed June 30, 2016.

[42] DOE, National Association of State Energy Officials (NASEO), National Association of Regulatory Utility Commissioners (NARUC), NGA, and National Emergency Management Association (NEMA), 2015, "Agreement for Enhanced Federal and State Energy Emergency Coordination, Communications, and Information Sharing," available at https://naseo.org/Data/Sites/1/eeac-agreement-and-terms-of-reference-final-february-2016---no-signatures.pdf, accessed June 30, 2016.

6 Tipping-Point Gap Analysis

6.1 Electric Response Capability Assessment Method and Assumptions

No matter how well the electric industry is prepared, hurricanes, earthquakes, storms, and other natural and man-made disasters can cause significant damage to the electric grid, creating widespread power outages. Following these events, electric utilities must respond safely, swiftly, and efficiently to restore service to large numbers of affected customers. Mutual assistance is an essential part of the electric power industry's service restoration process and contingency planning. Electric utilities impacted by a major outage event are able to increase the size of their workforce by "borrowing" restoration workers, contractors, and utility workers from other utilities.[43] In order to assess national electricity system response and recovery capabilities a tipping point analysis was performed comparing outages in actual and potential NREs with the resources available for response and recovery across regions of the country.

DOE Form OE-417 data was collected from 2000 to 2014, to determine those historical events for which a national level response was required.[44] [45] The list in Table 11 includes severe weather events such as Hurricane Sandy, the June 2012 North American derecho, and the 2002 Oklahoma Ice Storm. In each of these events, there were widespread impacts on a large number of electrical customers which would have had led to a long restoration time without the intervention of mutual assistance workers from outside the affected region.

Table 11 Historical Events That Required a National-Level Response (based on DOE OE-417 Data)

Date	Hazard	Hazard Type	Number of Customers Affected	Restoration Time (Days)
10/29/2012	Hurricane Sandy	Hurricane/Tropical Storm	5,272,354	6
9/12/2008	Hurricane Ike	Hurricane/Tropical Storm	4,995,291	14
6/29/2012	June 2012 North American derecho	Severe Weather – Thunderstorm	4,201,504	5
9/4/2004	Hurricane Frances	Hurricane/Tropical Storm	3,043,093	5
9/18/2003	Hurricane Isabel	Hurricane/Tropical Storm	2,669,342	4
1/4/2008	Western U.S. Storm (California)	Severe – Winter Storm	2,606,931	10
1/30/2002	January 28–30, 2002, Oklahoma Ice Storm	Severe Weather – Ice Storm	1,976,134	10
10/29/2011	2011 Halloween Nor'easter	Severe Weather – Thunderstorm	1,871,186	6
1/18/2010	PG&E Severe Thunderstorm	Severe Weather – Thunderstorm	1,700,000	10
12/31/2005	PG&E Severe Thunderstorm	Severe Weather – Thunderstorm	1,667,316	5
9/15/2004	Hurricane Ivan	Hurricane/Tropical Storm	1,652,669	5
8/29/2005	Hurricane Katrina	Hurricane/Tropical Storm	1,521,526	5
12/14/2002	PG&E Severe Winter Storm	Severe Weather – Winter Storm	1,500,000	5

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[43] EEI, 2016a.

[44] DOE, 2016, "Electric Disturbance Events (OE-417)," available at http://www.oe.netl.doe.gov/oe417.aspx, accessed June 30, 2016.

[45] EEI, 2016a.

Available resources in the form of lineman, spare transformers, and utility pole and cross arm manufacturers was collected to provide a regional metric of response and recovery resources. Figure 8 below summarizes the data on resource availability for lineman, spare transformers, and utility pole and cross arm manufacturers by region in a dashboard format.

The following are some general regional observations based on the data collected:

- SERC is in the best position with respect to resource availability to address power outages;

- The number of lineman per 1,000 customers does not exhibit much regional variation and ranges from a low value of 0.56 for WECC and 1.13 for SPP;

- Despite frequent hurricanes and thunderstorms and having an exemplary restoration record, FRCC's ranking in resource availability is low—second to last in linemen and spare transformers;

- SERC, SPP, and WECC lead in the availability of spare transformers;

- There are no pole or cross arm manufacturers in NPCC (although there are manufacturers in Canada); and

- TRE is low with respect to both availability of on-site spare transformers and wooden pole/cross arm manufacturers.

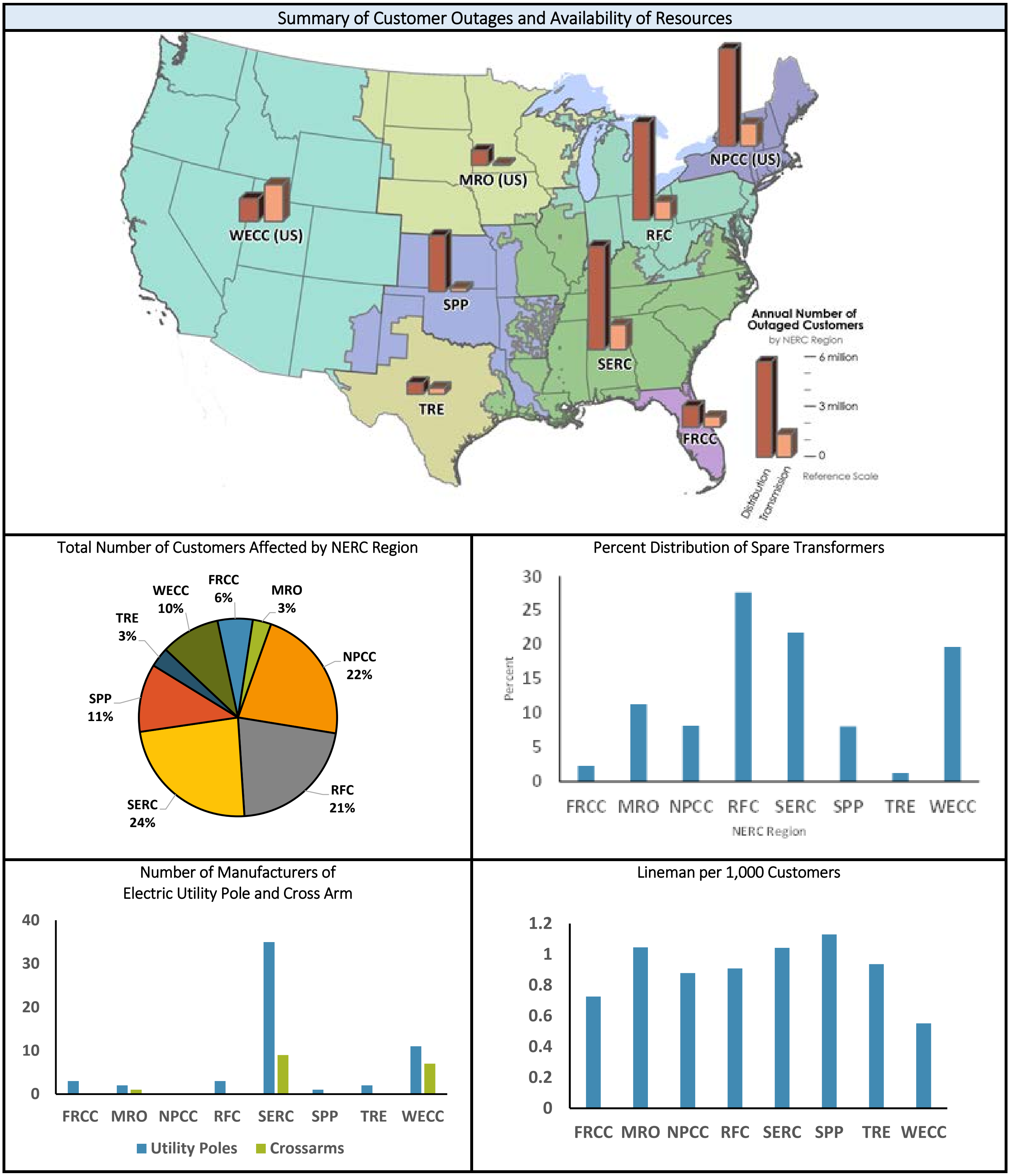

Figure 8 Resource Availability Summary

6.2 Results

An industry-wide NRE is defined to be a natural and man-made event that is forecasted to cause or that causes widespread power outages impacting a significant population or several regions across the United States and requires resources from multiple RMAGs. The NRE concept was developed through the Edison Electric Institute (EEI) as a process improvement opportunity after Hurricane Sandy. Hurricanes such as Sandy and Katrina required the actions of mutual assistance workers to help restore the electric sector after major damage. Electric service would not have been restored as quickly after these Hurricanes without the assistance from electrical construction crews available through mutual assistance agreements. Examples of types of possible natural and man-made events that would qualify as an NRE include:

- Seismic events,
- Hurricanes,
- Cyber-attacks, and
- Severe weather such as ice storms.

The impacts of a seismic event, for example, could damage grid infrastructure and make restoration efforts difficult. Areas of seismic activity with large potential consequences for grid infrastructure include the New Madrid seismic zone in the Midwest/Southeast and the Cascadia subduction zone in the Pacific Northwest.

The modeled results and findings from the Regional Resiliency Assessment Program (RRAP) were used to understand the scale and impacts of electricity system disruptions under potential NRE events. The RRAP conducts regional assessments of the nation’s critical infrastructure and is led by DHS. RRAP analyses address a range of hazards that could have regionally and nationally significant consequences. Argonne National Laboratory (Argonne) has completed 56 RRAPs during 2009 to 2014 that addressed a variety of postulated hazards, including tornadoes, ice storms, earthquakes, hurricanes, solar storms, and other threats to the electric sector.

A RRAP is intended to assess the integrated preparedness and protection capabilities of critical infrastructure owners and operators and emergency planning and response organizations, including the electric sector. It also coordinates protection and response planning efforts to enhance resilience and address security gaps within the geographic region. The RRAP team interacts with lifeline sectors such as the electric industry to establish whether the utility or regional response organization has sufficient capabilities to deal with the specified hazard. The following analysis looks at hazards which have been examined and have been assessed to require multi-region assistance for restoration.

Table 12 lists a selection of hazards analyzed by Argonne for the DHS RRAP and other projects. If these hazards occurred, analysis and discussions with the affected electric companies have shown that the regional mutual assistance network would not have resources available to deal with widespread damage. Severe weather events identified in Table 12 include thunderstorms and ice storms. A coordinated cyber-attack has been identified as a possible major threat to the electric power grid. (Note that the list of hazards in Table 12 is not all inclusive, and undoubtedly there are other hazards that would require multi region assistance.)

Table 12 Representative Catastrophic Events That Could Require a National-Level Response

Hazard Event	Description	Hazard Type	Region	Affected Population
San Andreas 7.8 M Earthquake	Most-probable catastrophic earthquake in Southern California	Earthquake	California	18 to 20 million
Palos Verde 7.1. M Earthquake	Most-probable worst-case earthquake scenario for the Los Angeles–Long Beach, California area	Earthquake	California (Los Angeles)	4 to 5 million
Cascadia Subduction Zone 9.0 M Earthquake	Cascadia Subduction Zone is a 680-mile fault that runs 50 miles off the coast of the Pacific Northwest	Earthquake	Pacific Northwest (Washington, Oregon, Idaho)	9 to 62 million
New Madrid Seismic Zone 7.7 M Earthquake	Basis of National-Level Exercise conducted May 2011	Earthquake	Central U.S.	7 to 100 million
2013 Storm Equivalent to Great Miami Hurricane	Great Miami Hurricane was a Category 4 storm that passed over Miami in 1926, estimated economic loss of $165 billion (2010 USD)	Hurricane	Florida (Miami)	7 million
Tampa Bay Category 5 Hurricane[46]	Worst-case hurricane that would devastate the entire Tampa Bay region, including massive flooding	Hurricane	Florida (Tampa Bay)	4 million
Cyber-Attack[47]	Hypothetical cyber scenario of an electricity blackout that plunges 15 U.S. states, including New York City and Washington D.C., into darkness and leaves 93 million people without power	Cyber-Attack	Northeast U.S.	93 million
2016 Storm Equivalent to Blizzard of 1949, January 1–6	Considered to have produced the most adverse weather conditions in the history of the U.S. West; worst winter storm in recent history.	Winter Storm	Central U.S. (Plains States)	4 million

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[46] Tampa Bay Regional Planning Council, 2010, *The Tampa Bay Catastrophic Plan, Scenario Information and Consequence Report*, available at http://www.tbrpc.org/tampabaycatplan/pdf/Project_Phoenix_Scenario_Info.pdf, accessed June 30, 2016.

[47] Lloyd’s, 2015, *Business Blackout, The insurance implications of a cyber attack on the US power grid*, Emerging Risk Report, available at https://www.lloyds.com/~/media/files/news%20and%20insight/risk%20insight/2015/business%20blackout/business%20blackout20150708.pdf, accessed June 30, 2016.

Table 13 provides information on the predicted extent of damage from each hazard, in addition to the estimated number of mutual assistance workers and restoration times. The number of mutual assistance workers in Table 13 can be compared with those shown in Table 9 as a function of NERC region; in all cases, the required number of mutual assistance workers is greater than that available in the affected NERC region.

ANL performed analysis for the events listed in Tables12 and 13 and estimated resource needs as well as a restoration timeline. Restoration time is a complex function of the specific electric components damaged and the supporting interdependent infrastructure. As indicated in Table 13, for the earthquake cases damage to the electric components includes lost generating units, substations, and transmission lines. Restoration times are estimated to range from several weeks up to one year depending on the damage sustained. For example, due to upgrades and redundancy enhancements to the transmission network supporting San Francisco most of the damage from the San Andreas earthquake is to the distribution system. The analysis indicates that a limiting factor for restoration in this area is the availability of qualified lineman and the need for invoking mutual assistance agreements for additional personnel, including from Canadian and Mexican utilities. The San Francisco distribution system is largely underground making repair more challenging and, even without transmission system issues, rotating blackouts can be expected as crews work to repair the distribution network.

In contrast, significant damage to transmission system components associated with the Palos Verde, Cascadia, and New Madrid earthquakes, would require acquisition of long-lead time components ranging from months for breakers and up to a year for transformers if suitable spares or substitutions were unavailable. In the case of the Palos Verde earthquake, infrastructure damage from ground shaking would include the permanent loss of 180 substations and cascading failures to a large number of associated transmission and distribution lines. Mutual assistance agreements for both crew (outside of WECC) and high-voltage components would need to be exercised for timely system restoration.

With respect to hurricane events, poles, transformers, and generation units would sustain significant damage from wind and storm surge. Utilities typically suspend generation prior to a hurricane making landfall as a preventative measure to reduce hazards to equipment, and to insure the safety of personnel, however emergency conditions may dictate that the plant continue to operate to provide vital service, unless conditions worsen. As with seismic events, restoration times are a complex function of damage to specific equipment, resource availability, and logistics. Restoration time estimates assume the availability of out-of-region repair crews and no extensive logistical complications (i.e., equipment transportation availability).

It should be noted that in such significant NREs, it is not only the repair of the actual electric grid that affects the restoration time. The given restoration timelines in the Table 13 are highly dependent on not only the amount of damage done to the electric infrastructure but also the other lifeline infrastructures. Other lifeline infrastructures such as the availability of roads (logistics) to move personnel, material and equipment can further delay the restoration of the electric grid. Availability of a communication systems for logistics i.e., personnel, material movements, communications and coordination, is paramount to the length of the restoration time lines. Also it should be remembered that in major events some materials have long lead times (i.e. large transformers) and if spares or substitutes are it can increase the time needed for recovery.

Table 13 Resources and Restoration Time for Representative Catastrophic Events That Could Require a National-Level Response

Hazard Event	Mutual Assistance Workers	Number of Damaged Electric Components					Restoration Time[a]
		Power Plants	High-Voltage Substations	Transmission Lines	Power Poles	Transformers	
San Andreas 7.8 M Earthquake	147,000	24 (3,800 MW)	60 (12–1,000 kV)	280	N/A	N/A	Weeks to 1 month[48]
Palos Verde 7.1. M Earthquake	35,000	89 (8,100 MW)	182 (69–500 kV)	200	N/A	N/A	Weeks to months
Cascadia Subduction Zone 9.0 M Earthquake	70,000	64 (3,700 MW)	176 (69–345 kV)	252	N/A	N/A	3 months to 1 year[49]
New Madrid Seismic Zone 7.7 M Earthquake	54,000	~100 (11,300 MW)	74 (230–500 kV)	170 to 200	N/A	N/A	Weeks to several months[50]
2013 Storm Equivalent to Great Miami Hurricane	52,000	N/A	N/A	1,900	31,000	7,000	2 weeks to 1 month
Tampa Bay Category 5 Hurricane	21,000	N/A	N/A	1,100	18,000	4,000	Weeks to months[51]
Cyber Attack	Not available	50 (18,000 MW)	0	0	0	0	2 to 4 weeks

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[48] The Lifelines Council, 2014, *Lifelines Interdependency Study I Report*, The City and County of San Francisco, available at http://sfgov.org/esip/sites/default/files/Documents/homepage/LifelineCouncil%20Interdependency%20Study_FINAL.pdf.

[49] Oregon Seismic Safety Policy Advisory Commission (OSSPAC), 2013, *The Oregon Resilience Plan – Cascadia: Oregon's Greatest Threat*, available at https://www.oregon.gov/OMD/OEM/osspac/docs/01_ORP_Cascadia.pdf.

[50] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=25&ved=0ahUKEwi124nR4Y7OAhWRMx4KHSWmC744ChAWCGAwDg&url=http%3A%2F%2Ftraining.fema.gov%2Fhiedu%2Fdocs%2Fcrr%2Fcatastrophe%2520readiness%2520and%2520response%2520-%2520session%25207%2520-%2520critical%2520infrastructure.doc&usg=AFQjCNF6sBkNxgWRpL9CWndCUsTJvdaOdg&sig2=ttDmhE9zsnuAwmSGFL2neg&cad=rja.

[51] Tampa Bay Regional Planning Council, 2010.

Table 13 (Cont.)

Hazard Event	Mutual Assistance Workers	Number of Damaged Electric Components					Restoration Time[a]
		Power Plants	High-Voltage Substations	Trans-mission Lines	Power Poles	Trans-formers	
2016 Storm Equivalent to Blizzard of 1949: January 1–6	42,000	0	0	40–50	63,900	12,700	2 to 6 weeks

[a] All restoration times are based on information from DHS studies and public literature, with the exception of the Palos Verde Earthquake and the Great Miami Hurricane studies which were conducted for DOE.

For this analysis the tipping point for an NRE is reached once a disaster requires resources in the form of personnel, equipment, or materials greater than that available in a given NERC region. In general, there appears to be many possible hazards, natural and man-made, with the potential to require the movement of mutual assistance workers and replacement parts on a national basis.

For equipment, replacement of damaged electrical equipment could also require a national effort; Table 13 indicates that a Cascadia Subduction Zone (CSZ) seismic event could require the replacement of 176 high-voltage transformers. Table 7 shows that there are 937 high-voltage transformers available as spares in the United States, most of them located in RFC and SERC (eastern U.S.) regions. The movement of any spare transformers from RFC and SERC to the Pacific Northwest could become a bottleneck in the rapid recovery of the electric sector after a CSZ seismic event.

Additional information on the cost for such response and recovery efforts was pursued (which is taken to be the sum of the costs of personnel, equipment, and spare and replacement parts). However, such information was unavailable and represents a considerable gap in planning and preparing for such NREs.

Figure 9 shows the representative events that could lead to a national-level response by NERC region.

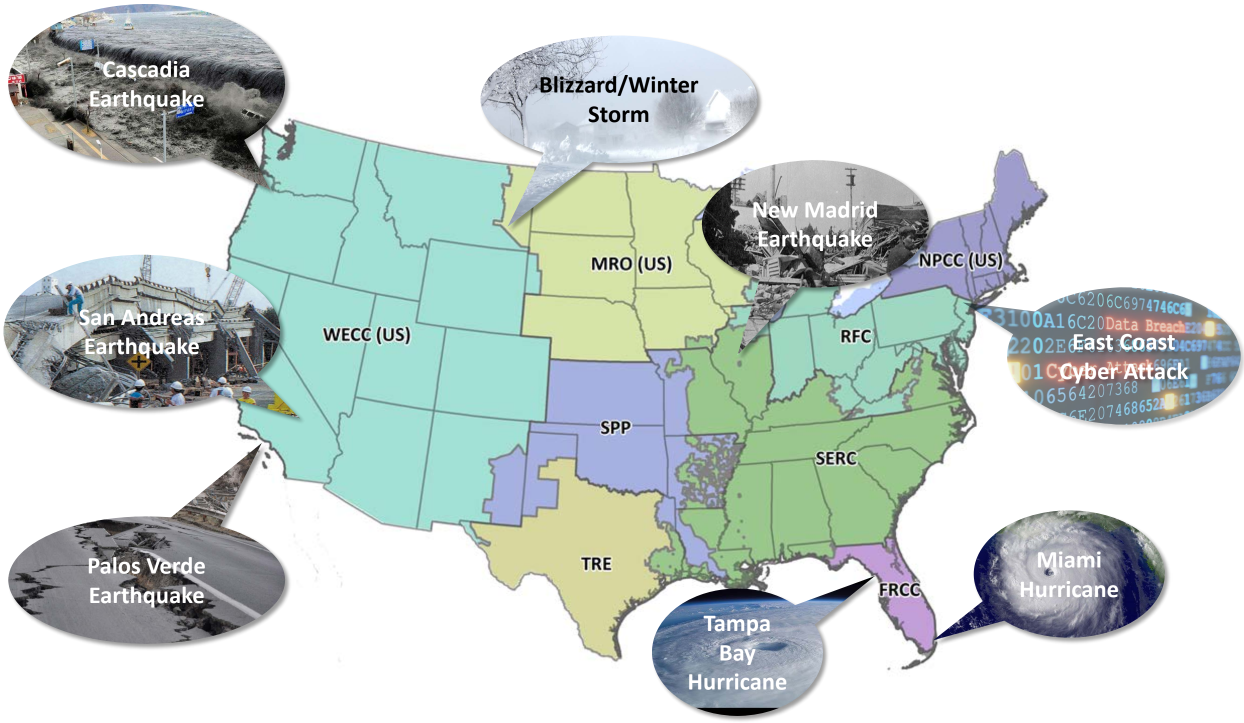

Figure 9 Representative Events That Could Require a National-Level Response

7 Conclusions and Recommendations

Utilities and government have had considerable experience with restoring electric service after widespread outages caused by ice storms, hurricanes, or other natural events. When an NRE is declared, the industry's mutual assistance efforts will be scaled to the national level and coordinated to ensure the efficient allocation of resources. Lessons learned from these events can be used to inform the planning process, improve emergency management, and enhance overall response capabilities. Past experiences indicate that the most significant challenges include communication and information sharing, logistical coordination, and managing issues related to system interdependencies. The following recommendations would enhance the effective allocation and management of resources deployed in response to a national-level event.[52,53,54,55]

- Utilities should consider having contracts or MOU's in place with manufactures for emergency materials that indicate what can be provided when and where the utility stands on the manufacturer's priority list for delivery.

- Utilities and federal, state, and local governments, and law enforcement agencies should develop official MOUs that detail each party's responsibilities pre-, during-, and post-event. The agreements would outline who is in charge, how decisions will be made, and the allocation of resources.

- Utilities and government response coordinators should share response plans with each other that designate one point of contact to coordinate mutual assistance requests. Having an established communication process will facilitate communications during the early phases of response and recovery.

- More accurate forecasting tools and data would help inform decision making with respect to potential resource needs in advance of a storm. Such information would facilitate earlier and more specific utility requests for resources in order to decrease the time it will take to restore service.

- Utilities should consider development of logistics plans for out of town personnel accommodations and marshalling locations.

- Utilities should develop a comprehensive assimilation program for out-of-area workers, including system maps, and guidance on work rules and environment to ensure that all personnel work safely, are aware of potential hazards, and abide by the host utility's

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[52] National Academy of Sciences, 2012, *Terrorism and the Electric Power Delivery System*, National Academies Press, available at http://www.nap.edu/catalog/12050/terrorism-and-the-electric-power-delivery-system.

[53] EEl, 2016b, A Governor's Guide to Energy Assurance, Roles and Responsibilities for Ensuring a Robust, Secure and Reliable Energy Infrastructure," available at http://www.oe.netl.doe.gov/docs/prepare/NGAGOVGUIDEENERGY.pdf, accessed June 22, 2016.

[54] Gridwise Alliance, 2013.

[55] American Public Power Association, 2007, *Mutual Aid Before the Storm*, available at http://www.publicpower.org/Media/magazine/ArticleDetail.cfm?ItemNumber=18911, accessed August 6, 2016.

health and safety guidelines. This information should be prepared in advance to reduce delays in utilizing non-utility work crews.

- Electricity restoration drills should be conducted to ensure that established plans, communication protocols, and procedures in place for restoration activities operate as intended.

- Federal and state regulations should be modified to provide utilities, when needed, with temporary exemptions from laws that restrict their use of equipment, access to roads, materials, supplies, and other critical elements for restoration of electric service. This might include, for example, formalized partnerships between industry and government for purposes of expediting the movement of equipment.

- Utilities should work with telecommunication providers in advance to have plans to establish emergency service for the utility or consider alternate communication systems.in their plans.

- Federal and state agencies should work to reduce obstacles to data access (e.g., standardized information and format) and facilitate communication in order to form a common operating picture for contingency planning, collaboration, and coordination of restoration efforts for long-term outages.

- The appropriate federal agencies should grant electric utility personnel “first responder” status. The Federal Communications Commission (FCC) should provide prioritized access for electric utilities to use public networks, wired and wireless, for personnel communications and the monitoring and control of electrical grid systems and components during events that could require a national-level response. The FCC should allocate and protect the communications spectrum for utility and first responders’ use.

- The federal government (e.g., FEMA, FCC, DOE, and other agencies that could be involved in emergency response efforts) should ensure that these types of streamlined emergency procedures (that were implemented during Superstorm Sandy) become standard practice during future events that could require a national-level response, to the extent necessary and practicable, to help facilitate emergency response processes and procedures.

- The electric industry should develop methods, processes, and tools to effectively identify asset owners for downed wires (e.g., electric utility, telephone and cable TV providers) to reduce hazards to the public and speed restoration efforts while reducing the need for public officials, such as police or fire officials, to remain on site until a trained utility repair line worker arrives to determine whether it is a live electrical wire, a de-energized electrical wire, or non-electrical (e.g., telephone and cable TV) wire.

- Research and development of advanced technologies is often beyond the capabilities of individual utilities. Industry and government should consider partnering on areas such as, material design (e.g., the use of plastic vs. ceramic insulators), advanced sensors, and visualization tools linking outage and load data in order to improve system response and recovery capabilities.

- Government and industry should consider strategies for ensuring sufficient availability of materials and inventory for national critical emergency needs on a regional/national basis.

- Government and industry should work together to establish training programs for future requirements of personnel in needed fields such as linemen, control systems

- Prior to a catastrophic event have preauthorized releases for the movement of personnel, materials and equipment. I.e., preauthorization of forms and requirements for truck and rail transportation routes

Appendix A: Spare Transformer Information

Table A-1 Breakdown of Spare Transformers by Voltage Class and Electric Utility (2014 data)

Utility Name	NERC Region	Number of Spare Transformers				
		Low Voltage	Medium Voltage	High Voltage	Extra-High	Total
AEP Indiana Michigan Transmission Company, Inc.	RFC	0	0	0	1	**1**
AEP Ohio Transmission Company, Inc.	RFC	0	0	0	7	**7**
AEP Oklahoma Transmission Company, Inc.	SPP	0	0	1	0	**1**
AEP Texas Central Company	TRE	0	3	2	0	**5**
AEP Texas North Company	TRE	0	20	0	0	**20**
Alabama Power Company	SERC	0	12	19	6	**37**
Alaska Electric Light and Power Company	AK	0	1	0	0	**1**
ALLETE, Inc.	MRO	0	4	3	0	**7**
Ameren Illinois Company	SERC	0	1	1	0	**2**
American Transmission Company LLC	RFC	1	0	6	10	**17**
Appalachian Power Company	RFC	0	26	32	7	**65**
Arizona Public Service Company	WECC	0	3	6	12	**21**
Atlantic City Electric Company	RFC	0	36	28	0	**64**
Avista Corporation	WECC	3	0	9	1	**13**
Baltimore Gas and Electric Company	RFC	0	15	13	1	**29**
Black Hills Power, Inc.	WECC	0	1	1	0	**2**
Black Hills/Colorado Electric Utility Company, LP	WECC	5	0	0	0	**5**
CenterPoint Energy Houston Electric, LLC	TRE	0	0	5	2	**7**
Central Hudson Gas & Electric Corporation	NPCC	0	3	2	2	**7**
Cheyenne Light, Fuel and Power Company	WECC	0	0	3	0	**3**
Cleco Power LLC	SPP	0	0	5	0	**5**
Cleveland Electric Illuminating Company, The	RFC	4	0	0	0	**4**
Commonwealth Edison Company	RFC	33	11	15	3	**62**
Connecticut Light and Power Company	NPCC	0	0	1	2	**3**
Consolidated Water Power Company	RFC	0	1	0	0	**1**
Consumers Energy Company	RFC	0	1	3	0	**4**
Delmarva Power & Light Company	RFC	0	18	13	2	**33**
Duke Energy Carolinas, LLC	SERC	2	116	71	10	**199**
Duke Energy Florida, Inc.	FRCC	0	40	4	4	**48**
Duke Energy Indiana, Inc.	RFC	0	2	11	2	**15**
Duke Energy Ohio, Inc.	RFC	0	2	3	0	**5**
Duke Energy Progress, Inc.	SERC	0	0	66	6	**72**
Duquesne Light Company	RFC	0	2	0	1	**3**
El Paso Electric Company	WECC	19	1	2	0	**22**

Table A-1 (Cont.)

Utility Name	NERC Region	Number of Spare Transformers				
		Low Voltage	Medium Voltage	High Voltage	Extra-High	Total
Emera Maine	NPCC	0	31	8	0	**39**
Entergy Arkansas, Inc.	SERC	0	17	12	7	**36**
Entergy Gulf States Louisiana, L.L.C.	SERC	0	8	8	2	**18**
Entergy Louisiana, LLC	SERC	0	4	26	2	**32**
Entergy Mississippi, Inc.	SERC	0	0	19	8	**27**
Entergy New Orleans, Inc.	SERC	0	3	4	0	**7**
Entergy Texas, Inc.	SERC	0	9	4	2	**15**
Fitchburg Gas and Electric Light Company	NPCC	0	5	2	0	**7**
Florida Power & Light Company	FRCC	10	0	2	8	**20**
Georgia Power Company	SERC	0	28	6	5	**39**
Golden Spread Electric Cooperative, Inc.	SPP	42	14	3	0	**59**
Green Mountain Power Corp	NPCC	0	3	0	0	**3**
Gulf Power Company	SERC	0	1	16	0	**17**
Idaho Power Company	WECC	0	25	28	4	**57**
Indiana Michigan Power Company	RFC	0	2	0	6	**8**
Indianapolis Power & Light Company	RFC	11	5	3	0	**19**
International Transmission Company	RFC	0	0	3	3	**6**
Interstate Power and Light Company	MRO	2	0	0	0	**2**
ITC Midwest LLC	RFC	1	0	6	1	**8**
Jersey Central Power & Light Company	RFC	19	0	0	0	**19**
Kansas City Power & Light Company	SPP	13	9	4	2	**28**
KCP&L Greater Missouri Operations Company	SPP	20	12	2	2	**36**
Kentucky Power Company	RFC	0	6	5	0	**11**
Kentucky Utilities Company	SERC	0	1	9	1	**11**
Lockhart Power Company	SERC	4	18	0	0	**22**
Madison Gas and Electric Company	RFC	0	14	1	0	**15**
Massachusetts Electric Company	NPCC	0	19	0	0	**19**
MDU Resources Group, Inc.	MRO	1	0	1	0	**2**
Metropolitan Edison Company	RFC	31	0	0	0	**31**
Michigan Electric Transmission Company LLC (10/06)	RFC	0	0	0	2	**2**
MidAmerican Energy Company	MRO	0	18	3	4	**25**
Mississippi Power Company	SERC	0	2	4	1	**7**
Monongahela Power Company	RFC	0	1	3	6	**10**
Nevada Power Company, d/b/a NV Energy	WECC	0	6	3	1	**10**
New England Hydro-Trans. Elec. Co., Inc.	NPCC	0	0	0	1	**1**
New England Power Company	NPCC	0	9	10	4	**23**
New Hampshire Transmission, LLC	NPCC	0	0	0	1	**1**

Table A-1 (Cont.)

Utility Name	NERC Region	Number of Spare Transformers				
		Low Voltage	Medium Voltage	High Voltage	Extra-High	Total
New York State Electric & Gas Corporation	NPCC	0	20	8	1	**29**
Niagara Mohawk Power Corporation	NPCC	0	11	11	1	**23**
Northern Indiana Public Service Company	RFC	0	36	0	0	**36**
Northern States Power Company (Minnesota)	MRO	0	23	10	2	**35**
Northern States Power Company (Wisconsin)	MRO	0	4	15	0	**19**
NorthWestern Energy Corporation	MRO	168	9	28	0	**205**
Northwestern Wisconsin Electric Company	MRO	0	15	1	0	**16**
NSTAR Electric Company	NPCC	33	0	4	5	**42**
Ohio Edison Company	RFC	15	0	0	0	**15**
Ohio Power Company	RFC	0	37	28	5	**70**
Ohio Valley Electric Corporation	RFC	2	0	0	0	**2**
Oklahoma Gas and Electric Company	SPP	0	1	3	3	**7**
Otter Tail Power Company	MRO	0	6	3	0	**9**
Pacific Gas and Electric Company	WECC	60	69	86	12	**227**
PacifiCorp	WECC	0	11	8	8	**27**
Pennsylvania Electric Company	RFC	50	0	0	0	**50**
Pennsylvania Power Company	RFC	1	0	0	0	**1**
Portland General Electric Company	WECC	0	1	3	0	**4**
Potomac Electric Power Company	RFC	0	11	10	1	**22**
PPL Electric Utilities Corporation	RFC	0	26	10	1	**37**
Public Service Company of Colorado	WECC	0	2	2	0	**4**
Public Service Company of Oklahoma	SPP	0	1	0	2	**3**
Public Service Electric and Gas Company	RFC	0	30	30	3	**63**
Puget Sound Energy, Inc.	WECC	0	12	14	0	**26**
Rochester Gas and Electric Corporation	NPCC	0	12	6	0	**18**
San Diego Gas & Electric Company	WECC	0	8	9	4	**21**
Sharyland Utilities, L.P.	TRE	0	3	1	0	**4**
Sierra Pacific Power Company d/b/a NV Energy	WECC	0	2	0	0	**2**
Smoky Mountain Transmission LLC	SERC	0	1	0	0	**1**
South Carolina Electric & Gas Company	SERC	0	10	32	0	**42**
Southern California Edison Company	WECC	0	107	9	10	**126**
Southern Electric Generating Company	SERC	1	0	0	0	**1**
Southern Indiana Gas and Electric Company	RFC	0	3	2	1	**6**
Southwestern Electric Power Company	SPP	0	9	9	6	**24**
Southwestern Public Service Company	SPP	0	39	9	1	**49**
The Allegheny Generating Company	RFC	0	3	0	0	**3**
The Dayton Power and Light Company	RFC	7	3	4	1	**15**
The Empire District Electric Company	SPP	0	21	6	0	**27**

Table A-1 (Cont.)

Utility Name	NERC Region	Number of Spare Transformers				
		Low Voltage	Medium Voltage	High Voltage	Extra-High	Total
The Narragansett Electric Company	NPCC	0	6	3	0	**9**
The Potomac Edison Company	RFC	0	1	2	2	**5**
The United Illuminating Company	NPCC	0	1	0	1	**2**
Trans-Allegheny Interstate Line Company	RFC	0	0	0	3	**3**
Tucson Electric Power Company	WECC	0	4	5	2	**11**
UGI Utilities, Inc.	RFC	0	1	0	0	**1**
Union Electric Company	SERC	0	2	8	1	**11**
UNS Electric, Inc.	WECC	0	4	0	0	**4**
Upper Peninsula Power Company	RFC	8	7	0	0	**15**
Vermont Transco LLC	NPCC	0	0	12	0	**12**
Virginia Electric and Power Company	SERC	0	8	16	26	**50**
Wabash Valley Power Association, Inc.	RFC	0	1	1	0	**2**
West Penn Power Company	RFC	0	0	3	0	**3**
Western Massachusetts Electric Company	NPCC	0	1	3	0	**4**
Wheeling Power Company	RFC	0	1	0	0	**1**
Wisconsin Power and Light Company	MRO	4	4	0	0	**8**
Wisconsin Public Service Corporation	MRO	2	3	2	0	**7**
Wolverine Power Supply Cooperative, Inc.	RFC	0	32	1	0	**33**

Table A-2 Standard Nominal Three-Phase System Voltages per ANSI C84.1-1989

Voltage Class	Three-wire System (volts)	Four-wire System (volts)
Low Voltage		208 Y/120
	240	240/120
	480	480 Y/277
	600	
Medium Voltage	2,400	
	4,160	4,160 Y/2,400
	4,800	
	6,900	
		8,320 Y/4,800
		12,000 Y/6,930
		12,470 Y/7,200
		13,200 Y/7,620
	13,800	13,800 Y/7,970
		20,780 Y/12,000
		22,860 Y/13,200
	23,000	
		24,940 Y/14,400
	34,500	34,500 Y/19,920
	46,000	
	69,000	
High Voltage	115,000	
	138,000	
	161,000	
	230,000	
Extra-High Voltage	345,000	
	500,000	
	765,000	
Ultra-High Voltage	1,100,000	

Sources: http://static.schneider-electric.us/assets/consultingengineer/appguidedocs/section4_0307.pdf, and American National Preferred Voltage Ratings for Electric Power Systems and Equipment (60 Hz), ANSI C84.1-1989.