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Weather-Related Power Outages and Electric System Resiliency

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Summary

High winds, especially when combined with precipitation from seasonal storms, can cause damage to electricity utility systems, resulting in service interruptions to large numbers of electricity customers. While most such power outages are caused by damage from trees and tree limbs falling on local electricity distribution lines and poles, major power outages tend to be caused by damage to electricity transmission lines, which carry bulk power long distances. Depending on the severity of the storm and resulting impairment, power outages can last a few hours or extend to periods of several days, and have real economic effects. Power outages can impact businesses (primarily through lost orders and damage to perishable goods and inventories), and manufacturers (mainly through downtime and lost production, or equipment damage). Data from various studies lead to cost estimates from storm-related outages to the U.S. economy at between $20 billion and $55 billion annually. Data also suggest the trend of outages from weather-related events is increasing.

Suggested solutions for reducing impacts from weather-related outages include improved tree-trimming schedules to keep rights-of-way clear, placing distribution and some transmission lines underground, implementing Smart Grid improvements to enhance power system operations and control, inclusion of more distributed generation, and changing utility maintenance practices and metrics to focus on power system reliability. However, most of these potential solutions come with high costs which must be balanced against the perceived benefits.

A number of options exist for Congress to consider which could help reduce storm-related outages. These range from improving the quality of data on storm-related outages, to a greater strategic investment in the U.S. electricity grid. Congress could empower a federal agency to develop standards for the consistent reporting of power outage data. While responsibility for the reliability of the bulk electric system is under the Federal Energy Regulatory Commission (as per the Energy Policy Act of 2005), no central responsibility exists for the reliability of distribution systems. One possible option could be to bring distribution systems under the Electric Reliability Organization for reliability purposes. Recovery after storm-related outages might be enhanced by a federal role in formalizing the review or coordination of electric utility mutual assistance agreements (MAAs). This would not necessarily mean federal approval of MAAs, but may help in the cooperative coordination of additional federal and state resources, especially in a wide, multi-state weather event. While there has been much discussion of transmission system inadequacies and inefficiencies, many distribution systems are in dire need of upgrades or repairs. The cost of upgrading the U.S. grid to meet future uses is expected to be high, with the American Society of Civil Engineers estimating a need of $673 billion by 2020. While the federal government recently made funding available of almost $16 billion for specific Smart Grid projects and new transmission lines under the American Recovery and Reinvestment Act of 2009, there has not been a comprehensive effort to study the needs, set goals, and provide targeted funding for modernization of the U.S. grid as part of a long-term national energy strategy. Such an effort would also require decisions about the appropriate roles of government and the private sector.

Power delivery systems are most vulnerable to storms and extreme weather events. Improving the overall condition and efficiency of the power delivery system can only serve to improve the resiliency of the system, and help hasten recovery from weather-related outages. Ultimately, however, electric utilities are responsible for this infrastructure. They are in the business of selling electricity, and they cannot sell electricity if their power delivery systems are out of service.

Contents

Figures

Tables

Contacts

Introduction

High winds, especially when combined with precipitation from seasonal storms, can cause damage to electricity utility systems, resulting in service interruptions to large numbers of electricity customers. While most such power outages[1] are caused by damage from trees and tree limbs falling on local electricity distribution lines and poles, major power outages tend to be caused by damage to electricity transmission lines, which carry bulk power long distances.

Depending on the severity of the storm and resulting impairment, power outages can last a few hours or extend to periods of several days. This in turn can have real economic effects, as power outages can impact businesses (primarily through lost orders and damage to perishable goods and inventories), and manufacturers (mainly through downtime and lost production, or equipment damage).

Potential issues for Congress concern the resiliency of the electric power system, and whether the economic impacts of storm-related power outages require additional measures to be undertaken by the federal government in mitigating storm-related outages. Congress has already recognized the importance of the reliable operation of the bulk power system with the Energy Policy Act of 2005[2] (EPACT) authorization of an Electric Reliability Organization[3] (ERO).

This report will focus on the impacts of sustained power outages as might result from the result of seasonal storms, and whether there is a role for the federal government in hastening the restoration of power from weather-related outages.

Anatomy of Weather-Related Power Outages

Electric power is generated and sent over transmission lines to substations which reduce the voltage levels for distribution to end-use customers, as shown in **Figure 1**. The network of cables enabling electric power to be sent to customers generally exists in an exterior or "above ground" environment largely exposed to the elements. As such, power outages can result from seasonal storms which often combine the furies of wind, rain, snow, or ice. The more severe weather events usually cause the greatest damage to electric power transmission and distribution infrastructure as damage can result from trees or branches falling on electricity lines. While data on storm-related power outages exist, they are not generally considered to be complete or well-characterized with regard to the cause of the outage event. It has been estimated that 90% of customer outage-minutes are due to events which affect local distribution systems.[4] However, the remaining 10% stem from generation and transmission problems, which can cause wider-scale outages affecting larger numbers of customers.

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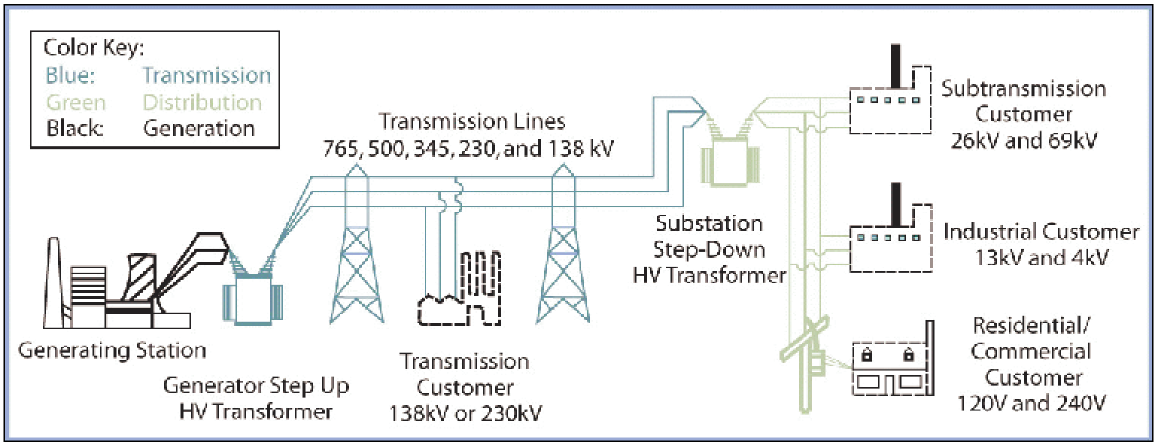
[1] A power outage results in a complete loss of power for the end-use customer.

[2] P.L. 109-58.

[3] 16 U.S.C. §824o.

[4] Alison Silverstein, *Transmission 101*, National Association of Regulatory Utility Commissioners, April 20, 2011, p. 30, http://www.naruc.org/grants/Documents/Silverstein%20NCEP%20T-101%200420111.pdf.

Figure 1. Electric Power System Elements



Source: U.S.-Canada Power System Outage Task Force, *Final Report on the August 14, 2003, Blackout in the United States and Canada: Causes and Recommendations*, April 2004, p. 5, https://reports.energy.gov/BlackoutFinal-Web.pdf.

U.S. Storm-Related Outages

The North American Electric Reliability Corporation (NERC) requires electric utilities to report events which cause disturbances that interrupt service (i.e., power outages) of more than 300 megawatts (MW) or affect 50,000 customers or more. A University of Vermont analysis[5] of NERC data describes 933 events causing outages from the years 1984 to 2006, and is presented in **Table 1**.

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[5] Paul Hines, Jay Apt, and Sarosh Talukdar, *Trends in the History of Large Blackouts in the United States*, University of Vermont, 2008, http://www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf.

Table 1. Large Blackouts in the United States

(statistics for outage cause categories)

	% of events	Mean size in MW	Mean size in customers
Earthquake	0.8	1,408	375,900
Tornado	2.8	367	115,439
Hurricane/Tropical Storm	4.2	1,309	782,695
Ice Storm	5	1,152	343,448
Lightning	11.3	270	70,944
Wind/Rain	14.8	793	185,199
Other cold weather	5.5	542	150,255
Fire	5.2	431	111,244
Intentional attack	1.6	340	24,572
Supply shortage	5.3	341	138,957
Other external cause	4.8	710	246,071
Equipment Failure	29.7	379	57,140
Operator Error	10.1	489	105,322
Voltage reduction	7.7	153	212,900
Volunteer reduction	5.9	190	134,543

Source: Paul Hines, Jay Apt, and Sarosh Talukdar, *Trends in the History of Large Blackouts in the United States*, University of Vermont, 2008, http://www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf.

Notes: Totals are greater than 100% because some events fall into multiple initiating-event categories.

According to the Vermont study, almost 44% of the events in the period were weather-related (i.e., caused by tornado, hurricane/tropical storm, ice storm, lightning, wind/rain, or other cold weather). The study noted that the data include many events smaller than the NERC reporting threshold. It also noted that some of the reported events have "multiple initiating" causes, since some events (such as lightning) can trigger other outages or operator errors.

A 2004 study[6] by Lawrence Berkeley Laboratory (LBL) looking at power interruptions characterized power outages as being of *short* duration lasting less than five minutes, and *sustained* duration outages[7] lasting longer than five minutes (and extending to hours or days). Power outages caused by storm-related events can vary in duration but tend to be sustained disruptions. The study noted that weather-related events are not always captured in power outage data.[8]

The U.S. Department of Energy (DOE) maintains its own database of grid disturbance events.[9] A recent analysis[10] by LBL's Evan Mills of the DOE database shows an increasing number of

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[6] Kristina Hamachi LaCommare and Joseph H. Eto, *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers*, Ernest Orlando Lawrence Berkeley National Laboratory, September 2004, http://certs.lbl.gov/pdf/55718.pdf.

[7] Per the definition of a "sustained interruption" used by the Institute of Electrical and Electronics Engineers (IEEE). Guide for Electric Power Distribution Reliability Indices, No. 1366.

[8] "… widespread power losses resulting from major natural events (primarily storms but also hurricanes and earthquakes) are sometimes not included in the same data categories as more routine power losses. As a result, power losses from natural events are not always included in data used for cost estimates." LaCommare and Eto, op. cit., p. 5.

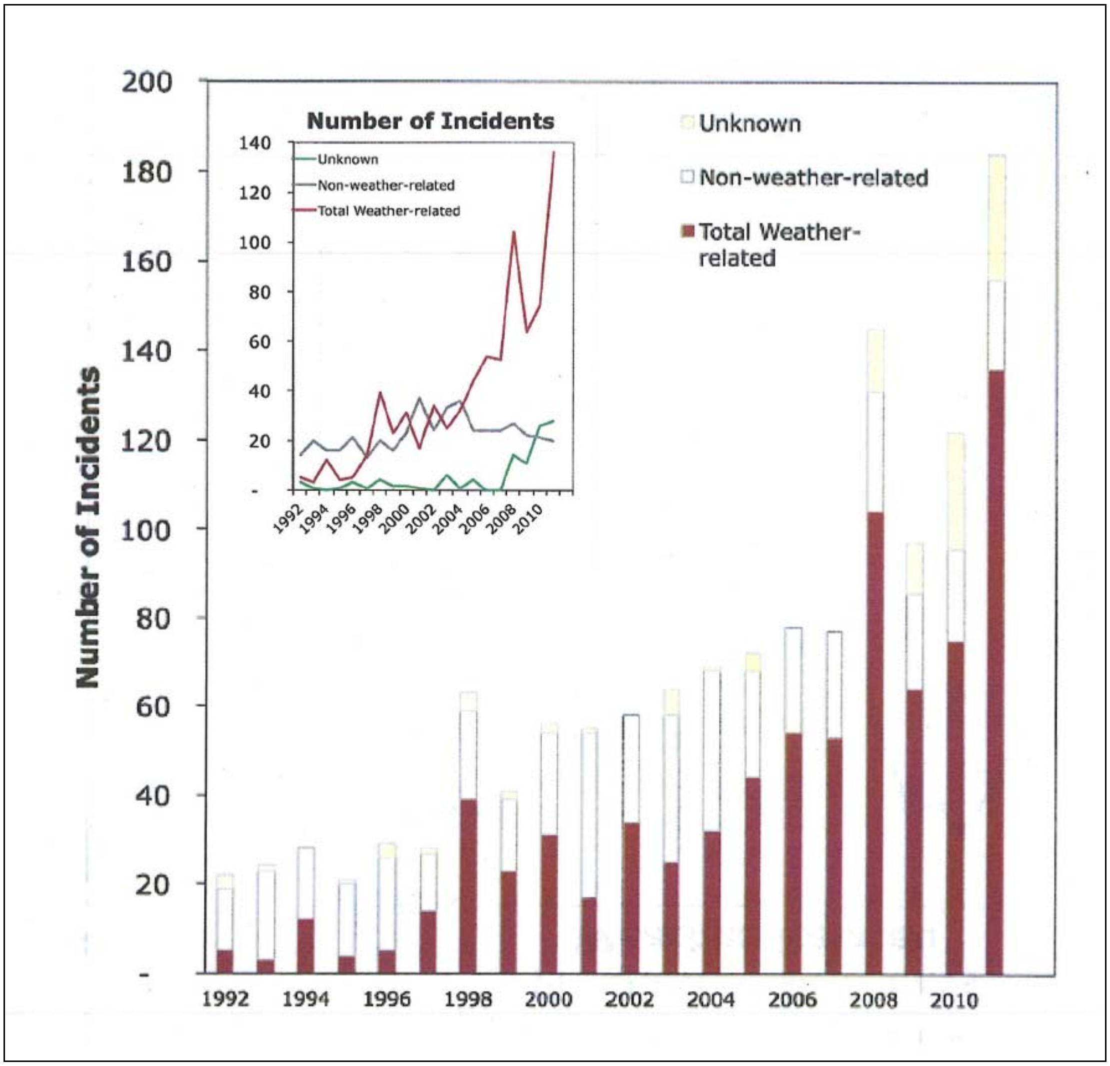
[9] U.S. Department of Energy, Energy Information Administration, Form OE-417. See http://www.eia.gov/cneaf/electricity/page/disturb_events.html.

[10] Evan Mills, *Extreme Grid Disruptions and Extreme Weather*, Lawrence Berkeley National Laboratory, U.S. Disaster (continued...)

outages from 1992 to 2010, all dominated by weather-related events (see **Figure 2**). According to Mills, approximately 78% of the reported 1,333 electric grid disruptions in the period were weather-related (i.e., caused by temperature extremes, ice/snow/winter storm, thunderstorm/tornado/lightning, windstorm/hurricane/severe storm, and undefined weather events), and the grid disruptions affected 178 million metered customers.

Figure 2. Significant U.S Grid Weather-Related Grid Disturbances

(with inset of non-weather- vs. weather-related outage comparison)



Source: *Electric Grid Disruptions and Extreme Weather*. See http://evanmills.lbl.gov/presentations/Mills-Grid-Disruptions-NCDC-3May2012.pdf.

Notes: Historical "Grid Disturbance" data from the U.S. Department of Energy, Energy Information Administration. Form OE-417, "Electric Emergency Incident and Disturbance Report" (and before 1978 from the National Electric Reliability Council, Disturbance Analysis Working Group).

(...continued)

Reanalysis Workshop, May 3, 2012, http://evanmills.lbl.gov/presentations/Mills-Grid-Disruptions-NCDC-3May2012.pdf.

According to graphs shown in **Figure 2**, the number of observed outages from weather-related incidents seems to be increasing. Mills believes the reasons for the increased trend in outages may be due to a combination of power grid deterioration and a real increase in the number of observed extreme weather events.[11]

Outage Rates in Other Countries

The United States is generally considered to have one of the industrial world's most reliable electric power systems. However, when compared statistically to other nations, the U.S. grid does not necessarily meet those expectations.

There are two main indices generally used to measure reliability. The *system average interruption duration index*[12] (SAIDI) represents the average amount of time per year that power supply to a customer is interrupted, expressed in minutes per customer per year. The *system average interruption frequency index*[13] (SAIFI) represents the average number of times per year that the supply to a customer is interrupted, expressed as interruptions per customer per year. However, there is a lack of consistency in how the inputs to these indices are measured, both domestically and internationally. Much of the discrepancy again concerns whether or how storm-related outage events are counted as outage events. Some jurisdictions, both in the United States and internationally, consider storm-related outages as "extreme" events, and thus are not included in power outage statistics. Additionally, what is considered as unusual weather in one region may not be counted as unusual in another region.

> It should be noted, however, that weather circumstances that occur occasionally should not be considered as exceptional events. For example, snowstorms are not an exceptional event in Sweden, but could be seen as an exceptional event in southern Greece. Similarly, very hot temperature for sustained periods of time is not an exceptional event in Greece, but could be considered so in Sweden. Lightning should not be treated as an exceptional event anywhere in Europe.[14]

SAIDI and SAIFI reliability indices for nine industrial countries are summarized in **Table 2**. As can be seen, the United States has the highest average annual outage time per customer, and the third-highest average annual number of supply outages per customer.

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[11] Email from Evan Mills, Lawrence Berkeley National Laboratory, August 30, 2012.

[12] Council of European Energy Regulators, *4th Benchmarking Report on Quality of Electricity Supply 2008*, C08-EQS-24-04, December 10, 2008, http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Electricity/2008/C08-EQS-24-04_4th%20Benchmarking%20Report%20EQS_10-Dec-2008_re.pdf.

[13] Ibid.

[14] Ibid., p. 9.

Table 2. Comparison of International Reliability Indices

Country	SAIDI	SAIFI
United States	240	1.5
Austria	72	0.9
Denmark	24	0.5
France	62	1.0
Germany	23	0.5
Italy	58	2.2
Netherlands	33	0.3
Spain	104	2.2
United Kingdom	90	0.8

Source: Galvin Electricity Initiative, *Electric Reliability: Problems, Progress and Policy Solutions*, http://www.galvinpower.org/sites/default/files/Electricity_Reliability_031611.pdf.

It should be noted that many European countries consider the threshold for defining an extended outage as longer than three minutes[15] instead of the five minute standard generally used in the United States. European countries also commonly have a single regulatory body which is responsible for reliability of the entire nation's power system. These authorities generally authorize expenditures for improving the reliability of service. Overseeing the reliability of the bulk power system in the United States is the responsibility of the Federal Energy Regulatory Commission (FERC) as per EPACT, but responsibility for maintaining the reliability of the nation's electricity distribution systems is the responsibility of many state and local regulatory bodies. It is also likely that the physical size of the United States, and the historical weather extremes possible in any given season across the country, contribute to the U.S. standing in the statistics of **Table 2**.

However, the generally degraded condition of the U.S. electric grid's infrastructure also likely contributes to the statistical quandary. The American Society of Civil Engineers (ASCE) has labeled the nation's grid as a "patchwork system" that may ultimately break down without a massive investment of an estimated $673 billion by 2020.[16] ASCE estimated that over the next decade, there is a gap between what it viewed as needed and current spending annually of $12.3 billion for power generation, $37.3 billion for transmission systems, and $57.4 billion for distribution systems.[17]

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[15] Ibid., page 7.

[16] "The cumulative need, based on anticipated investment levels and the estimated investment gap, will be $673 billion by 2020, an average of about $75 billion per year. Based on investment over the past decade, closing the gap is within reach: the average annual need projected from 2012 through 2020 falls within the range of annual investment totals in the last decade, and there is not a single year through 2020 that is projected to be outside that range." American Society of Civil Engineers, *Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure*, 2011, http://www.asce.org/uploadedFiles/Infrastructure/Failure_to_Act/energy_report_FINAL2.pdf.

[17] "Based on current investment trends, the national electricity infrastructure gap is estimated to be $107B by 2020, or just over $11B per year. By 2020, shortfalls in grid investments are expected to account for almost 90% of the investment gap with nearly $95B in additional dollars needed to modernize the grid." Ibid.

Economic Costs Associated with Storm-Related Power Outages

Power outages can impact electricity consumers primarily through property loss and business disruption. This can result in lost orders, and damage to perishable goods and inventories for businesses. Power outages can critically affect manufacturing operations mainly through downtime as workers are idled, and potentially damage equipment and production processes. The loss of electricity can also disrupt many other electric power-dependent activities sometimes taken for granted (such as traffic control) which can result in further economic impacts.

A study in 2001 by the Electric Power Research Institute (EPRI) estimated the costs to the economy of power disturbances.[18] The study found that three sectors of the economy were particularly vulnerable to power outages:

> The digital economy (DE). This sector includes firms that rely heavily on data storage and retrieval, data processing, or research and development operations. Specific industries include telecommunications, data storage and retrieval services (including collocation facilities or Internet hotels), biotechnology, electronics manufacturing, and the financial industry.
>
> Continuous process manufacturing (CPM). This sector includes manufacturing facilities that continuously feed raw materials, often at high temperatures, through an industrial process. Specific industries include paper; chemicals; petroleum; rubber and plastic; stone, clay, and glass; and primary metals.
>
> Fabrication and essential services (FES). This sector includes all other manufacturing industries, plus utilities and transportation facilities such as railroads and mass transit, water and wastewater treatment, and gas utilities and pipelines.

These three sectors accounted for almost 40% of U.S. gross domestic product[19] in 2001, but disruptions to especially the DE and FES sectors impact other sectors of the economy through the services they provide.

EPRI recognized that the economic cost of power outages was largely related to the length of the outage (while noting even short duration outages of a few minutes could have large costs), and estimated the average cost of a one-hour outage for manufacturing and DE firms at $7,795 per firm. While the estimate recognizes that typically most companies experienced a much smaller loss (with a one-hour outage costing 56% of all DE, CPM, and FES establishments less than $500), the number was weighted by the much larger losses experienced by a few companies. An estimated 5% of establishments in these sectors incurred costs from a one-hour outage of $20,000 or more, with costs for individual establishments ranging as high as $1.5 million.[20]

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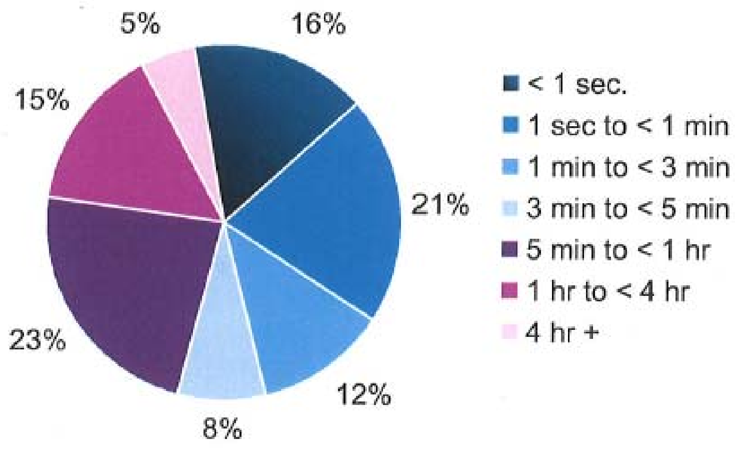
[18] Consortium for Electric Infrastructure for a Digital Society, *The Cost of Power Disturbances to Industrial & Digital Economy Companies*, June 29, 2001, http://www.onpower.com/pdf/EPRICostOfPowerProblems.pdf.

[19] "The market value of goods and services produced by labor and property in the United States, regardless of nationality." See http://www.bea.gov/glossary/glossary_g.htm.

[20] Consortium for Electric Infrastructure for a Digital Society, op. cit., p. 16.

EPRI estimated the annual cost of outages across all U.S. business sectors at $104 billion to $164 billion in 2001. With EPRI estimating the average number of power outages in a year over five minutes at 43% (see **Figure 3**), a reasonable estimate for the annual economic cost yields a possible $20 billion to $31 billion (using the Hines estimate of 44% of outages as weather-related) as a lower range. On the higher end (using Mills's estimate of 78% of outages as weather-related), an estimate of the cost yields $35 billion to $55 billion for annual weather-related outage costs.

Figure 3. Average Length of Power Outages in a Year



Source: Consortium for Electric Infrastructure for a Digital Society, *The Cost of Power Disturbances to Industrial & Digital Economy Companies*, June 29, 2001, http://www.onpower.com/pdf/EPRICostOfPowerProblems.pdf.

The 2004 LBL report estimated (in its base case) economic costs of sustained power interruptions at $26 billion, with the outages resulting from all causes including weather. In recognition of uncertainties in the data, LBL stated that the true cost of sustained outages could be higher or lower by tens of billions of dollars.[21]

Reducing Storm-Related Outages

Outages are largely a result of damage to distribution systems, which are generally exposed to the elements. Storms can inflict damage to electric power delivery systems in a variety of ways. Wind and rain from a hurricane-type event tends to cause different types of power system delivery failures than snow and ice. This section will look at various scenarios for reducing storm-related outages.

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[21] LaCommare and Eto, op. cit., Executive Summary.

Tree-Trimming Schedules

Many storm-related outages are a result of trees contacting or damaging power delivery systems. This is a common mode of electric service disruption especially affecting distribution systems (see **Figure 1**). To minimize the chances of power line contacts with trees, utilities typically trim tree branches to maintain a right-of-way[22] free of impinging vegetation.

To maintain reliability of the bulk power system and reduce the risk of outages, NERC has a vegetation management standard which applies to high-voltage transmission lines of 200 kiloVolts (kV) or higher, requiring the transmission line owner to have a vegetation management plan.[23] *Minimum* vegetation clearance distances are calculated by formula, varying from 0.82 feet (for a 69 kV line) to 8.06 feet (for a 765 kV line).[24] NERC's tree-trimming standard does not apply to low-voltage distribution lines, which are typically less than 69 kV.

NERC's reliability rules do not apply to distribution utilities which are commonly subject to state jurisdiction. Consequently, there is no national law mandating minimum standards for vegetation management around distribution lines. Schedules for tree-trimming have come under scrutiny as some utilities appear to be increasing the period between these operations as they seek to reduce maintenance costs. Some state and local jurisdictions have instituted laws or regulations for tree-trimming or vegetation management. For example, New York and several states in New England require electric distribution utilities to submit a plan for tree-trimming and vegetation management for approval by a state utility commission.

> Although each company develops its own plan, subject to state approval, they tend to maintain an eight- to 10-foot clearance around the sides and bottom of a power line and a 12- to 15-foot clearance above it. Trimming cycles range from every four to seven years, with additional trimming and vegetation management for areas that have been problematic in the past.[25]

Nevertheless, vigilant maintenance of vegetation clearances for power line rights-of-way are generally seen as a good practice that may help to minimize storm-related outages.

Undergrounding of Distribution/Transmission Lines

The practice of putting electricity distribution lines underground has come to be called "undergrounding." In both urban and suburban areas, the practice is common for new construction or in areas being redeveloped to improve aesthetics. Undergrounding is sometimes considered as an option to improve the reliability of service in some areas believed to be susceptible to storm damage.

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[22] A strip of land occupied by active electricity transmission or distribution facilities.

[23] North American Electric Reliability Corporation, *Transmission Vegetation Management NERC Standard FAC-003-2 Technical Reference*, September 2009, http://www.nerc.com/docs/standards/sar/FAC-003-2_White_Paper_2009Sept9.pdf.

[24] Clearances at sea level. Ibid., page 47.

[25] Lee R. Hansen, *Utility Tree Trimming in Other States*, State of Connecticut, December 19, 2011, http://www.cga.ct.gov/2011/rpt/2011-R-0459.htm.

Underground transmission can be used in urban areas or in other locations where the use of overhead transmission lines may be technically challenging or undesirable. Examples of these situations may include instances when traversing an overland route is difficult, where rivers or natural obstacles exist, or when the line passes through land with a scenic or environmental value judged too great to disturb with an overhead transmission line. Underground transmission may also be less of a regulatory obstacle for these reasons. Underground lines are also safer for wildlife (i.e., a lessened risk of electrical shock) and have far fewer long-term visual impacts.

The cost of burying power lines has been estimated as being from ten to twenty times more expensive than overhead cables,[26] with topography, subsurface conditions, and opportunity to use existing underground conduit among the factors contributing to the differences in cost estimates. While underground lines are less prone to severe weather events, maintenance costs may be higher, especially if the line has to be unearthed or brought to the surface for repair, or if the area is prone to flooding. Thus, the perceived benefits of burying power lines sometimes comes at a cost which communities are not willing to accept.[27] Costs of undergrounding are usually passed along to electricity customers, and collected over an assumed average 25-year service life. Some utilities are also willing to share the cost with communities as they may derive some benefits from undergrounding.[28] However, plans to underground power lines are not always approved by regulatory bodies in some jurisdictions, as electric utilities and transmission builders are often required to consider "least cost" options.

Implementing Smart Grid Improvements

Much of the infrastructure which serves the U.S. power grid is aging. The average age of power plants is now over 30 years, with most of these facilities having a life expectancy of 40 years.[29] Electric transmission and distribution system components are similarly aging, with power transformers averaging over 40 years of age,[30] and 70% of transmission lines being 25 years old or older.[31] As components of the system are retired, they are replaced with newer components often linked to communications or automated systems.

The modernization of the grid to accommodate today's power flows, serve reliability needs, and meet future projected uses is leading to the incorporation of information processing capabilities for power system controls and operations monitoring. The "Smart Grid" is the name given to the evolving electric power network as new information technology systems and capacities are

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[26] Jeff Griffin, "Underground Electric Transmission Installations Gaining Traction," *Underground Construction*, vol. 65, no. 6, June 2010, http://www.undergroundconstructionmagazine.com/underground-electric-transmission-installations-gaining-traction.

[27] Julie Patel, "Are You Willing to Pay Thousands to Keep the Power on After a Storm?," *Sun Sentinel*, June 25, 2011, http://articles.sun-sentinel.com/2011-06-25/business/fl-fpl-underground-lines-20110624_1_power-lines-utility-lines-tamara-tennant.

[28] Ken Silverstein, "Upgrading the Grid by Going Underground," *Forbes*, August 2, 2012, http://www.forbes.com/sites/kensilverstein/2012/08/02/upgrading-the-grid-by-going-underground/2/.

[29] Massachusetts Institute of Technology, *Retrofitting of Coal-Fired Power Plants for CO2 Emissions Reductions*, March 23, 2009, http://web.mit.edu/mitei/docs/reports/meeting-report.pdf.

[30] Thomas A. Prevost and David J. Woodcock, *Transformer Fleet Health and Risk Assessment*, Weidman Electrical Technology, IEEE PES Transformers Committee Tutorial, March 13, 2007, http://grouper.ieee.org/groups/transformers/info/S07/S07-TR_LifeExtension.pdf.

[31] K. Anderson, D. Furey, and K. Omar, *Frayed Wires: U.S. Transmission System Shows Its Age*, Fitch Ratings, October 25, 2006.

incorporated. A lot has been said about how the Smart Grid can potentially improve electric utility services, but many customers apparently have yet to be convinced that a Smart Grid will benefit them. Smart Grid improvements could help to avoid power outages, as the system would be able to detect problems, and potentially re-route power while alerting system operators to the location of the issue.[32]

Much of the Smart Grid would conceivably be deployed on electricity distribution systems. However, the privacy of customer information has been raised as an issue with smart meters (which relay information related to a customer's electricity usage back to the electric utility). Rate increases have accompanied Smart Grid-related projects in some states, as most of the costs related to smart meters have been directly passed on to electricity customers. Some state jurisdictions are requiring cost-benefit analyses before approving Smart Grid expenditures in rates.[33] Smart Grid programs will likely need to develop good performance metrics for reliability if these new capabilities are to provide the expected service improvements.[34]

Distributed Generation

Distributed generation is located close to the load it is meant to serve. According to DOE, distributed generation "… feeds into the distribution grid, rather than the bulk transmission grid."[35] As such, distributed generation includes traditional back-up power sources (such as the large gas-powered generators used by institutions and companies), combined heat and power facilities (used for industrial, district, and community power generation), and renewable electricity power systems used by businesses and residences. Microgrids[36] are another form of distributed generation. DOE estimated that as of 2007, there were more than 12 million distributed generation units installed across the United States, with a total capacity of 200 GigaWatts.[37]

Since distributed generation can directly serve the power consumer without external power lines, it is far less vulnerable to the kinds of weather-related service interruptions that can affect utility power systems. DOE stated that "weather is the primary reason for reliability problems, and includes problems caused by lightning strikes, high winds, snowfall, ice, and unexpectedly hot weather. The goal of both planners and operators is to have as resilient a system as possible that

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[32] Ken Silverstein, op. cit.

[33] Katherine Tweed, *Illinois Rejects Ameren's Smart Grid Plan*, Greentech Media, May 30, 2012, http://www.greentechmedia.com/articles/read/illinois-rejects-amerens-smart-grid-plans1/.

[34] Galvin Electricity Initiative, *Electricity Reliability: Problems, Progress and Policy Solutions*, February 2011, http://www.galvinpower.org/sites/default/files/Electricity_Reliability_031611.pdf.

[35] U.S. Department of Energy, *The Potential Benefits of Distributed Generation and Rate-Related Issues That May Impede Their Expansion*, February 2007, http://www.ferc.gov/legal/fed-sta/exp-study.pdf.

[36] A microgrid is any small or local electric power system that is independent of the bulk electric power network. For example, it can be a combined heat and power system based on a natural gas combustion turbine (which cogenerates electricity, and hot water or steam from water used to cool the natural gas turbine), or diesel generators, renewable energy, or fuel cells. A microgrid can be used to serve the electricity needs of data centers, colleges, hospitals, factories, military bases, or entire communities (i.e., "village power").

[37] "Over 99% of these units are small emergency reciprocating engine generators or photovoltaic systems, installed with inverters that do not feed electricity directly into the distribution grid. However, … this large number of smaller machines represents a relatively small fraction of the total installed capacity." U.S. Department of Energy, *The Potential Benefits of Distributed Generation and Rate-Related Issues That May Impede Their Expansion*, February 2007, http://www.ferc.gov/legal/fed-sta/exp-study.pdf, p. 33.

can adjust to problems without causing major consequences, and that when outages do occur, they are short-lived and affect the fewest number of customers as possible."[38] Aside from the potential to provide back-up power to the customer in the event of an outage, DOE found there were other potential benefits to system reliability from distributed generation.[39]

- Several utilities offer financial incentives to owners of emergency power units to make them available to grid operators during times of system need.
- Several regions offer financial incentives or price signals to customers to reduce demand during times of system need (e.g., demand response programs), and some participants in these programs use distributed generation to maintain near-normal on-site operations while they reduce their demand for grid-connected power.

DOE further observed that distributed generation can add diversity to power supply options, thus leading to improvements in overall system adequacy. DOE also stated that distributed generation "has the potential to reduce the number of outages caused by overloaded utility equipment."[40]

Reliability-Centered Maintenance Regulations

A 2005 study[41] by Davies Consulting for the Edison Electric Institute (EEI) looked at state regulatory investigations of electric utility responses after major storm-related outages.[42] The study came to a number of conclusions concerning utility performance and infrastructure with regard to the time required to restore service after major storms:

- The systems are resilient.
- Adequate funds are being spent on maintenance and reliability.
- Restoration strategies, plans, and practices meet standard utility practices, but more effective resource acquisition (mutual aid) practices need to be employed, such as getting crews on the road earlier and allowing utilities to recover these costs even if they are not used.
- Communication processes with all stakeholders and customers need to be improved—before, during, and after an event.
- Restoration structures and emergency management structures and practices (e.g., Incident Command Structures) need to be aligned.

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[38] U.S. Department of Energy, *The Potential Benefits of Distributed Generation and Rate-Related Issues That May Impede Their Expansion*, February 2007, http://www.ferc.gov/legal/fed-sta/exp-study.pdf, p. 42.

[39] Ibid.

[40] Ibid. p. 50.

[41] Davies Consulting, Inc., *State of Reliability Distribution Regulation in the United States*, Edison Electric Institute, September 2005, http://legalectric.org/f/2010/04/stateofdistributionreliability-2005.pdf.

[42] The events included the North Carolina and South Carolina ice storm of December 2003, Hurricanes Isabel and Juan (September 2003), the Utah snow storm of December 2004, four hurricanes in Florida in summer 2004, and the Maritime ice storm of November 2004.

While the EEI-sponsored study found that adequate amounts were being spent in maintenance and reliability, the study suggested that reliability-centered maintenance[43] (RCM) practices may be an effective tool in preventing some storm-related outages, and could allow for a quicker recovery after a storm-related outage, and encouraged state utility regulators to consider approval of RCM if it was shown to be cost-effective.

> Regulatory efforts, with regard to maintenance, follow two general approaches: development of time-based maintenance intervals with compliance reporting, typically on an annual basis; and development of a higher level maintenance approach with assessments or self-certification. Time-based maintenance may be cost effective for some technologies, but it is likely not effective for all assets. As more utilities evaluate the RCM model, regulators will have to review the benefits and accept the model as part of a cost effective maintenance program. If RCM-type approaches are proven to be effective, but are not accepted by the commissions, utilities will be forced to continue to use the time based methodology and may face a "wall" where assets will need to be replaced in large quantities. As a result, utilities may begin a large-scale and unfocused replacement strategy that does not produce commensurate reliability.[44]

However, the study noted that some state jurisdictions have instituted quality-of-service benchmarks for electric utilities, with penalties imposed on utilities not achieving reliability performance targets. The study observed that penalties rather than rewards would be the focus, as "many state regulators feel that utilities should not be rewarded for service they should already be providing. Second, many regulators believe that there is no tangible benefit to most customers when a utility achieves performance beyond targets."[45] Additionally, those customers willing to pay a premium for reliability (the study reasoned) would likely install their own back-up or distributed generation.

Mutual Assistance Agreements

Depending on the size and extent of a storm causing an outage, a utility may find it necessary to call upon other utilities via its mutual assistance agreements[46] (MAAs) to help it restore services. MAAs can reduce the duration of weather-related outages by bringing in outside resources to aid the recovery effort.

> 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" crews from other utilities. When called upon, a utility will send skilled line workers—both utility employees and

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[43] "Reliability centered maintenance … is a scientific process designed to develop a maintenance program, focuses on equipment condition and is matched to the wear-out pattern of that equipment based on operation, not time. Those industries using reliability centered maintenance such as the U.S. airline industry, the U.S. Navy (including nuclear submarines), nuclear power plants, and fossil fuel plants, indicate that adoption of RCM has increased reliability while simultaneously reducing costs." Davies Consulting, Inc., op. cit., p. 21.

[44] Ibid.

[45] Ibid.

[46] Most utilities have found that they cannot staff up internally to provide the manpower they need to respond to major storms. Therefore, they rely on mutual assistance agreements where they agree to share line crews and equipment to help each other respond to major storms. See http://www.eei.org/ourissues/electricitydistribution/Documents/StormRestoreReport.pdf.

> contractors—along with specialized equipment to help with the restoration efforts of a fellow utility.
>
> Mutual Assistance includes primary and secondary response with back-up contingency plans. Contingency plans are developed by the smaller, more regionalized RMAGs (Regional Mutual Assistance Groups). These plans assure that resource transfers have a minimal effect on a regional area in case an unexpected event occurs. Contingency plans can be done in various ways depending on the amount of resources being transferred either from a region or a larger geographic area such as across North America.[47]

MAAs are voluntary arrangements made with other electric utilities in states or regions unlikely to be affected by the same storm or weather-related event. As such, it may take time for MAAs to result in additional help arriving, as the utility workers must travel sometimes significant distances. Assuming that roadways are open, these convoys must travel at speeds which can be safely navigated by the bucket trucks and other specialized vehicles making the journey.

EEI provides advice on how to structure and arrange MAAs to its member utilities. While MAAs are voluntary and not regulated, they have come under state regulatory scrutiny especially in longer-duration outages. But the extent of damage can slow the response of other utilities to respond to calls for assistance, as a utility's first obligation is to restore service to its own customers in the event of an outage. Nevertheless, effective MAAs are invaluable to the recovery effort after a major storm-related outage.

Concluding Observations

In any discussion of storm-related power outages, two prominent themes emerge—preparation and recovery. If utilities are aware of an impending storm or weather-related event which may cause outages, they are expected to make preparations for restoration of services in as timely a manner as possible. Recovery from any such event will depend on the severity of the storm and the resulting damage. However, recovery can be hastened, and the amount of damage to electric power infrastructure can be minimized, if good maintenance, restoration, organization, and communications strategies are followed on an ongoing basis. Electric utilities should also be aware of local weather-related events in the past. If an area is prone to particular seasonal extremes of weather, then utilities would be expected to work with state and local regulatory authorities to look at ways to reduce vulnerabilities of the power and related infrastructure.

The cost of many aged parts of the electric power system have already been recovered in rates by electric utilities. The time for new investments may be approaching (if it is not already here) considering the projected future uses of the grid. Power delivery systems are most vulnerable to storms and extreme weather events. Improving the overall condition and efficiency of the power delivery system can only serve to improve the resiliency of the system, and help hasten recovery from weather-related outages. Ultimately, however, electric utilities are responsible for this infrastructure. They are in the business of selling electricity, and they cannot sell electricity if their power delivery systems are out of service.

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[47] See http://www.eei.org/ourissues/ElectricityTransmission/Reliability/Pages/ElectricSectorMutualAssistance.aspx.

Options for Congress

The inconsistency of data from outage reporting is an issue in quantifying the impacts of storm-related and other power outages. Congress could empower the National Institute of Standards or DOE or some other federal agency to develop standards for the consistent reporting of power outage data.

While responsibility for the reliability of the bulk electric system is under FERC, no central responsibility exists for distribution systems. One possible option would be to bring these systems under the ERO for reliability purposes. However, this would require changes in law, with the Federal Power Act[48] being key to any changes.

Formalizing review or even coordinating MAAs under a federal agency like the Federal Emergency Management Agency or the Department of Homeland Security may be an option that Congress may want to consider. This would not necessarily mean federal approval of MAAs, but may help in the cooperative coordination of additional federal and state resources, especially in a wide, multi-state weather event. The utility industry, however, may be opposed to government involvement in MAAs.

The aged condition of the electrical grid in many parts of the United States will likely only detract from and compound recovery efforts. While there has been much discussion of transmission system inadequacies and inefficiencies, many distribution systems are in dire need of upgrades or repairs. The cost of upgrading the grid to meet future uses is expected to be high, as the estimates of the ASCE show, and the importance of a robust grid to U.S. economic performance goes without question. While the federal government recently made funding available for specific Smart Grid projects or transmission lines under the American Recovery and Reinvestment Act of 2009,[49] there has not been a comprehensive effort to study the needs, set goals, and provide targeted federal funding for the modernization of the U.S. grid as part of a long-term national energy strategy. Such an effort would also require decisions about the appropriate roles of government and the private sector.

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[48] 16 U.S.C. §824o.

[49] The American Recovery and Reinvestment Act of 2009 (P.L. 111-5) made available $3.4 billion for funding Smart Grid projects, and approximately $6.5 billion in borrowing authority for transmission systems was authorized for the Western Area Power Administration and the Bonneville Power Administration. Additionally, $6 billion in loan guarantees was made available for renewable energy and electric power transmission.