The Heritage Foundation

BACKGROUNDER

No. 2959 | OCTOBER 29, 2014

America's Electricity Grid: Outdated or Underrated?

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Abstract

The high-voltage transmission system that interconnects the nation's generating plants and provides the electricity that we rely on in our daily lives is a remarkably complex infrastructure. This report considers how well that system is working, its strengths and its weaknesses, and the policies that can best ensure the system continues to perform its essential functions. The report also addresses how new initiatives, especially the "Smart Grid," will affect the transmission system. Finally, the report considers whether policy changes are needed to improve the system and, if so, what types of policies will ensure the highest reliability, safety, and security at the lowest possible cost.

Reliable electricity service is essential to the nation's health, welfare, and security. In 2000, the National Academy of Engineering named the modern transmission system as one of the greatest inventions of the 20th century.[1] Powering America's homes, factories, and gadgets, reliable electricity is a staple for modern comfort and the production of valuable goods and services. Yet as interwoven as the electric grid is into our daily lives, few understand how electricity is delivered to the consumer and the policies that influence this process. Despite the grid's functioning exceptionally well, many concerns exist about grid vulnerabilities, whether from natural causes or from terrorists trying to disrupt the power grid.

To address these vulnerabilities, policymakers can benefit by understanding the basic underpinnings of how the electric grid physically operates. Similarly, policies enacted at the federal and state levels, especially over the past two decades, have affected how the electric grid operates, including the efficiency of wholesale elec-

Key Points

- Efforts to enhance the electric grid's reliability and promote competitive wholesale electric markets have largely succeeded, encouraging new generation development, lower operating costs, and greater availability.
- Regional coordination has significantly reduced the chance of large, catastrophic blackouts, the last non-weather-related blackout occurring in 2003.
- Aging infrastructure, federal and individual state mandates for intermittent renewables, physical and cyber terrorism, and weather events all threaten transmission system reliability.
- While the federal government has enacted policies to strengthen wholesale competitive markets, it has also implemented policies that divert investments, force the use of unreliable energy resources, and socialize costs even where benefits are uncertain.
- There are practical steps based on economic principles that policymakers can take to ensure the bulk power system operates as efficiently as possible at the lowest cost.

This paper, in its entirety, can be found at **http://report.heritage.org/bg2959**

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The Advent of Electric Power Systems

In 1879, Thomas Edison developed the incandescent light bulb and invented a commercially viable lighting system.[1] A few years later, a generating station was built on Pearl Street in New York City to provide power for 400 of Edison's lamps through a web of direct current (DC) distribution lines running along wooden poles. In a DC system, power flows in one direction. For example, flashlight batteries use direct current to light the bulb, and those model electric train sets gathering dust in attics also run on DC.

The turning point for widespread electric service came in 1886, when George Westinghouse developed a power system that used alternating current (AC). In AC systems, the direction of power "flips" many times per second. In the U.S., for example, the direction switches (or cycles) 120 times per second. With AC power, a transformer, basically an iron ring with two sets of wires wrapped around it, changes voltage levels.[2] The advent of AC power allowed electricity transmission at high voltages, which could easily be stepped down to "customer friendly" voltages. This matters when transmitting electricity long distances because more energy is dissipated as heat at lower voltages—a phenomenon called resistance.

Like water flowing through a garden hose, the amount of power delivered from point A to point B depends on how much pressure is applied (by opening the faucet) and the diameter of the hose. For electricity, the pressure applied is measured by voltage (volts). The electric equivalent to the amount of water that flows through the hose per second is current, which is measured by amperage (amperes). The greater the voltage, the more current can be transmitted. The reason stems from a basic physical property of electric transmission, called Ohm's Law, which states that the percentage of electric losses from electric resistance (heat) decreases as voltage levels increase. For example, doubling the voltage used to transmit electricity decreases the percentage losses by a factor of four. This property led to the creation of today's high-voltage transmission system.

1. For a detailed history, see Charles F. Phillips, *The Regulation of Public Utilities: Theory and Practice*, 3rd ed. (Arlington, VA: Public Utilities Reports, 1993), Chaps. 13 and 14.
2. For additional discussion, see Jonathan A. Lesser and Leonardo R. Giacchino, *Fundamentals of Energy Regulation*, 2nd ed. (Arlington, VA: Public Utilities Reports, 2013), pp. 388–393.

tric markets and the need for new infrastructure investment. This brief report provides an introduction to the electric grid: What it is, how it operates, how it is regulated, and the challenges it faces.

The Bulk Power System

Beginning in the late 1920s, electric utilities began to integrate their operations to improve reliability and reduce costs. Previously, utilities had operated as "islands," meeting the demand for electricity solely from their own generating plants. To ensure reliable service, this meant building extra generating capacity to keep in reserve, in case unexpected problems caused their plants to shut down.[2] By integrating their operations, utilities could provide more reliable service without building as much backup generating capacity. In essence, if a generating plant at Utility A suffered a forced outage, one of Utility B's generators would be available to ensure the lights stayed on. The concept is similar to diversifying a financial portfolio. Instead of investing everything into just one company's stock, buying multiple stocks, bonds, and other investments reduces the risk of a sudden financial loss.

1. George Constable and Bob Somerville, *A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives* (Washington, DC: National Academies Press, 2003), chap. 1, http://www.greatachievements.org/ (accessed September 5, 2014).
2. Such shutdowns are called "forced outages," as distinguished from scheduled outages for maintenance.

Wholesale Electric Markets

Before 1992, all electric generation was owned by regulated electric utilities, except certain types of qualifying facilities (mainly renewable generation and industrial cogeneration) that were allowed under the Public Utilities Regulatory Policy Act of 1978 (PURPA).[1] There were no centralized wholesale electric markets where power could be bought and sold in the same way that agricultural commodities are bought and sold on the Chicago Mercantile Exchange and stocks on the New York Stock Exchange. Instead, utilities traded among each other, buying and selling power to balance their customers' demand.

In 1992, Congress passed the first Energy Policy Act (EPAact), which for the first time allowed all types of electric generation to be owned and operated independent of electric utilities. The development of these exempt wholesale generators (EWGs) created a need for formal wholesale markets. The restructuring of the electric industry that began in the mid-1990s, which allowed for independent generation owners to sell power directly to retail electric consumers of utilities, increased the need for formal wholesale markets. These markets began to develop in New England and the Mid-Atlantic, where many states had adopted restructuring.[2]

1. PURPA was one of five major pieces of energy legislation passed during the Carter Administration. PURPA's primary purpose was to encourage development of alternatives to oil-fired and natural gas–fired generation, in response to the OPEC oil embargo of 1974 and (at the time) rapidly diminishing supplies of natural gas. Ironically, the Fuel Use Act of 1978, one of the other pieces of legislation, encouraged utilities to switch to burning more coal.
2. As discussed below, many of these same wholesale markets are under assault because of increasing state and federal subsidies for renewable generation, which are causing significant distortions, including premature retirement of unsubsidized generating plants.

Moreover, linking generating plants together to meet electricity demand of multiple utilities helped to lower costs because utilities could operate a group of generating plants to ensure the lowest cost units were supplying power, in essence dispatching generating plants to meet customer demand from lowest to highest operating cost.

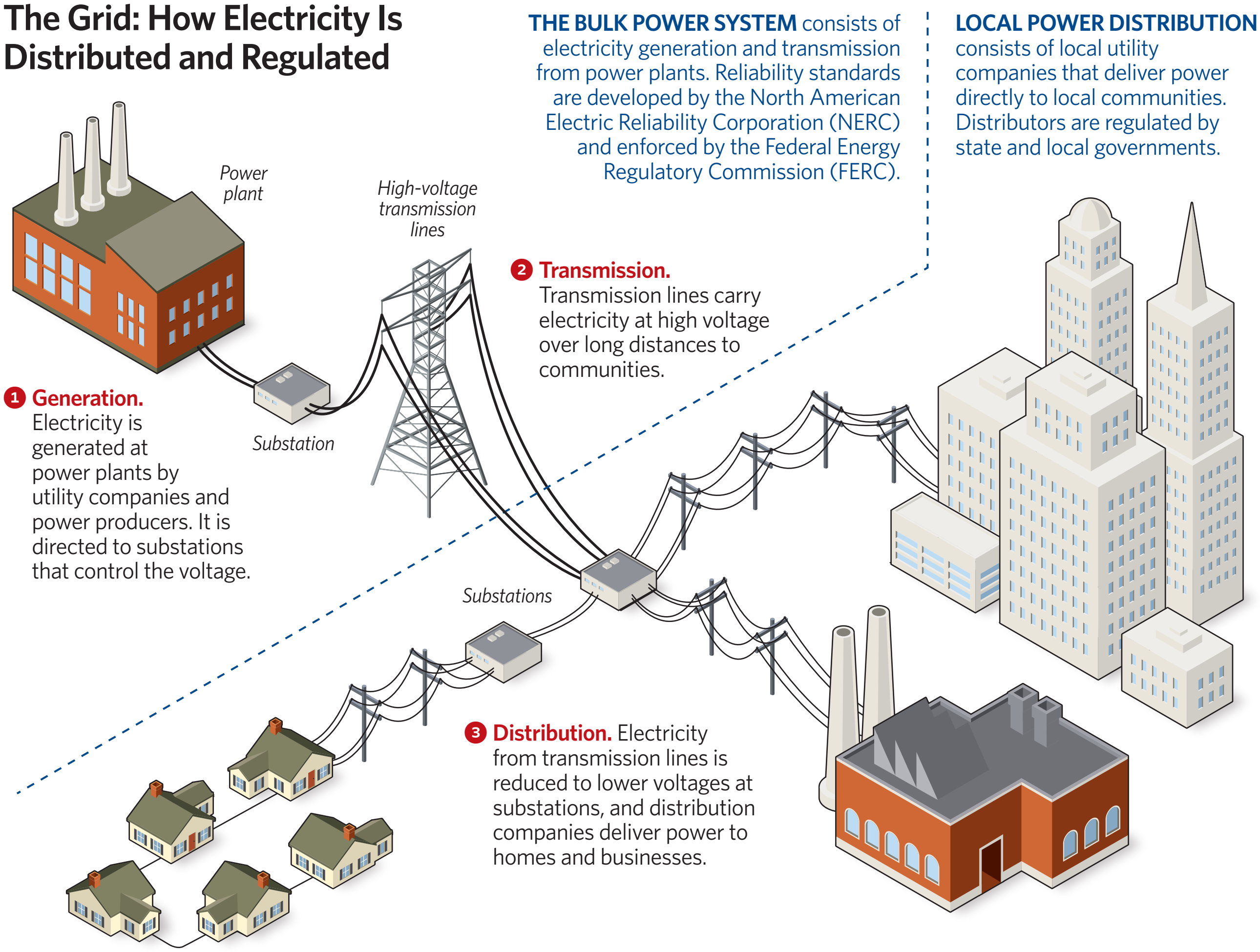
This integration required construction of high-voltage transmission lines to interconnect individual utilities, although the length of these lines was limited by electrical losses.[3] After World War II, higher-voltage transmission lines were constructed, which allowed utilities to transmit ("wheel") power over greater distances, further reducing costs and increasing reliability. Today, large electric transmission lines typically transfer power at hundreds of thousands of volts, and 230–500 kilovolt (kV) systems form the backbone of the continental U.S. electricity grid.[4] By comparison, a typical neighborhood distribution line might operate at several thousand volts and the voltage level in a typical house or apartment is just 110 volts.

By the early 1960s, many utilities across the country had formed voluntary groups to coordinate operation of their generating plants and transmission systems. These provided additional reliability at a relatively low cost. Then, in November 1965, an improperly set resistor at a hydroelectric plant on the Saint Lawrence River triggered a massive blackout in the Northeast. This blackout led the electric industry to create the North American Electric Reliability Council (NERC) and prompted far more regional coordination among utilities to ensure the power system could avoid future large catastrophic outages. As a result of increased coordination among utilities and transmission system operators, there have been few such outages since. The most recent major non-weather-related transmission outage was in August 2003, when a

3. The feasible distance to transmit power was called "economic transmission distance." This was an important concept for determining how to allocate low-cost electric power supplies generated at federal hydropower projects.
4. Some extra-high voltage transmission lines operate at 765 kV. Transmission voltages are not practical for customers. In the U.S., for example, most electric appliances are designed to run on 110 volts. A few, such as electric dryers and water heaters, are designed for 220 volts. As a result, power delivered to a local electric utility must be reduced to these lower, usable voltages.

FIGURE 1

The Grid: How Electricity Is Distributed and Regulated



Note: FERC regulation does not include Texas.

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downed transmission line in Ohio caused a multistate blackout in a number of Mid-Atlantic states.[5]

Until passage of the Energy Policy Act of 2005 (EPAct), these reliability standards from NERC were voluntary. However, partly in response to the 2003 blackout, Congress included a requirement in EPAct 2005 that NERC, which was renamed the North American Electric Reliability Corporation, develop specific reliability and operation standards to ensure the reliability and safe operation of the bulk power system. EPAct further tasked the Federal Energy Regulatory Commission (FERC) with enforcing NERC's reliability standards[6] and ensuring that the bulk power system is operated in ways that ensure competition in the wholesale electric markets. (See text box, "Wholesale Electric Markets.")

Today, over 200,000 miles of high-voltage transmission lines crisscross the U.S. (see Figure 1) delivering electricity from almost 6,000 generating plants[7] to utilities for local distribution. This network of large generating stations and high-voltage transmission lines is called the bulk power system.

5. The last major storm-related outage took place in October 2012 because of Hurricane Sandy.

6. The Energy Policy Act of 2005 (EPAct) added Section 215 to the Federal Power Act. This section gave FERC and NERC the authority to establish and enforce reliability standards on "all users, owners and operators of the bulk-power system," including public power entities. See Federal Power Act § 215(b)(1); 16 U.S. Code § 824o(b)(1).

7. The U.S. Energy Information Administration defines a "major generating plant" as having a generating capacity of one megawatt (MW) or more. See U.S. Energy Information Administration, *Electric Power Annual 2011*, January 2013, http://www.eia.gov/electricity/annual/archive/2011/ (accessed September 5, 2014).

In some ways, this network resembles the Interstate Highway System.

Unlike trucks that are dispatched along specific highways or natural gas in pipelines, electric power cannot be steered along specific routes. Instead, power flows through the transmission based on physical laws, always flowing along the paths of least electric resistance. Because of this and because power cannot be stored cost-effectively, power system operators must continually adjust generators to keep everything operating within a narrow range of voltage levels and frequency.[8] Without these continuous adjustments, the power system would rapidly fail.

As a result, the need for ensuring the reliability of the power system has led to far greater coordination among the different players, including independent transmission operators (ISOs) and the regional transmission organizations (RTOs) that oversee transmission system operations and wholesale power markets.

Regulating the Electric Transmission Grid

Historically, local electric utilities were granted franchise monopolies in exchange for agreeing to serve everyone in their designated area, which is called the obligation to serve. As long as a customer paid his bill, a local utility was not allowed to refuse service. Nor can a utility refuse to connect new customers in its area. State utility commissions regulate the prices local utilities can charge. In areas of direct retail competition, regulators set the price for local distribution service (i.e., the price the local utility can charge for providing the poles and wires to deliver electricity to homes and businesses).

In the same way, FERC oversees the bulk power system that transmits electricity across state lines, which is subject to federal regulation. FERC regulates the rates that transmission system owners can charge for the services they provide. (The exception is Texas, because its electric system is not connected to any other states.)

FERC also regulates wholesale sales of electricity. Because most wholesale power markets are competitive, FERC typically grants companies that wish to sell in wholesale markets market-based rate authority, which means that the company has no market power (i.e., the ability to influence market prices) and therefore can sell power at whatever prices the market will bear. For the few companies that FERC claims have market power, FERC sets the maximum cost-based prices that the companies are allowed to charge, in the same way that FERC sets the maximum prices that regulated interstate natural gas pipelines can charge their customers.

Although FERC oversees wholesale prices, it cannot require transmission system owners to build new transmission lines, nor can FERC override state siting regulations that prohibit a transmission line from bisecting a state park or passing through a specific neighborhood. Nor can FERC require or prohibit construction of a new generating plant.

FERC can prevent individual states from adopting rules that regulators determine would adversely affect the interstate wholesale markets. For example, states cannot adopt policies intended to force wholesale prices down, such as forcing local distribution utilities to build new generation to increase the supply of power and thus lower prices.

State and Federal Electric Policy

Regulation of the retail power sector has long been the responsibility of states. In recent years, however, the federal government has imposed various mandates to engineer the mix of fuels used to generate electricity. The Energy Policy Acts of 1992 and 2005 created various tax incentives for renewable resources, especially wind and solar generation. Federal environmental regulations, such as the Environmental Protection Agency's (EPA) proposed rules on carbon dioxide emissions from coal-fired power plants, effectively prohibit construction of such plants and are intended to phase out coal use.[9] Similarly, EPA rules on water discharge temperatures restrict operations of some nuclear plants that rely on rivers for cooling water.

As much as federal electric policies have focused on creating competitive wholesale power markets,

8. For example, most household lights and appliances are designed to operate at 110 volts. If the voltage fluctuates above or below that value by more than a few volts, lights and appliances will not work.

9. Southern Company, which supplies electricity to consumers in several Southern states, is currently constructing a 582 MW coal-fired power plant with carbon capture in Kemper County, Mississippi. However, the plant's cost has ballooned to $5.5 billion, more than double the original estimate of $2 billion. The plant is not expected to enter service until sometime in 2015.

other federal policies such as production tax credits for wind power have distorted the same wholesale markets by artificially subsidizing the costs of renewable energy.[10]

As much as federal electric policies have focused on creating competitive wholesale power markets, other federal policies such as production tax credits for wind power have distorted the same wholesale markets by artificially subsidizing the costs of renewable energy.

Individual states have developed their own electric and energy policies, including renewable portfolio standards that mandate that a certain percentage of electricity sold to consumers come from renewable energy. Detailed siting requirements can restrict the types of power plants that are constructed. Moreover, in states that have restructured their electric industry and allow direct retail electric competition, utility consumers can contract directly with wholesale electric suppliers, much as they can select their cellular phone service provider.

Because of state and regional differences, retail and wholesale electric prices vary across the country. For example, in the Pacific Northwest, large quantities of low-cost federally owned hydropower plants sell electricity to local electric utilities in the region. In contrast, electricity prices in New England have historically been the highest in the continental U.S. because those states are located far away from traditional fuel sources used to generate electricity (coal and natural gas) and because they tend to have older and less efficient plants, higher labor costs, and limited options for siting plants.[11] Not surprisingly, given their history of high electric prices, many New England states were early adopters of retail electric competition.

The Challenges Ahead

The efforts to enhance reliability and promote competitive wholesale electric markets have been largely successful. For example, the most recent major network outage occurred in 2003 and encompassed the Upper Midwest and the Northeast.[12] Competitive wholesale power markets have encouraged new generation development, lower operating costs, and greater plant availability.[13] For example, PJM Interconnection alone, which oversees operation of the bulk power system including wholesale power markets in the middle Atlantic, has added more than 28,000 megawatts (MW) in new generating capacity since 2007.[14]

Renewable Energy. In some ways, by creating an expectation that power will always be available, the electric industry is a victim of its own success. As electricity's importance in our daily lives has increased, so has the magnitude and complexity of the transmission system. Moreover, the need for new transmission system investment and the allocation of costs of that investment have been affected

10. For example, Third Way, a think tank, stated, "It is increasingly likely that the United States could see a significant percentage of its nuclear power plants close, thanks to low natural gas prices and ongoing subsidies for renewable energy. For anti-nuclear activists, this news may seem rosy. But if you care about climate change this is very bad news." Josh Freed, "Shutting Down U.S. Nuclear Plants Is Still Bad News for Environmentalists," Third Way, March 2014, http://content.thirdway.org/publications/794/Third_Way_Memo_-_Shutting_Down_Nuclear.pdf (accessed September 5, 2014).
11. Shale gas reserves, such as those in the Marcellus Shale, which extends from New York State southwest into Pennsylvania and beyond, have the potential to change this.
12. For a detailed review, see North American Electric Reliability Corporation, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations," April 2004, http://www.nerc.com/pa/rrm/ea/Pages/Blackout-August-2003.aspx (accessed September 5, 2014).
13. For an analysis of operating efficiency improvements at competitive generating facilities, see Lucas W. Davis and Catherine Wolfram, "Deregulation, Consolidation and Efficiency: Evidence from U.S. Nuclear Power," *American Economic Journal*: *Applied Economics*, Vol. 4, No. 4 (October 2012), pp. 194–225. See also Kira R. Fabrizio, Nancy L. Rose, and Catherine D. Wolfram, "Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on U.S. Electric Generation Efficiency, *American Economic Review*, Vol. 97, No. 4 (September 2007), pp. 1250–1277.
14. PJM, "2016/2017 RPM Base Residual Auction Results," p. 22, http://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2016-2017-base-residual-auction-report.ashx (accessed September 5, 2014).

by subsidies for renewable solar and especially wind generation. Ironically, that has adversely affected reliability because of their inherent intermittency: The wind does not always blow, and the sun has a maddening tendency to disappear at night.

One element of reliability and well-functioning markets is sufficient transmission capacity. When transmission capacity is constrained in an area, such as northern Virginia or New York City, the lowest cost electric supplies cannot always be delivered. Instead, consumers must rely on less-efficient, higher-cost local generation, which leads to higher wholesale electric prices. Yet siting and building new transmission facilities in these areas can raise complex issues. These include concerns about siting, property easements, impacts on property values, and allocation of costs. When proposed transmission lines cross multiple states, the process becomes even more difficult, especially when any one state can veto the siting.

Under Section 216 of the Federal Power Act, in 2007 the U.S. Department of Energy (DOE) identified two National Interest Electric Transmission Corridors—one in the West and the other covering the Mid-Atlantic states. The corridors are geographic areas where transmission congestion or other transmission constraints adversely affect consumers. Although the U.S. Court of Appeals overturned the DOE's designations in 2011 because the DOE failed to prepare environmental impact statements for the corridor designations,[15] the court's ruling did not change the transmission congestion issues in those areas. In response to the court ruling, the DOE instead has issued several reports, most recently an August 2014 draft "National Electric Transmission Congestion Study."[16] The DOE Congestion Study identifies key areas where transmission systems are congested, particularly urban areas such as the Mid-Atlantic states and Washington, DC; southeast New York state; and southern California—the latter stemming from the permanent closure of the San Onofre nuclear power plant in June 2013.

Despite identification of areas in which transmission capacity is limited, a "not in my backyard" (or anyone else's, in some cases) attitude toward new transmission line siting has resulted in cancellation or delay of some new transmission lines.

For example, in 2011, PJM cancelled the proposed Potomac Appalachian Transmission Highline (PATH) project, a 275-mile transmission line that would have run through West Virginia, Virginia, and Maryland to deliver electricity into Northern Virginia. Although the line was designed to improve reliability in eastern PJM, changing forecasts of electricity demand growth and intense opposition to siting the line led to the project's cancellation.

State and federal policies that mandate and subsidize development of far-flung wind generation and solar power also have increased the need for new transmission infrastructure and the operating stress on the bulk power system. These subsidies began in 1978 under the Public Utilities Regulatory Policies Act, which mandated that local electric utilities purchase the output from wind generators at administratively set avoided costs, which typically were based on forecasts by regulators that predicted the cost to a utility of building and operating new generating plants. These predictions were often wildly wrong.

For example, in the early 1990s, many energy planners were predicting crude oil prices above $200 per barrel and shortages of natural gas. Neither prediction was correct. Yet as a result of these erroneous forecasts, avoided costs were set at levels far higher than the cost of alternative generation. As discussed previously, the production tax credit that was introduced in 1992 has subsidized wind generation and is adversely affecting wholesale electric markets.[17]

In addition to affecting wholesale electric markets, wind generation physically affects the transmission system. Unlike the steady and controllable generation from conventional and nuclear generators, the inherent variability of wind power creates additional stress on the bulk power system because electricity demand varies continuously and supply and demand must be balanced in every instant. Otherwise, outages can occur. The inherent variability of wind

15. *California Wilderness Coalition v. US Dept. of Energy*, 631 F.3d 1072 (9th Cir. 2011).

16. U.S. Department of Energy, "National Electric Transmission Congestion Study," August 2014, http://energy.gov/sites/prod/files/2014/08/f18/NationalElectricTransmissionCongestionStudy-DraftForPublicComment-August-2014.pdf (accessed September 12, 2014). The final report will be published later in 2014 after the mandatory 60-day comment period.

17. For example, see Jonathan Lesser, "Wind Generation Patterns and the Economics of Wind Subsidies," *The Electricity Journal*, Vol. 26, No. 1 (January/February 2013), pp. 8–16.

and solar power means that additional generating resources must be standing ready to supply power if the wind stops blowing or clouds hide the sun.[18]

Further, policies promoting wind and solar generation have increased the need for transmission investment because regions with the best quality resources (i.e., large tracts of windy or sunny land)[19] are in remote areas of the country, far from urban centers. For example, Texas spent more than $7 billion to build a network of high-voltage transmission lines to bring wind power in west Texas to urban centers in the east.

Physical Threats. The transmission system is also vulnerable to acts of physical and cyber vandalism, sabotage, and terrorism. For example, on February 5, 2014, *The Wall Street Journal* detailed a sniper attack on a large power substation near San Jose, California, in April 2013.[20] The attack knocked the substation out of service for almost an entire month.

In a 2012 report, the National Research Council identified a number of physical threats, especially to high-voltage transformers. The report stated that these transformers are "very large, difficult to move, custom-built, and difficult to replace. Most are no longer made in the United States, and the delivery time for new ones can run to months or years."[21] The report also highlighted the increasing risk from cyberterrorism, owing to the transmission grid's increasing dependence on computerized operations, especially "supervisory control and data acquisition (SCADA) systems that gather real-time measurements from substations and send out control signals to equipment, such as circuit breakers."[22]

Infrastructure. Another critical issue is aging transmission system infrastructure. As equipment ages, it can become less reliable and more prone to sudden failures. Having sufficient information about the condition of this infrastructure is a key component to ensuring optimum reliability. For example, new planning methods to determine the number and locations of spare transformers on the bulk power system can be evaluated by RTOs, individual utilities that own transmission lines, and state and federal regulators.[23] These methods can reduce costs and lessen the likelihood of extended outages.[24]

Still another challenge stems from who pays for grid improvements, especially new transmission lines needed to interconnect renewable resources. Although retail consumers ultimately pay for these investments, how the costs are allocated among different consumers has become controversial. Typically, cost allocation is based on the cost-causation principle, which can be thought of as similar to a "you break it, you buy it" policy in a retail store.

This approach began to break down with the need to integrate greater quantities of subsidized solar and wind generation. Historically, transmission grid operators would allocate transmission line costs to the local utility where the physical interconnection took place, even if the power generated by a wind facility was to be delivered to customers of a different utility. For example, the transmission interconnec-

18. For a discussion of how California intends to integrate over 11,000 MW of variable generating resources into its power system, see North American Electric Reliability Corporation and California Independent System Operator Corporation, "Maintaining Bulk-Power System Reliability While Integrating Variable Energy Resources—CAISO Approach," November 2013, http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC-CAISO_VG_Assessment_Final.pdf (accessed September 5, 2014).

19. Wind and solar power facilities have low power densities. *Power density* is a measure of electric power production per unit of area (e.g., watts per square meter, etc.). In contrast, *energy density* is a measure of energy content per unit of mass (e.g., joules per kilogram). A typical large wind-power facility has a power density of 1–2 watts per square meter because the turbines must be widely spaced. In contrast, a nuclear power plant may have a power density of hundreds of watts per square meter.

20. Rebecca Smith, "Assault on California Power Station Raises Alarm on Potential for Terrorism," *The Wall Street Journal*, February 5, 2014, http://online.wsj.com/news/articles/SB10001424052702304851104579359141941621778 (accessed September 5, 2014).

21. See National Research Council, Committee on Enhancing the Robustness and Resilience of Future Electrical Transmission and Distribution in the United States to Terrorist Attack, *Terrorism and the Electric Power Delivery System*, National Academies Press, 2012, p. 2, http://www.nap.edu/openbook.php?record_id=12050 (accessed September 5, 2014).

22. Ibid.

23. For example, see Charles Feinstein and Jonathan Lesser, "Opening the Black Box," *Public Utilities Fortnightly*, January 2014, pp. 36–42, http://www.fortnightly.com/fortnightly/2014/01/opening-black-box (accessed September 5, 2014).

24. Ibid. The authors describe a specific analysis performed for the PJM Interconnection on optimal location of spare transformers. As a result of their analysis, PJM redeployed spare transformers, including to a substation where, just two weeks after a spare was sited, the existing transformer failed.

tion costs for a wind power facility built in rural Iowa would be allocated to the local electric utility even if the power was being delivered to consumers in Ohio.

Integration costs were small as long as renewable generation additions were small. Yet as the amount of subsidized renewable generation began increasing dramatically, requiring entirely new high-voltage transmission lines to be built, interconnection costs rose and local electric utilities balked. For example, two utility members of the Midwest Independent System Operator (MISO), a transmission organization covering numerous states in the Midwest, threatened to withdraw from MISO altogether.

To address these cost allocation issues, FERC issued Order 1000 in 2011. This major rule was designed, among other things, to adopt a broader cost socialization approach for "public policy initiatives," such as renewable generation. As a result of Order 1000, many infrastructure costs associated with interconnecting wind and solar facilities will be socialized across all transmission system users, forcing many users to further subsidize renewable energy beyond the federal and state tax handouts. However, Order 1000 has proved controversial, and its cost-socialization requirements have been appealed by the Coalition for Fair Transmission Policy, a group that includes state utility regulators, utilities, and independent transmission companies.[25]

Costs, Benefits, and Interdependencies. Ultimately, given these challenges we must recognize at least three basic facts.

First, system reliability comes at a cost. However, because the benefits of reliability are not evenly distributed—individuals and firms may place far different values on avoiding interruptions to electric service—determining how costs should be allocated can be difficult and controversial.

Second, measuring these benefits is difficult. Asking an individual what he is willing to pay for reliable electric service is likely to evoke an odd stare, not a specific dollar value. Similarly, siting decisions for new transmission lines often hinge on high transaction costs and difficult-to-ascertain costs, such as the impacts on property values and concerns about health effects of electromagnetic radiation.[26] Moreover, system reliability cannot, except in limited circumstances (e.g., an industrial firm building its own generating plant) be tailored to individual customers' willingness to pay. Even if one consumer in a neighborhood is willing to pay twice as much as another consumer to avoid a blackout, the local utility can only provide both consumers with the same reliability.

Third, the interdependencies of the transmission grid mean that a local event—a downed transmission line or a shot-up substation—can have widespread impacts, just as the 2003 incident in Ohio affected millions of customers in New York City.

The interdependencies of the transmission grid mean that a local event—a downed transmission line or a shot-up substation—can have widespread impacts.

Of course, some of these characteristics are not unique to the electric industry. Siting a new highway or airport can raise similar questions about costs, benefits, and who should pay. Nevertheless, the interconnected nature of the industry, the difficulty in estimating the benefits and costs of transmission system infrastructure, and controversy over how to allocate costs efficiently and fairly can make transmission system projects daunting. Moreover, the interconnected nature of the transmission system creates the opportunity for inevitable conflicts when state and federal policymakers disagree.

Clearly, given the vital nature of safe and reliable electric service to the U.S. economy and our daily lives, the bulk power grid should be operated in ways that promote vibrant competitive wholesale electric markets made possible by reliable transmission capacity.

25. The case is *South Carolina Public Service Authority, et al. v. Federal Energy Regulatory Commission* and is pending before the U.S. Court of Appeals, District of Columbia Circuit.

26. Some individuals, for example, are concerned about exposure to electric and magnetic fields, which are generated by all electric currents, including from small appliances and cell phones. For a review of research on potential health impacts from high-voltage transmission lines, see National Institutes of Health, National Institute of Environmental Health Sciences, "Assessment of Health Impacts from Exposure to Power-Line Frequency Electric and Magnetic Fields," August 1998, http://www.niehs.nih.gov/health/assets/docs_a_e/emf1.pdf (accessed September 5, 2014).

New Innovations: Help or Hype?

One of the most discussed aspects of the transmission system (as well as local distribution systems) is the "Smart Grid." The idea behind the Smart Grid is to employ more advanced, computerized technology to make "dumb" wires "smart"[27]—to employ two-way communications technology that provides real-time information on consumer demand for power and the condition of the entire transmission system. Moreover, Smart Grid proponents promote the ability of consumers to make more economically efficient decisions on electric usage, such as reducing consumption when demand and wholesale prices peak and having "smart" appliances that can be controlled automatically to respond to real-time electric market prices.

Despite the hype, few studies have estimated the potential benefits and costs of a Smart Grid. In 2010, the Electric Power Research Institute (EPRI) published a report with a framework for analyzing the costs and benefits of small utility demonstration projects.[28] In 2011, the EPRI published a report with a preliminary estimate of the potential costs and benefits to U.S. retail electric consumers of the Smart Grid.[29] That report suggested an additional cost to consumers of $338 billion to $476 billion over 20 years, with potential benefits of $1,294 billion to $2,028 billion. Although these benefits appear far larger than the costs, both are highly speculative. For example, the 2011 EPRI report estimated $74 billion in improved "qualify of life" benefits, including greater "comfort" and "convenience." However, accurately measuring such attributes, much less defining them in measurable ways, is difficult.

Moreover, although the U.S. government and many state governments have advertised the Smart Grid as something entirely new,[30] much of the technology is not. For example, SCADA systems that became popular in the 1960s used two-way communications to monitor the health of the transmission system.[31] Thus, Smart Grid technologies are more evolutionary than revolutionary, stemming from improvements in computing technology and wireless communications. Finally, some Smart Grid investments, such as charging stations for electric vehicles, benefit the few who can afford (subsidized) electric vehicles at the expense of the many who cannot.

The 2009 American Recovery and Reinvestment Act (the "stimulus bill") gave the Department of Energy $4.5 billion to modernize the electric power grid, as called for under the Energy Independence and Security Act of 2007.[32] Through March 2012, the DOE had spent $2.96 billion in Smart Grid projects. In April 2013, the DOE published a report detailing this spending and its economic impacts, estimating that the spending had created the equivalent of 40,000 new jobs.[33]

The DOE also developed a Smart Grid Computational Tool to estimate the benefits of specific Smart Grid applications.[34] However, the benefits depend heavily on numerous assumptions, such as consumers' responsiveness to real-time price signals, the value of reduced system outages, and the value of reductions in air pollution emissions.

27. See "Wiser Wires," *The Economist*, October 9, 2009, http://www.economist.com/node/14586006 (accessed September 5, 2014).
28. Electric Power Research Institute, *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*, January 2010, https://www.smartgrid.gov/sites/default/files/pdfs/methodological_approach_for_estimating_the_benefits_and_costs_of_sgdp.pdf (accessed September 18, 2014).
29. Electric Power Research Institute, "Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid," March 2011, http://www.rmi.org/Content/Files/EstimatingCostsSmartGRid.pdf (accessed September 5, 2014).
30. See Office of Electricity Delivery and Energy Reliability, "Smart Grid," http://energy.gov/oe/technology-development/smart-grid (accessed September 5, 2014).
31. See Sandia National Laboratories, "SCADA History," November 4, 2011, http://energy.sandia.gov/?page_id=5508 (accessed September 5, 2014).
32. For the statement of policy on Smart Grid, see Energy Independence and Security Act of 2007, 42 U.S. Code § 17381.
33. U.S. Department of Energy, "Economic Impact of Recovery Act Investments in the Smart Grid," April 2013, http://energy.gov/oe/downloads/economic-impact-recovery-act-investments-smart-grid-report-april-2013 (accessed September 5, 2014). Table 2 of that report lists the 20 companies receiving the most money for Smart Grid projects. The economic analysis presented in this report suffers from the fundamental flaw of failing to recognize that the $2.96 billion was money taken from taxpayers, which was then given to selected companies. Instead, the analysis treated the entire amount as additional expenditures. Ibid., p. 6, Table 2.
34. To download the tool, see U.S. Department of Energy, "Smart Grid Computational Tool," http://www.smartgrid.gov/recovery_act/program_impacts/computational_tool (accessed September 5, 2014).

Finally, whereas the claimed benefits of Smart Grid technologies stem from advanced use of electronics, the National Research Council report highlighted the increased vulnerabilities of the transmission system to cyberterrorism. Thus, the same technologies that are providing new benefits can also increase the vulnerability of the transmission grid.

Addressing Policy Recommendations and Proposals

Undoubtedly, the U.S. transmission system faces operational risks. Some of these risks, such as vandalism, sabotage, and cyberterrorism, have been studied extensively. Experts have recommended numerous policy changes to reduce the risk of attack and to speed up the recovery from an attack.[35] Some of these recommendations, such as locating spare transformers in key areas, will also provide improved reliability.

Applying basic economic principles, the bulk power system should be operated as efficiently as possible to provide an optimum level of reliability at the lowest possible cost.

Integrating Renewable Generation. The public policy emphasis on renewable generating resources, primarily wind generation, has become increasingly costly. Even though the federal Production Tax Credit (PTC) expired at the end of 2013, wind generating facilities that began construction before that date are eligible for the tax credit. Moreover, the PTC credit, which in 2013 was $24 per megawatt-hour (MWh) on a pre-tax basis or $35 per MWh on an after-tax basis, is as large as the average wholesale price of power in some markets. A Congressional Research Service report estimated that a one-year extension of the PTC would cost over $12 billion in lost tax revenues.[36] Moreover, there has been increasing concern over the impacts of subsidized wind generation on competitive wholesale markets and premature retirement of baseload ("round-the-clock") generating resources such as nuclear power.

Thus, while the federal government enacted policies to strengthen wholesale competitive markets, it has also enacted policies that have adversely affected those same markets because of continued subsidies for renewable generation. Federal policies that work at cross-purposes are inefficient, to say the least.

Rethinking Other Policies. The inherent variability of wind and solar resources requires additional investment in transmission system infrastructure, including investment in natural gas generation to be held in reserve in case of sudden drops in wind generation output. Consequently, RTOs must set aside greater amounts of generation in reserve, which means additional generation is needed to meet demand. Moreover, integrating far-flung wind and solar resources requires spending billions of dollars on new transmission lines that would otherwise not be needed, and those costs are further socialized across all transmission system users. This leads to higher electric bills, which adversely affect consumers.

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The Smart Grid Mandate. In states that have not instituted direct retail electric competition, electric consumers purchase power from their local electric utility at rates set by regulators. These rates often reflect a variety of objectives, from subsidies to promote economic development and retention of manufacturing jobs to special low-income rates. Moreover, because different methods of assigning causation can result in vastly different allocations of costs among customer groups, regulated tariffs can allocate costs inefficiently compared with the market. Regulated retail rates rarely reflect economic efficiency by pricing electricity at its true market value, which varies from day to day and even hour to hour.

Although the Smart Grid offers potential economic benefits through real-time pricing of electricity, those benefits will be minimal if retail consumers cannot directly access competitive power markets

35. National Research Council, *Terrorism and the Electric Power Delivery System*.
36. For example, see Philip Brown, "U.S. Renewable Electricity: How Does the Production Tax Credit (PTC) Impact Wind Markets?" Congressional Research Service *Report for Congress*, June 20, 2012, http://fas.org/sgp/crs/misc/R42576.pdf (accessed September 5, 2014).

and do not base their consumption decisions on market prices. If ratepayers are forced to spend billions of dollars on smart meters that track real-time consumption, then utility regulators should enact policies that allow utility rates to reflect real-time market values to the greatest extent possible.

The DOE should not subsidize Smart Grid development. Similarly, electric vehicle users, not taxpayers, should pay the costs of local distribution system infrastructure needed for their vehicles. The U.S. government already heavily subsidizes electric vehicle production and purchase, primarily to the benefit of high-income consumers. These subsidies should also be eliminated because they exacerbate the costs needed for new distribution system infrastructure.

What the U.S. Should Do

Congress and the Administration should:

1. **Eliminate all renewable resource subsidies, which encourage uneconomic expansion of the transmission grid to interconnect widely dispersed resources.** The continuing subsidies, such as the PTC, adversely affect the competitive wholesale electric markets and grid operations because of their variable output. Intermittent generation exacerbates the need for backup generation, yet renewable energy subsidies discourage new generation investment.

2. **Eliminate the cost-socialization requirements under FERC Order No. 1000 and allow transmission systems to determine how best to allocate costs among transmission system owners and users.** Transmission system owners and users are better suited to identify the costs and benefits of system investments and how to allocate those investments.

3. **Eliminate DOE subsidies of Smart Grid spending for specific utilities, such as those designed to encourage electric vehicle penetration.** Electric vehicles remain a niche, high-cost product. Their development and purchases are heavily subsidized and primarily benefit upper-income individuals. The government should avoid additional subsidies of the infrastructure needed to accommodate electric vehicle recharging.

4. **Improve transmission grid resilience and recovery.** The NRS 2012 report contains numerous recommendations to reduce power system vulnerability to both cyber attacks and physical threats, such as the snipers that shot out the substation near San Jose in 2013. The report also contains recommendations for restoring power after a major outage, such as stockpiling transformers and other long-lead-time equipment and better contingency planning. New analytical methods to improve reliability planning, including optimal location of spare equipment, can also be implemented. Finally, rather than implementing one-size-fits-all federal standards, utilities and transmission system operators should be able to work together to identify risks and appropriate strategies to address those risks.

Conclusion

Despite its complexity, the U.S. electric system is remarkably reliable. The bulk power system of generation and high-voltage transmission lines has enabled universal access to affordable electricity. However, the increasing demands placed on the power system to meet policy mandates and its potential vulnerability to physical threats and cyber attacks require policy changes. Some of these are simple and ought to be uncontroversial. For example, improving security at key substations to prevent disruptions would cost little compared with the potential costs of major equipment failures. Similarly, contingency planning that hastens recovery in the event of a major outage and stockpiling sufficient spare parts in key locations are practical actions with benefits that would likely far outweigh the additional costs.

More difficult are policies designed to improve the grid's economic efficiency. Subsidies always distort markets, and the production subsidies for wind power have damaged competitive wholesale power markets and increased the costs of operating the bulk power system. These policies have not only led to premature retirements of baseload generating facilities, which are needed to supply low-cost electricity, but also discouraged new investment. They directly contradict other policy goals that sought to enhance competitive generation markets and encourage investment. Federal policies that work at cross-purposes simply waste the money of taxpayers and electric consumers.

Although renewable generation subsidies have strong advocates, it is past time for these resources to compete without government mandates and subsidies. Production tax credits and mandates for renewable energy supplies impose high costs, with few benefits.

Cost allocation is another policy issue. Proper cost allocation is crucial to maximizing economic efficiency. Federal mandates, such as FERC Order 1000, have imposed cost allocation schemes based on purported collective benefits. Yet the claimed benefits are suspect. A better approach would be to allow transmission system participants to determine how best to allocate costs. As long as key competitive principles are maintained, transmission system owners are best suited to determine the most efficient cost-allocation policies.

Finally, new infrastructure siting must be addressed in ways that uphold property rights and that balance state and local sovereignty with broader regional needs for an efficient, reliable, electric system. Although there are no simple answers, a starting point may be to more clearly analyze the benefits and costs of new infrastructure. Moreover, it is possible to design mechanisms that compensate the relatively few who experience harm, while still obtaining the benefits of new infrastructure.

The U.S. transmission system is a remarkable piece of engineering that is fundamental to our economy and way of life. With several policy changes, it can continue to provide reliable, safe, and secure electricity supplies that continue to enhance our lives.

Policymakers have pushed to integrate more renewable energy into the grid through subsidies, mandates, and targeted tax credits and have also called for government spending on Smart Grid technologies that essentially computerize the grid. Instead of promoting preferred technologies driven by special interests with taxpayer-funded subsidies, Congress should eliminate these subsidies and implement market-based reforms that will truly improve the electricity grid's efficacy and resiliency.

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