Ensuring the Resilience of the U.S. Electrical Grid

Part II: Managing the Chaos – and Costs – of Shared Risks

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INTRODUCTION

The North American power grid is indeed a modern marvel, and yet at the same time it is increasingly a system facing great risk. Part of this is merely due to the age of many of its essential components, for as the American Society of Civil Engineers (ASCE) has noted,

> *Altogether, our nation's electric energy infrastructure is a patchwork system that has evolved over a long period of time, with equipment of widely differing ages and capacities. For example, about 51% of the generating capacity of the U.S. is in plants that were at least 30 years old at the end of 2010. Most gas-fired capacity is less than 10 years old, while 73% of all coal-fired capacity is 30 years or older. Moreover, nationally, 70% of transmission lines and power transformers are 25 years or older, while 60% of circuit breakers are more than 30 years old".*[1]

The organization assigned the U.S. energy infrastructure a grade of "D+" on its most recent assessment in 2009.[2] *The Report Card for America's Infrastructure* went on to describe congestion in transmission and distribution systems that complicates routine maintenance and exacerbates risks of systemwide failures.[3]

MEASURING THE RISKS

Measurements of risk are generally described as a function of both the potential severity of an adverse event and the likelihood of such events taking place. This binary set of factors highlights the key relationship between not only if an event will happen but also how bad the impacts would be if it did, and enables effective risk-based decisions about how to reduce risk by helping distinguish frequent but relatively minor events from those that may be less frequent but would be significantly more important if they did occur.

Importantly, while severe weather and other disruptive events provide ample evidence of the increased likelihood of events taking place, it is actually the increased severity that creates the more significant impacts, for in today's hyper-complex and ever more interdependent world the impact of any given event can cascade well beyond its immediate vicinity. This reality was demonstrated on March 11, 2011 when a powerful tsunami hit Japan's nuclear power generation capabilities in Fukushima and resulted in power and other disruptions that affected global manufacturing. As one analyst noted,

> *The quake and tsunami damaged or closed down key ports, and some airports shut briefly. This disrupted the global supply chain of semiconductor equipment and materials. Japan manufactures 20% of the world's semiconductor*

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1 American Society of Civil Engineers, "Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure", April 26, 2012, pgs. 18-19.

2 American Society of Civil Engineers, *Report Card for America's Infrastructure*, 2009.

3 *Ibid*.

products, including NAND flash, an indispensable electronic part of Apple's iPad. Japan also supplies the wings, landing gears and other major parts of Boeing's 787 Dreamliner… Automakers Toyota, Nissan, Honda, Mitsubishi and Suzuki [also] temporarily suspended production. Nissan may move one production line to the U.S. A total of 22 plants, including Sony, were shut in the area.[4]

As a result, the effects of a tsunami and related power disruption half the world away included a global economic impact totaling in the billions of dollars and lost economic productivity involving everything from consumer products to automobiles and companies in Japan, Vietnam and the United States, to name only a few. Given the trends of global trade and worldwide sourcing for everything from raw materials to consumer goods, industrial equipment, and even consulting and professional services, the scale of deleterious impacts from cascading failures in an interconnected world is significant and rising.

SOURCES OF THE GROWING RISK

1) Severity: Many risk analysts believe the most noteworthy trend of late has been the particular increase in probable severity of impacts from any significant disruption. The root cause of concern in this regard is the dramatic and mostly unconscious increase in the complexity of the interdependencies within our overall economy which mean that, because a disruption in a highly interconnected area like electrical power will have pronounced cascading effects across all manner of economic, transportation, telecommunications, and financial services industries, the severity of any disruption might be orders of magnitude worse than people would expect based on historical precedent. This was the case in the August 14, 2003, blackout in portions of the Northeast and Midwest United States and Ontario, Canada, causing an estimated economic loss of $6 billion in the United States alone (see case study in Part I).

Specifically, some of the main concerns in this regard include the personal and private sector costs of disruptions through lost productivity or damage to homes and workplaces, as well as the social impact of potential widespread death and destruction such as when a severe heat wave that hit France in 2003 resulted in some 14,800 deaths. At the same time, one must also take account of potential national and homeland security impacts stemming from the loss of power to critical command and control centers that would negatively impact the coordination of response efforts, potentially including even our nation's defensive forces.

2) Likelihood: The likelihood of the national power grid being impacted by adverse events is also on the rise due to myriad significant threats and hazards. In fact, according to the Department of Energy, of the five massive U.S. blackouts over the past 40 years, three of them occurred in the past nine years while the average outage from 1996-2000 affected 409,854 people, a 15% increase over the previous five-year period.[5] This is in large part because today's threats can stem from physical decay of the existing decades-old infrastructure as well as exposure of more and more of the system to the impacts of a growing population that is increasing per-person power consumption while moving both to crowded cities or spreading further and further into areas that were once scarcely inhabited.

America's electric system, "the supreme engineering achievement of the 20th century," is aging, inefficient, congested and incapable of meeting the future energy needs of the Information Economy without operational changes and substantial capital investment over the next several decades.

- Grid 2030: A National Vision for Electricity's Second 100 Years, U.S. Department of Energy, 2003

Hazards also come from changing weather patterns that include major storms and more days and even weeks or months of extreme temperatures. As can be plainly seen from the challenges of combating droughts and the buckling of the pavement of American highways during the summer of 2012, for example, the manifestation of extreme hot or cold weather can push infrastructure beyond its design limitations, which in turn creates additional unforeseen cascading effects. While the impact to various physical linkages, couplings, substations, and other equipment of the power grid may be less visible than buckling highways, the results of the extreme temperatures on the built environment of the electrical grid are no less pronounced, including equipment

4 Kimberly Amadeo, "Impact of Japan's Earthquake on the Economy", About.com, May 16, 2012.

5 *The Smart Grid: An Introduction*, Department of Energy, Washington, DC, December 2008.

failure, high-stress of the system, and shorter maintenance and replacement intervals for critical components.

Another important potential risk facing the electrical grid is that of malicious actors, be they terrorists like al Qaeda or Hezbollah, the military of other nations competing economically or otherwise with the U.S., or even lone-wolf anarchists or disgruntled employees. While attacks like these may seem unlikely, their intent and potential impacts mean they must be considered in terms of protecting the power grid, especially in light of the well-publicized potential cyber vulnerabilities of key segments of our existing electrical grid infrastructure.

SOME GOOD NEWS

The good news regarding the ability of the electrical system to absorb and recover from impacts is that for a variety of routine disruptions such as thunderstorms, minor substation failures, and the like our numerous economic and regulatory imperatives drive fairly resilient operations for much of the electrical power industry. In fact, the entire system is designed to meet a "3 nines" reliability standard, which translates to being 99.97% reliable.[6] This overall systemic resilience has evolved over time because industry participants have economic incentives to keep the system operating due to the regulations governing their operating agreements. For example, even if a local generation or transmission disruption occurs most power companies still have to provide power even if it means buying electricity at current market rates – even though those rates can spike precipitously during those same adverse events.

As a result, stable performance is an economic imperative because failure to keep the system operating can cost a tremendous amount of revenue to a firm. Power companies also have inherent incentives to implement process and structural solutions that minimize down-time following an adverse event, for in addition to regulatory concerns downtime means electricity is not being used and thus further lost revenues.

6 The Galvin Electricity Initiative, "The Electric Power System is Unreliable."

INDIA'S 2012 POWER BLACKOUT

More than 670 million people in India lost electrical power on July 30 and 31, 2012 – the largest blackout in history. According to Rabindra Nath Nayak, chairman of state-owned Power Grid Corp. of India Ltd., India suffered transmission infrastructure failures because electrical supply has not kept pace with demand. In fact, regular roving brown-outs across India have led a good portion of the private sector there to invest in private generators to ensure continuity of operations when the electrical grid fails, with some even using their own power as a primary source and the grid as a back-up. Nonetheless, the July power outage was unprecedented in its scale, having been exacerbated by provincial level grids drawing more than their allotted quotas from the national grid. The late monsoon could also possibly be to blame, as more farmers than usual were using electrically powered water pumps to irrigate their fields, and the nation's hydroelectric power plants were under powered due to the late rains.

As discussed in the official Enquiry Committee's report, the following four factors led to the initiation of the grid failure:

1. Weak Inter-regional Corridors due to multiple outages: The system was weakened by multiple outages of transmission lines in the Western Region(WR)-Northern Region (NR) interface. Effectively, 400 kV Bina-Gwalior-Agra (one circuit) was the only main AC circuit available between WR-NR interface prior to the grid disturbance.
2. High Loading on 400 kV Bina-Gwalior-Agra link: The overdrawal by some of the NR utilities, utilizing Unscheduled Interchange (UI), contributed to high loading on this tie line.
3. Inadequate response by State Load Dispatch Centers to the instructions of Regional Centers to reduce overdrawal by the NR utilities and underdrawal/excess generation by the WR utilities.
4. Loss of 400 kV Bina-Gwalior link: Since the interregional interface was very weak, tripping of 400 kV Bina-Gwalior line on zone-3 protection of distance relay caused the NR system to separate from the WR. This happened due to load encroachment (high loading of line resulting in high line current and low bus voltage). However, there was no fault observed in the system.

The report's primary conclusions are that better technical management of the grid is required along with stricter adherence to grid governance regulations and additional investment in repairs and maintenance.

Sources: India Ministry of Power

The power companies fall under federal and state regulatory oversight for the operation of generating facilities and transmission systems, and the rates that local utilities are allowed to charge is generally regulated by state agencies.[7] This bifurcation of locally set rates but federally and state-mandated performance measures can cause tensions with regard to long term investments because the regulatory oversight prevents free market investments that can be recouped under normal financial operations such as freely-floating prices.

Nonetheless, the interplay between regulators and industry works in terms of meeting the routine decisions about investments that need to be addressed, and as a result of these drivers the electricity segment has proven generally highly resilient under most scenarios because its primary components can withstand massive localized degradation without necessarily impacting the rest of the system.

BUT SHARED RISKS REMAIN

Nonetheless, reliability is still a concern, and is intimately tied to resilience of the system. In fact, as noted by the Galvin Electricity Initiative regarding being 99.97% reliable, "while this sounds good in theory, in practice it translates to interruptions in the electricity supply that cost American consumers an estimated $150 billion per year."[8]

As another source reports, "The grid is designed to work at least 99.97 percent of the time, but just 0.03 percent still equals an average loss of 2.6 hours of power each year for customers across the U.S."[9] Furthermore, as CNN has reported, "Experts on the nation's electricity system point to a frighteningly steep increase in non-disaster-related outages affecting at least 50,000 consumers… During the past two decades, such blackouts have increased 124 percent – up from 41 blackouts between 1991 and 1995, to 92 between 2001 and 2005, according to research at the University of Minnesota."[10]

But particularly pernicious is the shared nature of these risks. For example, too many industry players relying on the same few equipment suppliers for critical parts can result in an acute shortage after a large event. Potential transportation or supply chain interruptions further complicate the shared risks – whether for transporting raw materials to power plants or the mobility of power crews repairing various damaged infrastructure. It is from these kinds of unmanaged interdependencies resulting from today's complex world that the bad event can cascade into systemic collapse, as occurred following Hurricane Katrina in 2005. Addressing such issues through strategic resilience investments presents a host of inherently cross-sector and cross-segment challenges and requires concerted public private partnership to identify and remediate the lack of flexibility and adaptability within certain key infrastructure nodes.

The Current Costs of Power Disruptions

- ***A rolling blackout across Silicon Valley totaled $75 million in losses.***
- ***In 2000, the one-hour outage that hit the Chicago Board of Trade resulted in $20 trillion in trades delayed.***
- ***Sun Microsystems estimates that a blackout costs the company $1 million every minute.***
- ***The Northeast blackout of 2003 resulted in a $6 billion economic loss to the region.***

- U.S. Department of Energy

Even amid safeguards for routine risks, it remains an area of concern whether these drivers as currently understood by the industry partners are sufficient in today's word of non-linear and unpredictable risk. Prior historical experience, for example, is likely insufficient in terms of understanding the vulnerability of the system to targeted attacks – even if the current electrical system is reasonably secure against randomly generated failures occurring at random times and places it is still fragile in the sense that a targeted attack against a relative few key nodes could have significant disproportionate impact. This was the finding of *Modeling Cascading Failures in the North American Power Grid*, a 2006 study by researchers at Penn State University that concluded:

> *The North American power grid has been proven both theoretically and empirically to be highly robust to random failures. However, this research highlights the possible damage done to the network by a more targeted attack upon the few transmission substations with high between-*

7 American Society of Civil Engineers, "Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure", April 26, 2012, p.16.

8 The Galvin Electricity Initiative, *Id*.

9 Face the Facts USA Initiative, "A dramatic rise in power failures", August 19, 2012.

10 Thom Patterson, "U.S. electricity blackouts skyrocketing", *CNNTech*, October 15, 2010.

ness and high degree. Our results… suggest that even the loss of a single high-load and high-degree transmission substation reduces the efficiency of the power grid by 25%. This vulnerability at the transmission level deserves serious consideration by government and business officials so that cost effective counter measures can be developed.[11]

Unfortunately, the ill-defined roles and overlapping responsibilities for public, private and other parties mean that solutions to certain types of non-routine challenges fall into the gaps between segments and sectors. These include preparing for uncommon but highly consequential hazards, as well as addressing interdependencies that lie beyond anyone's specific remit but which, if left unaddressed, could lead to cascading failures across multiple critical infrastructure segments and sectors. Such areas of shared aggregate risk can be considered governance gaps in the sense that they occur where no specific entity has direct control over or responsibility to manage the shared and interconnected risks.

Significantly, these governance gaps are most prevalent regarding low probability, high consequence events. As a result, the electrical system tends to be resilient against high and even medium-likelihood events, but less prepared for the massive cascading effects that stem from the multi-faceted disruptions to workforce, supply chains, and electricity generation and delivery that would accompany certain low-likelihood but high consequence events such as massive earthquakes, nuclear or biological terrorism, or other catastrophic events. It is in addressing these types of events where the most significant of the governance gaps arise, for the private sector owners and operators of much of the nation's critical infrastructure, including the electrical grid, have less direct impetus to address these gaps than they do the more routine hazards.

Another significant gap is addressing so-called future risk, a notion that stems from the need to focus not only on linear historical patterns but also on changing trends, processes, and technologies that will affect interdependent critical infrastructure resiliency in unforeseen ways. This is crucial to address because long-term planning assumptions tend to be built around historical patterns, but these patterns may be very, very wrong as the evolving picture of future risk means the frequency or magnitude of outages changes sharply over time.

This type of risk is emerging as a major concern given that changing weather patterns are resulting in more and more days at the extreme ends of the temperature range and some of the underlying systems were not designed to operate under such conditions for prolonged periods. Another example of this type of future risk is the role of ubiquitous telecommunications in all of our lives and most or all business and government functions. With the extreme reliance upon electricity as a critical enabler of telecommunications the significance of any disruption increases, as evidenced by how firms relying on voice over internet protocol (VOIP) phones cannot use them if their access to the internet is down, or if the internet itself has disrupted service.

In dealing with such changes by looking to the future needs for a more resilient electrical power grid there are two key trends to consider: running at peak capacity, and costs today for savings and benefits tomorrow.

CAPACITY CONCERNS

As described by *National Geographic*, "In Canada and the U.S. the grid carries a million megawatts across tens of millions of miles of wire. It has been called the world's biggest machine."[12] And yet there is a significant and inexorable trend of operating at or near absolute peak capacity within the system as demand continues to grow more quickly than supply. This inherently raises the risk of more and larger blackouts, for each fault that occurs at or near the peak load by definition occurs when there is less slack in the system, and there is a decreasing amount of slack in the system overall. Specifically, each system operates under governance regimes that require excess capacity of 10-15% greater than the anticipated peak demand.

> ***The system tends to be less prepared for the massive cascading effects that stem from the multi-faceted disruptions to workforce, supply chains, and electricity generation and delivery that would accompany certain low-likelihood but high consequence events.***

Despite this, in some areas there is already a failure to meet those standards, and recent analysis suggests that Texas, in particular, will have a reserve margin of only

11 R. Kinney, P. Crucitti, R. Albert, V. Latora, (2005), Modeling Cascading Failures in the North American Power Grid, *Physics of Condensed Matter*, 46, 101-107.

12 Joel Achenbach, "The 21st Century Grid: Can we fix the infrastructure that powers our lives?", *National Geographic*, July 2010.

9.8% in 2014, 6.9% in 2015, and will exceed its capacity reserves by 2022.[13] Resolving the mismatch between peak demand and available capacity will require either additional power generation in terms of new or expanded power plants or better management of current usage levels by spreading out demand across non-peak hours – a main driver behind the ideas of the smart grid.

COSTS TODAY, BENEFITS TOMORROW

In terms of building in greater resilience through a smarter grid, there are significant costs, but also important gains, associated with a transition to many of these new technologies. The costs include the initial build-out of one or two-way communications devices within the existing footprint of the current electricity consumers. For example, while it can be shown that the labor savings enabled by remotely reading power meters will save tremendously on costs over time, physically replacing and connecting the new meters still involves a significant up-front cost, for it requires upgrading the current analog meters, which cost about $40 each, with newer digital and communications-enabled smart meters costing as much as $200. When this is multiplied across the many millions of household and business users the costs mount up quickly. Similarly, upgrading the readers will also require upgraded information systems to handle all the newly available data and to be able to remotely control various key parts of the system. Furthermore, the shift to a smart grid involves more than just infrastructure upgrades –it also means a need for large-scale retraining of the workforce to operate in a smart-device enabled environment.

On the other hand, smart grid benefits include not only gains from better managing daily use and reducing load on the system during peak capacity hours, but also determining when and where throughout the system a problem has occurred. This is because with real or near-real time monitoring of the system the ability to modulate the levels of electricity being generated and delivered will be much more precise. Furthermore, the smart grid will allow operators the ability to isolate discrete sub-sections of the grid which facilitates bringing back online those adjacent but unaffected areas that currently now get caught up in the less precise neighborhood or local area power shut-offs.

Another form of tangible savings comes from cost avoidance by circumventing the need to build additional infrastructure to service peak capacity that is used only on relatively rare occasions. This can be achieved by optimizing the management of electricity demand during peak periods, specifically by automatically communicating with industrial and household consumers so they can make more informed choices about their consumption relative to total demand on the system or even allowing power companies to control from afar such relatively minor aspects as a household's air conditioning or other major appliances. While this may seem trivial, the Department of Energy has noted, "10% of all generation assets and 25% of distribution infrastructure are required less than 400 hours per year, roughly 5% of the time. While smart grid approaches won't completely displace the need to build new infrastructure, they will enable new, more persistent forms of demand response that will succeed in deferring or avoiding some of it." These considerable savings therefore come not from decreasing the amount of total power created or by reducing the amount used, but rather from better managing the specific times that the amounts required are used.

Experts note a frighteningly steep increase in non-disaster-related outages affecting at least 50,000 customers.

CONCLUSION

As a nation, we will need to find better ways to manage these areas of shared responsibility stemming from current and future evolutions of the aggregate and shared risk picture. This requires finding solutions that blend broader risk management needs for a more resilient electrical grid with the private sector's ability to invest in ways that meet challenges effectively and efficiently. It also requires an open dialogue about the full costs and potential benefits of a more interactive and modernized smart grid that allows consumers to help by reducing demand during peak periods and provides deeper insights into the otherwise opaque real-world operating conditions of the grid itself. Ultimately these costs will be borne by the consumer, and yet individual consumers have a hard time recognizing the incrementally more resilient aspects of the system, such as the smarter grid that tracks faults and problems more accurately can enable better overall system management through increased situational awareness, enabling early and better intervention and reducing incidents.

13 "Texas power supply outlook worsens, grid says", Reuters, May 22, 2012.