Lexington Institute

Ensuring the Resilience of the U.S. Electrical Grid

Part III: Requirements For A More Resilient System

By Michael Barrett

November 2012

INTRODUCTION

Despite all the wondrous aspects of our electrical power grid and our increasing dependence upon it, for all too many of us it is essentially invisible, and as a result we take a properly functioning and secure grid for granted. This is true despite the fact that on any given day, some 500,000 Americans experience a power outage.[1]

Fortunately, most of these outages are brief and their occurrence is spread across the entire population, as opposed to being a chronic problem in any specific area. Indeed, with the possible exception of California during the late 1990s, multiple generations of Americans have never really had to contemplate life with prolonged periods of routine disruption and widespread service outages.

Nonetheless, the potential economic impacts of disruptions are already significant. According to the Galvin Electricity Initiative, annual interruptions to the electrical supply cost the nation an estimated $150 billion (see nearby table for industry-specific impacts).

Ensuring the Resilience of the U.S. Electrical Grid

Annual U.S. Power Disruption Costs by Industry[2]

Industry	*Average Cost of 1-Hour Interruption*
Cellular communications	*$41,000*
Telephone ticket sales	*$72,000*
Airline reservation system	*$90,000*
Semiconductor manufacturer	*$2,000,000*
Credit card operation	*$2,580,000*

At the same time, the steady and reliable flow of proper voltage and quantity of electricity is increasingly important as productivity in our professional and personal lives becomes ever more dependent upon sensitive computer chips and other devices with minimal tolerance for disruptions and power fluctuations. For example, the amount of the total electrical load used by devices with computer chip technologies was approximately 40% in 2011, and will be up to 60% by 2015.[3]

Furthermore, systemic risks to the nation's overtaxed electric grid continue to grow in size, scale and complexity. When one accounts for the central economic role but also the many various threats, hazards and concerns associated with protecting this sprawling, decentralized, and essential system it is clear that collective action to ensure the longevity and resilience of the electrical grid is in our best interests.

[1] Thom Patterson, "U.S. electricity blackouts skyrocketing", CNNTech, October 15, 2010.

[2] "The Electric Power System is Unreliable", Galvin Electricity Initiative.

[3] The Smart Grid: An Introduction, U.S. Department of Energy, Washington, DC, December 2008.

Whatshould that action look like, what forms should it take? Simply put, the two main aspects in assessing risk can be defined as the sum of the likelihood and severity of an adverse event. It therefore follows that the best means of reducing risk is to take steps that either reduce the likelihood of an event or that reduce the severity should an event occur. This corresponds to the following practical recommendations, each of which individually and in concert contribute to a more resilient electrical power system.

REDUCING THE LIKELIHOOD OF DISRUPTIONS

Among the grid's three primary components (i.e., generation, transmission, and distribution), it is the local distribution segment where most disruptions typically occur. This is in part because federal regulatory requirements ensure that the generation capacity includes not only enough to meet peak demand but also a 10-15% reserve, which is generally sufficient to avoid disruption within generation, and the long haul transmission lines are also strongly regulated and generally well maintained. It is the more localized distribution systems that tend to cause the problems. This can include downed power lines, transformer malfunctions, and underground equipment failures.[4]

The primary set of preventive measures includes two main categories, routine repairs and use of "tripwires", as described below:

Effects of Electricity Interruption on U.S. GDP and Jobs 2012-2020[5]		
	Average Annual Impacts	*Cumulative Losses*
Gross Domestic Product	*-$55B*	*-$496B*
Jobs	*-$461,000*	*NA*
Business Sales	*-$94B*	*-$847B*
Disposable Personal Income	*-$73B*	*-$656B*

Note: Losses in business sales and GDP reflect impacts in a given year against total national business sales and GDP in that year. These measures do not indicate declines from 2010 levels.
Sources: EDR Group and LIFT model, University of Maryland, INFORUM Group, 2012.

Fully funding routine maintenance and timely repairs and replacements of parts across the system. Preventive maintenance and clearing of debris and growing trees are critical aspects of risk management for nearly all infrastructure and electrical power grids are no exception. However, in practice the power companies face a number of challenges from federal, state and local rules and regulations. For example, while the need to ensure worn out parts are replaced quickly and that trees and other natural obstacles are kept clear of the power lines is well documented, the ability to conduct these and other reasonable preventive activities often is limited because of resource constraints and legal challenges based on right-of-way and potential environmental impacts. Sadly, these real-world obstacles can complicate or delay basic maintenance and upgrade activities and pave the way for massive infrastructure failures and cascading negative effects.

Nonetheless, such impediments must be addressed because routine investments in preventive measures can help minimize or avoid events and in turn save orders of magnitude of costs by preventing events from coming to pass. For example, the cost versus benefit of routine maintenance and clearing lines can be seen quite dramatically from the case of the 2003 Northeast Power blackout – North America's worst ever such event – which was initiated by high voltage lines brushing against overgrown tree limbs in Ohio and ended up affecting some 50 million people and causing losses in excess of $6 billion. Similar right-of-way disputes complicate the already arduous task of maintaining hundreds and hundreds of miles of infrastructures and impede routine maintenance across the system, causing delays and missed opportunities for cost-effective pre-event risk mitigation.

Building in systematic circuit-breaker tripwires that will temporarily shut down a portion of the system whenever a given safe operating range of temperature or some other defined variable is exceeded is another important means to reduce the likelihood of disruptions. While the grid does currently have circuit breakers at some substations there are also many fuses that, unlike circuit-breakers, must be replaced in order to restore the flow of power. In a period of volatile environmental factors and changing usage patterns the lack of more easily reset circuit-breakers is a major shortcoming because we need an approach that is more flexible.

[4] American Society of Civil Engineers, pp. 32-34.

[5] American Society of Civil Engineers, "Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure", April 26, 2012, p.9.

For example, it may be necessary to isolate entire segments of the grid to prevent troubled areas from taking the rest of the regional grid with them when they falter. The ability to quickly restore functionality once the anomaly passes is also vital. This level of insight requires us to gain better knowledge of routine operations and deviations from typical usage patterns. Fortunately, we are headed in the right direction because these are precisely the objectives of many aspects of the Smart Grid. Real-time, two-way communication of specific usage data will enable many more detailed measurements of various operating conditions and enable the operators of the power grid to safely quarantine malfunctioning parts before their impacts can cascade across the rest of the system.

Resilience is the ability to avoid or absorb impacts while continuing or rapidly resuming operations at an acceptable level.

MINIMIZING IMPACTS – FIVE STRATEGIES

Regardless of how many preventive steps are taken or how well they are implemented, the reality of operating such a complex and broad-based system in a dynamic technological age means that inevitably there will be disruptions and outages, be the cause human error, technological failure, criminal or terrorist act, or simply an act of nature. Therefore the second critical aspect of reducing overall risk and promoting resilience involves a focus on five main areas: redundancy, safety stocks of spare parts, substitute systems, the ability to manage or shift demand, and ensuring that alternative production facilities are available in unaffected sectors of the grid.

- The first approach, redundancy, is often the most expensive and is only used sparingly because the investment in and upkeep of excess capacity runs counter to the private sector's chronic operational cost cutting imperative to more efficiently manage the balance between demand and supply of everything from raw inputs to spare parts and power generation, transmission and delivery. Nonetheless, ensuring a certain excess capacity of redundant capability is appropriate for a few select items where repair is exceedingly difficult and/or a failure would have such a large impact as to render it unacceptable. Indeed, in terms of generation capacity the system has a significant amount of required redundancy in that the operators are generally required to maintain a capacity of 115% of their peak demand requirements, providing a 15% cushion, albeit at an extraordinary cost relative to the more routinely used base load generation.

- A related issue is the movement towards sufficient safety stocks of spare parts. This includes interchangeable parts and standardized designs that can be replaced in whole or as separate modules serving discrete purposes, and also standardizing the interfaces of everything from physical gaskets and valves to interoperable control systems and computers using seamlessly integrated enterprise software systems. The efficiency gains from standardized parts that are interchangeable come from having many fewer parts in inventory and also being able to quickly replace part or all of a damaged system with equivalent "off-the-shelf" as opposed to specially designed parts. This approach applies to many modern industries but was not a feature of the original designs of the decentralized power grid infrastructure, which means there is a great variance among the sizes, power requirements, weight, and other characteristics of many critical generation, transmission and distribution parts. More uniformity would enable cost-effective solutions because instead of having in place fully redundant capacities that go unused day to day this approach relies on standardizing select equipment and infrastructure and the storage of some interchangeable spare parts. An added benefit of this approach would enable stockpiles of spares to be shared across regions, and across firms, to more broadly spread out the cost of buying and storing them.

- The third significant approach to resilience is to identify substitute systems that can be used in the event of a disruption affecting the primary system. For a typical user this generally means ensuring access to a proper sized generator and sufficient amounts of fuel to operate it to run at least your most critical systems for a prolonged period without having to rely upon the grid. Another example of substitute systems on a larger scale would be finding ways to physically connect the flow of power among and across the four essentially separate regional power grids servicing North America. For example, the proposed Tres Amigas project in eastern New Mexico would share generated power across a large loop of multi-gigawatt-capacity superconducting cable for the Eastern, Western and

Texas interconnections to allow the excess capacity within one system to flow to the affected system.

- Fourth, shifting the timing of household electricity use is an effective way to reduce the demands upon an impacted system. For example, automatic messages sent to many thousands of users during critical peak periods could enable them to voluntarily reduce their usage by delaying the use of laundry machines or dishwashers and raising or lowering the thermostat a degree or two. Dynamic pricing models offer incentives for non-peak energy use. While the impact to each user would be minimal, the overall aggregate demand reduction could enable the entire system to meet total need without requiring additional generation capacity. In severely impacted areas such techniques as scheduled rolling black-outs could be used. Because such decisions will hold drastic impacts for consumers and other stakeholders, processes for involving them in deliberative processes will be necessary.

- Finally, significant resilience gains could be realized by managing industrial demand by shifting to alternative industrial production facilities located in unaffected regions of the grid. This would require a level of redundant production capacity that is not consonant with current standards for lean manufacturing and just-in-time delivery. Should an event as large and severe as Hurricanes Katrina and Sandy happen again, such an approach could reduce overall demand to a level that the impacted system, though impaired, can meet.

  In practice this would require implementing tax incentives and other cost-saving measures that would help ensure that energy intensive and/or critical goods industries have geographically disparate production facilities.

  While strategically desirable, such moves would not only carry major associated costs, but with substantial numbers of jobs connected to these facilities, their impacts on communities that include tax bases, schools and even voting patterns could be substantial. This would create further social and political concerns. Ideally, this approach could be used on a purely voluntary and organized basis that includes thorough cost-benefit analyses and development of a true public-private partnership. Although, inherent complications of addressing national priorities through both local politics and state regulatory infrastructures must be expected.

CONCLUSION

The above examples of specific tools and means of achieving greater resilience could significantly improve our national power grid and the economic prospects dependent upon it. However, in the real world there are important trade-offs that must be made that present challenges for regulators. For example, keeping consumer costs as low as possible versus relaxing the controls on the price of electricity to allow for higher returns that can fund modernization and spare capacity, while maintaining pricing that does not require consumers in one jurisdiction to subsidize those in another. The use of price ceilings and caps on what utilities can charge is a double-edged sword in this regard because it both protects today's consumers from volatile and increasing prices and also stifles the free market's ability to fully invest in decades-long infrastructure improvement projects because costs may not be able to be recouped and therefore returns are uncertain.

While there are no easy answers or painless trade-offs, these are significant public policy issues that need to be addressed in advance of an adverse event because, importantly, the cost of taking these measures pre-event is significantly less than suffering a major systemic collapse. In this manner, additional resilience is like a form of insurance because it involves a small, consistent payment that defrays the potential impacts of an adverse event. And, as with insurance, if you wait to invest until the day you really need the protection you have waited too long.