Turning the Tide on Outages[1]

What are the true costs of implementing — or failing to implement — a stronger, smarter and more robust grid

Approaching a month during which the nation will observe the 8th anniversary of the August 2003 Blackout (over 50 million consumers affected and more than $6 billions in losses), the 6th anniversary of Hurricane Katrina (more than 1800 deaths and over $150 billion in economic losses), and the August 1, 2007 collapse of the I-35W bridge in Minneapolis (killing 13 and disrupting traffic and the local economy for a year), in addition to the hundreds of black-outs, water main breaks and daily traffic gridlocks, have stimulated growing public awareness of the necessity for accelerated programs of replacement, rehabilitation and new investment in the U.S. infrastructure.

Focusing on the electric power sector, the power outages and power quality disturbances cost the U.S. economy over $80 billion annually, and up to $188 billion per year. Transmission and distribution losses in the U.S. were about 5% in 1970, and grew to 9.5% in 2001, due to heavier utilization and more frequent congestion. Regarding the former, starting in 1995, the amortization/ depreciation rate exceeded utility construction expenditures. Since that crossover point in 1995, utility construction expenditures have lagged behind asset depreciation. This has resulted in a mode of operation of the system that is analogous to harvesting more rapidly than planting replacement seeds. As a result of these diminished “shock absorbers,” the electric grid is becoming increasingly stressed, and whether the carrying capacity or safety margin will exist to support anticipated demand is in question.

To assess impacts using actual electric power outage data for the U.S., which are generally available from several sources, including from the U.S. DOE’s Energy Information Administration (EIA) and the from the North American Electric Reliability Corporation (NERC). In general, the EIA database contains more events, and the NERC database gives more information about the events. Both databases are extremely valuable sources of information and insight. In both databases, a report of a single event may be missing certain data elements such as the amount of load dropped or the number of customers affected. In the NERC database, the amount of load dropped is given for the majority of the reported events, whereas the number of customers affected is given for less than half the reported events.

Analyses of these data collected revealed that in the period from 1991 to 2000, there were 76 outages of 100 MW or more in the second half of the decade, compared to 66 such occurrences in the first half (Figure 1).

Furthermore, there were 41% more outages affecting 50,000 or more consumers in the second half of the 1990s than in the first half (58 outages in 1996–2000 versus 41 outages in 1991–1995). In addition, between 1996 and 2000, outages affected 15% more consumers than they did between 1991 and 1995 (the average size per event was 409,854 customers affected in the second half of the decade versus 355,204 in the first half of the decade). Similar results were determined for a multitude of additional statistics such as the kilowatt magnitude of the outage, average load lost, etc. These trends have persisted in this decade. NERC data show that during 2001-2005 we had 140 occurrences of over 100 MW dropped, and 92 occurrences of over 50,000 or more consumers affected.

---

[1] Massoud Amin *is leading extensive R&D efforts in smart grids and infrastructure security and is* a leading expert on the U.S. electricity grid. *Before becoming the Honeywell/H.W. Sweatt Chair in Technological Leadership, a professor of Electrical and Computer Engineering, and a University Distinguished Professor at the University of Minnesota, he directed all Infrastructure Security, Grid Operations/Planning, and Energy Markets at the Electric Power Research Institute (EPRI) after 9/11. Prior to that he led mathematics and information sciences at EPRI, worked on self-repairing energy infrastructures, coined the term "smart grid" in 1998, considered as the "father of smart grid," and led the development of over 24 technologies transferred to industry.*

The U.S. electrical grid has been plagued by ever more and ever worse blackouts over the past 15 years. In an average year, outages total 92 minutes per year in the Midwest and 214 minutes in the Northeast. Japan, by contrast, averages only 4 minutes of interrupted service each year. The outage data excludes interruptions caused by extraordinary events such as fires or extreme weather.

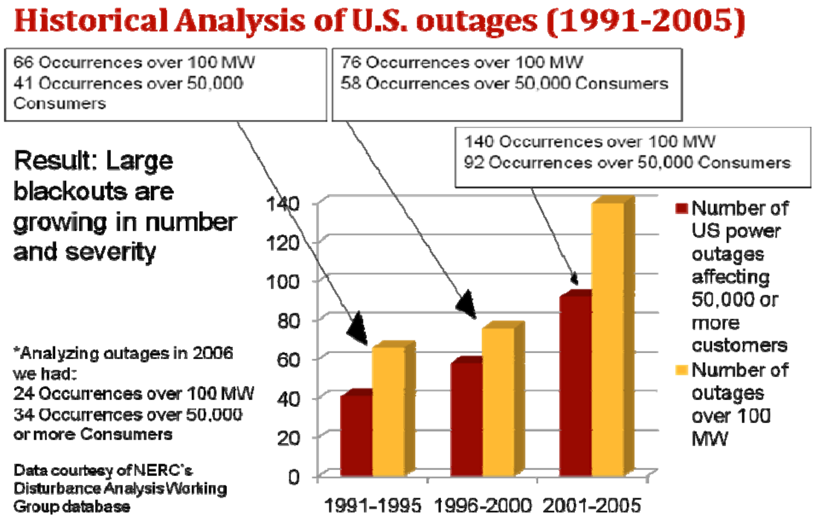

Figure 1: U.S. Electric Power Outages over 100MW and affecting over 50,000 Consumers (1991-2005)

I analyzed two sets of data, one from the U.S. Department of Energy's Energy Information Administration (EIA) and the other from the North American Electric Reliability Corp. (NERC). Generally, the EIA database contains more events, and the NERC database gives more information about the events, including the date and time of an outage, the utility involved, the region affected, the quantity of load dropped, the number of customers affected, the duration of the outage, and some information about the nature of the event.

These two data sets each contain events not listed in the other data set. In general, the EIA database contains more events, and the NERC database gives more information about the events. The narrative data in the NERC (and also the EIA) databases are sufficient to identify factors such as equipment failure or severe weather (or a combination of both!) that may have contributed to an outage. Establishment of precise cause is beyond the scope of most of the narratives. Both databases are extremely valuable sources of information and insight.

In both databases, a report of a single event may be missing certain data elements such as the amount of load dropped or the number of customers affected. In the NERC database, the amount of load dropped is given for the majority of the reported events, whereas the number of customers affected is given for less than half the reported events.

In the EIA database, the number of customers affected is reported more frequently than the amount of load dropped.

In both sets, each five-year period was worse than the preceding one: According to data assembled by the U.S. Energy Information Administration (EIA) for most of the past decade, there were 156 outages of 100 megawatts or more during 2000-2004; such outages increased to 264 during 2005-2009. The number of U.S. power outages affecting 50,000 or more consumers increased from 149 during 2000-2004 to 349 during 2005-2009, according to EIA (Figure 2):

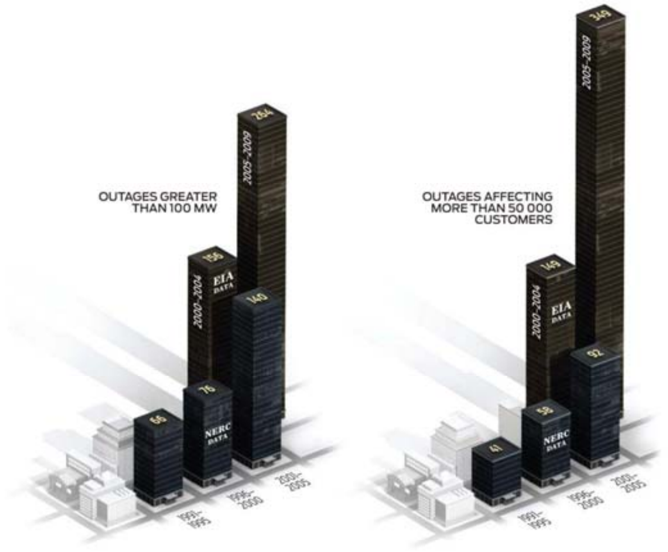

Figure 2: Power Outages have steadily increased[2 3] in the most recent decade

In 2003 EIA changed their reporting form from EIA-417R to OE-417. Both forms were attached with descriptions of reporting requirements (page 3 and page 6 respectively). In all, the reporting requirements are very similar, with OE-417 being a little more stringent. The main change in the requirement affecting the above figures is that all outages greater than 50,000 customers for 1 hour or more be reported in OE-417, where it was only required for 3 hours or more in EIA-417R prior to 2003. Adjusting for the change in reporting in 2003 (using all the data from 2000-2009 and only counting the outages that met the less stringent requirements of the EIA-417R form used from 2000-2002): There were 152 outages of 100 megawatts or more during 2000-2004; such outages increased to 248 during 2005-2009. The number of U.S. power outages affecting 50,000 or more consumers increased from 130 during 2000-2004 to 272 during 2005-2009 (Figure 3):

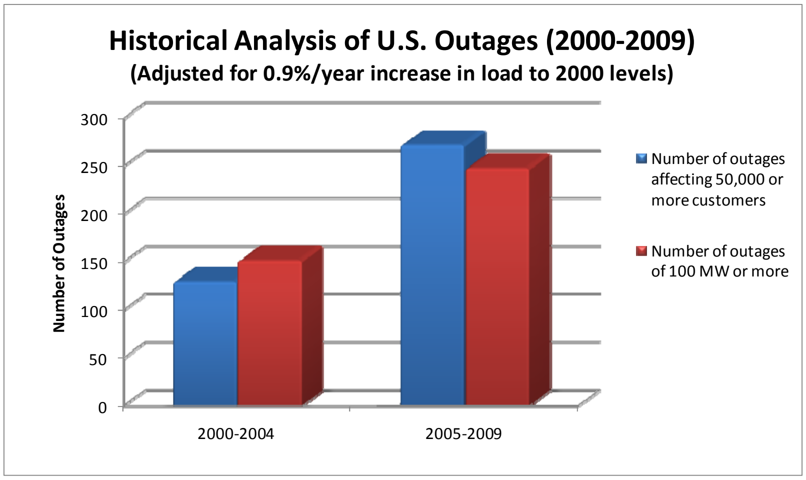

Figure 3: U.S. Electric Power Outages over 100MW and affecting over 50,000 Consumers during 2000-2009, adjusted for 0.9% annual increase in load and adjusted for change in reporting in 2003 (using all the data from 2000-2009 and only counting the outages that met the less stringent requirements of the EIA-417R form used during 2000-2002)

---

[2] Source: Amin, M. "U.S. Electrical Grid Gets Less Reliable," IEEE Spectrum, January 2011, and online at http://spectrum.ieee.org/energy/policy/us-electrical-grid-gets-less-reliable

[3] Research is supported by a grant from the NSF and a contract with SNL. For preparations of Figures 3, I gratefully acknowledge Mr. Anthony Giacomoni, my Graduate Research Assistant, in the department of Electrical & Computer Engineering at the UofM Twin Cities.

In summary the number of outages adjusted for 0.9% annual increase in load and adjusted for change in reporting in 2003 is:

	Occurrences of 100MW or more	Occurrences of 50,000 or more consumers
2000-2004	152	130
2005-2009	248	272

As an energy professional and electrical engineer, I cannot imagine how anyone could believe that in the United States we should learn to “cope” with these increasing blackouts— and that we don’t have the technical know-how, the political will, or the money to bring our power grid up to 21st century standards. Coping as a primary strategy is ultimately defeatist. We absolutely can meet the needs of a pervasively digital society that relies on microprocessor-based devices in vehicles, homes, offices, and industrial facilities. And it is not just a matter of “can.” We must—if the United States is to continue to be an economic power. However, it will not be easy or cheap.

Costs/benefits of full deployment of smart grids[4]

In a recent nation-wide survey, most of consumers in the U.S. (~68%) didn't know what "Smart Grid," meant. We must assess and clearly articulate:

1) what is the "Smart Grid" or what will it do for consumers?

2) what are the costs/benefits and range of new consumer-centered services enabled by smart grids? What is the smart grid’s potential to drive economic growth?

Regarding the first question... *So what is the smart self-healing grid?*

Here are the definitions for the smart "self-healing" grid, which I proposed and have utilized in all pertinent projects while at EPRI and beyond since January 1998:

- The term “smart grid” refers to the use of computer, communication, sensing and control technology which operates in parallel with an electric power grid for the purpose of enhancing the reliability of electric power delivery, minimizing the cost of electric energy to consumers, improving security, quality, resilience, robustness, and facilitating the interconnection of new generating sources to the grid.

- A system that uses information, sensing, control and communication technologies to allow it to deal with unforeseen events and minimize their adverse impact. It is a secure "architected" sensing, communications, automation/control, and energy overlaid infrastructure as an integrated,

---

[4] Earlier versions of this draft are published at:

1. GreenTech Media, Smart Grid Research & Analysis, September 29, 2010: "Turning the Tide on Outages: What are the true costs of implementing—or failing to implement—a stronger, smarter and more robust grid, asks Massoud Amin" http://www.greentechmedia.com/articles/read/turning-the-the-tide-on-outages/
2. University of Minnesota News, October 4, 2010: "A smarter way of looking at power, U professor advocates for "smart self-healing grid" to boost U.S. energy security," http://www1.umn.edu/news/features/2010/UR_CONTENT_256684.html
3. Connected Planet, October 7, 2010: "The Rising Tide of Outages: Moving toward a greener, more resilient North American Smart Grid" http://connectedplanetonline.com/topics/smart-grids/the-rising-tide-of-outages-1007/
4. October 8, 2010: The Rising Tide of Power Outages and the Need for a Stronger and Smarter Grid at http://tli.umn.edu/blog/
5. The Economist, January 10, 2011: The Ideas Economy: http://ideas.economist.com/blog/us-electric-grid-gets-less-reliable
6. Amin, M. “U.S. Electrical Grid Gets Less Reliable," IEEE Spectrum, January 2011, and online at http://spectrum.ieee.org/energy/policy/us-electrical-grid-gets-less-reliable

> reconfigurable, and electronically controlled system that will offer unprecedented flexibility and functionality, and improve system availability, security, quality, resilience and robustness.

The concept of smart grids, pertinent R&D programs aimed at developing self-healing grids, and the associated terminology, date back to 1990s. Of particular interest is a large-scale research program conducted jointly by the Electric Power Research Institute (EPRI) and the U.S. Department of Defense (DOD) during 1998 – 2002, titled Complex Interactive Networks/ Systems Initiative (CIN/SI). 108 professors and over 240 graduate students in 28 U.S. universities participated, along with 52 utilities and grid operators. Several leading controls researchers led and/or participated in project teams. This work provided the mathematical foundations and simulations for the smart self-healing grid and showed that the grid can be operated close to the limit of stability given adequate situational awareness combined with better secure communication and controls.

Since then, there have been several convergent definitions of "smart grids", including within the 2007 Energy Bill, along with informative reports by EPRI (1998-present), NIST and U.S. DOE (2007-2010), and definitions by the IEEE, FERC, GE and Wikipedia. Many define "Smart Grid" in terms of its functionalities and performance objectives (e.g., two-way communications, interconnectivity renewable integration, demand response, efficiency, reliability, self-healing, etc.).

There are many definitions, but there is one vision of a highly instrumented overlaid system with advanced sensors and computing with the use of enabling platforms and technologies for secure sensing, communications, automation and controls as keys to: 1) engage consumers, 2) enhance efficiency, 3) ensure reliability, 4) enable integration of renewables and electric transportation.

Recent policies in the U.S., China, India, EU, and other nations, combined with potential for technological innovations and business opportunities, have attracted a high level of interest in smart grids. Smart grids are seen as a fundamentally transformative, global imperative for helping the planet deal with its energy and environmental challenges. The ultimate goal is for an end-to-end electric power system (from fuel source, to generation, transmission, distribution, and end use) that will:

- Allow secure and real-time 2-way power and information flows
- Enable integration of intermittent renewable energy sources and help decarbonize power systems
- Enable energy efficiency, effective demand management, and customer choice
- Enable the secure collection and communication of detailed data regarding energy usage to help reduce demand and increase efficiency.

In 2007, the United States Congress passed the Energy Independence and Security Act outlining specific goals for the development of the nation’s smart grid. Section 1301 of this Act states that, “It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid:

1. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
2. Dynamic optimization of grid operations and resources, with full cyber-security…”

Smart Grid is a concept and a range of functionalities: It is designed to be inherently flexible, accommodating a variety of energy production sources and adapting to and incorporating new technologies as they are developed. It allows for charging variable rates for energy, based upon supply and demand at the time. In theory, this will incentivize consumers to shift their heavy uses of electricity (such as for heavy-duty appliances or processes that are less time-sensitive) to times of the day when demand is low (called peak shaving or load leveling). As an example of these range of functionalities, in 2008, U.S. Department of Energy (DOE) defined functions of a smart grid as:

- "Self-healing" from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attacks
- Providing power quality for 21st century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently.

Smart grid conceptualization and development is occurring internationally. Some information for activities in the EU and in China, for example, is available at http://www.smartgrids.eu/ and http://www.juccce.com/program_events/juccce_china_smart_grid_cooperative respectively.

Regarding the second set of questions... *what are the costs/benefits and range of new consumer-centered services enabled by smart grids? What is the smart grid's potential to drive economic growth?*
To begin addressing these, the costs of full implementation for a nationwide Smart Grid range over a 20-year period (2010-2030):

- According to energy consulting firm Brattle Group, the necessary investment to achieve an overhaul of the entire electricity infrastructure and a smart grid is $1.5 trillion spread over 20 years (~$75 billion/year), incl. new generators and power delivery systems.

- A detailed study by the Electric Power Research Institute (EPRI) published in April 2011, finds that that the estimated *net* investment needed to realize the envisioned power delivery system of the future is between $338 and $476 billion. The new estimates translate into annual investment levels of between $17 and $24 billion over the next 20 years.

  The costs cover a wide variety of enhancements to bring the power delivery system to the performance levels required for a smart grid. They include the infrastructure to integrate distributed energy resources and achieve full customer connectivity but exclude the cost of generation, the cost of transmission expansion to add renewables and to meet load growth and a category of customer costs for smart-grid-ready appliances and devices.

Despite the costs of implementation, investing in the grid would pay for itself, to a great extent. Integration of the Smart Grid will result in:

1) Costs of outages reduced by about $49B per year,

2) Increased efficiency and reduced emissions by 12-18% per year (PNNL report, January 2010),

3) A greater than 4% reduction in energy use by 2030; translating into $20.4 billion in savings,

4) More efficient to move electrical power through the transmission system than to ship fuels the same distance. From an overall system's perspective, with goals of increased efficiency, sustainability, reliability, security and resilience, we need both:

- Local microgrids (that can be as self-sufficient as possible and island rapidly during emergencies), and
- Interconnected, smarter and stronger power grid backbone that can efficiently integrate intermittent sources, and to provide power for end-to-end electrification of transportation.

5) Reduction in the cost of infrastructure expansion and overhaul in response to annual peaks. The demand response and smart grid applications could reduce these costs significantly.

6) The benefit-to-cost ratios are found to range from 2.8 to 6.0. Thus, the smart gird definition used as the basis for the study could have been even wider, and yet benefits of building a smart grid still would exceed costs by a healthy margin. By enhancing efficiency, for example, the smart grid could reduce 2030 overall CO2 emissions from the electric sector by 58 percent, relative to 2005 emissions.

7) Increased cyber/IT security, and overall energy security, if security is built in the design as part of a layered defense system architecture.

8) Electricity's unique capability to be produced from a wide variety of local energy sources, along with its precision, cleanliness, and efficiency, make it the ideal energy carrier for economic and social development.

From a broader perspective, in a single century, electricity became the foundation and prime mover of our modern society. Not just as a clean and convenient form of energy, but as the toolmaker's dream. Electricity opened the doors of invention to new technologies of incredible precision, intelligence and communication, and to new forms of instrumentation and innovation.

In addition, as noted earlier, the current high-voltage system needs to be expanded and strengthened (U.S. DOE National Electric Transmission Congestion Study, AEP HV transmission assessment for wind integration, and EPRI assessments 2003-2009). The total cost of the expanded transmission system is about $82 billion.

On options and pathways forward, I am often asked **"should we have a high-voltage power grid or go for a totally distributed generation, for example with microgrids?"** We need both, as the "choice" in the question poses a false dichotomy. It is not a matter of "this OR that" but it is an "AND." To elaborate briefly, from an overall energy system's perspective (with goals of efficiency, eco-friendly, reliability, security and resilience) we need both 1) microgrids (that can be as efficient and self-sufficient as possible, and to island rapidly during emergencies), AND we need 2) a stronger and smarter power grid as a backbone to efficiently integrate intermittent renewable sources into the overall system.

A key challenge before us is whether the electricity infrastructure which underpins our economy, society, and quality-of-life, will evolve to become the primary support for the 21st century's digital society— a smart grid with self-healing capabilities — that powers our innovation and economy or be left behind as an 20th century industrial relic? and finally: What are the costs of not implementing change?

We must modernize the electric power infrastructure, and evolve it into a smarter, stronger, more secure and more resilient system. Electricity is the lynchpin and enabling infrastructure for all knowledge- and innovation-based economies. Our $14 trillion economy—all aspects of it—depends on reliable, disturbance-free access to electricity.

Appendix: Background

Where are we and how did we get here?

The existing electricity infrastructure evolved to its technology composition today from the convolution of several major forces, only one of which is technologically based. Today opportunities and challenges persist in world-wide electric power networks, these include: Reducing transmission congestion, increasing system/cyber security, increasing overall system and end-use efficiency while maintaining reliability -- many other challenges engage those who plan for the future of the power grid: producing power in a sustainable manner (embracing renewable fuels while accounting for their scalability limitations, e.g. increased use of land and natural resources to produce higher renewable electricity will not be sustainable, thus not being able to lower emissions from existing generators), delivering electricity to those who don't have it (not just on the basis of fairness but also because electricity is the most efficient form of energy, especially for things like lighting), and using electricity more wisely as a tool of economic development, and pondering the possible revival of advanced nuclear reactor construction. To prepare for a more efficient, resilient, secure and sustainable electrical system it is helpful to remember the historical context, associated pinch-points and forcing functions:

The trends of worldwide electrical grid deployment, costing trillions of dollars and reaching billions of people, began very humbly. Some obvious electrical and magnetic properties were known in antiquity. In the 17th and 18th centuries, partially through scientific experiments and partially through parlor games, more was learned about how electric charge is conducted and stored. But only in the 19th century, with the creation of powerful batteries, and through insights about the relations between electric and magnetic force could electricity in wires service large scale industries---first the telegraph and then telephones.

And only in the 1880s did the first grids come into being for bringing electrical energy to a variety of customers for a variety of uses, at first mostly for illumination but later for turning power machines and moving trolley cars. The most important of these early grids, the first established big city grid in North America, was the network built by Thomas Edison in lower Manhattan. From its power station on Pearl Street, practically in the shadow of the Brooklyn Bridge, Edison's company supplied hundreds and then thousands of customers. Shortly thereafter, Edison's patented devices, and those of his competitors---devices such as bulbs, generators, switching devices, generators, and motors---were in use in new grids in towns all over the industrialized world.

From a historical perspective the electric power system in the U.S. evolved in the first half of the 20th century without a clear awareness and analysis of the system-wide implications of its evolution. In 1940, 10% of the energy consumption in America was used to produce electricity. By 1970, this had risen to 25%, and by 2002 it had risen to 40%. (Worldwide, current electricity production is near 15,000 billion Kilowatt-hours per year, with The United States, Canada, and Mexico responsible for about 30% of this consumption.) This grid now underlies every aspect of our economy and society, and it has been hailed by the National Academy of Engineering as the 20th century's engineering innovation most beneficial to our civilization. The role of electric power has grown steadily in both scope and importance during this time and electricity is increasingly recognized as a key to societal progress throughout the world, driving economic prosperity, security and improving the quality of life. Still it is noteworthy that at the time of this writing there are about 1.4 billion people in the world with no access to electricity, and another 1.2 billion people have inadequate access to electricity (meaning that they experience outages of 4 hours or longer per day).

Once "loosely" interconnected networks of largely local systems, electric power grids increasingly host large-scale, long-distance wheeling (movement of wholesale power) from one region or company to another. Likewise, the connection of distributed resources, primarily small generators at the moment, is growing rapidly. The extent of interconnectedness, like the number of sources, controls, and loads, has grown with time. In terms of the sheer number of nodes, as well as the variety of sources, controls, and loads, electric power grids are among the most complex networks made.

In the coming decades, electricity's share of total energy is expected to continue to grow, as more efficient and intelligent processes are introduced into this network. Electric power is expected to be the fastest-growing source of end-use energy supply throughout the world. To meet global power projections, it is estimated by the U.S. DOE/EIA that over $1 trillion will have to be spent during the next 10 years. The electric power industry has undergone a substantial degree of privatization in a number of countries over the past few years. Power generation growth is expected to be particularly strong in the rapidly growing economies of Asia, with China leading the way.

The electric power grid's emerging issues include creating distributed management through using distributed intelligence and sensing; integration of renewable resources; use of active-control high-voltage devices; developing new business strategies for a deregulated energy market; and ensuring system stability, reliability, robustness, and efficiency in a competitive marketplace and carbon-constrained world.

In addition, the electricity grid faces (at least) three looming challenges: its organization, its technical ability to meet 25 year and 50 year electricity needs, and its ability to increase its efficiency without diminishing its reliability and security.

As an example of historical bifurcation points, the 1965 Northeast blackout not only brought the lights down, it also marked a turn in grid history. The previous economy of scale, according to which larger generators were always more efficient than small machines, no longer seemed to be the only risk-managed option. In addition, in the 1970s two political crises---the Mideast war of 1973 and the Iranian Revolution in 1979 -- led to a crisis in fuel prices and a related jump in electric rates. For the first time in decades, demand for electricity stopped growing. Moreover, the prospects of power from nuclear reactors, once so promising, were now under public resistance and the resultant policy threats. Accidents at Brown's Ferry, Alabama in 1974 and Three Mile Island, Pennsylvania in 1979, and rapidly escalating construction costs caused a drastic turnaround in orders for new facilities. Some nuclear plants already under construction were abandoned.

In the search for a new course of action, conservation (using less energy) and efficiency measures (to use available energy more wisely) were put into place. Electrical appliances were re-engineered to use less power. For example, while on the average today's refrigerators are about 20% larger than those made 30 years ago, they use less than half the electricity of older models. Furthermore, the Public Utility Regulatory Policy Act (PURPA) of 1978 stipulated that the main utilities were required to buy the power produced by certain independent companies which co-generated electricity and heat with great efficiency, providing the cost of the electricity was less than the cost it would take the utilities to make it for their own use.

What had been intended as an effort to promote energy efficiency, turned out, in the course of the 1980s and 1990s, to be a major instigator of change in the power industry as a whole. First, the independent power producers increased in size and in number. Then they won the right to sell power not only to the neighboring utility but also to other utilities further away, often over transmission lines owned by still other companies. With the encouragement of the Federal Energy Regulatory Commission (FERC), utilities began to sell off their own generators. Gradually the grid business, which for so long had operated under considerable government guidelines since so many utilities were effective monopolies, became a confusing mixture of regulated and unregulated companies.

Opening up the power industry to independent operators, a business reformation underway for some years in places like Chile, Australia, and Britain (where the power denationalization process was referred to as "liberalization"), proved to be a bumpy road in the US. For example, in 2001 in the state of California the effort to remove government regulations from the sale of electricity, even at the retail level, had to be rescinded in the face of huge fluctuations in electric rates, rolling blackouts, and amid allegations of price-fixing among power suppliers. Later that year, Enron, a company that had grown immense through its pioneering ventures in energy trading and providing energy services in the new freed-up wholesale power market, declared bankruptcy.

Restructuring of the US power grid continues. Several states have put deregulation into effect in a variety of ways. New technology has helped to bring down costs and to address the need for reducing emission of greenhouse gases during the process of generating electricity. Examples include high-efficiency gas turbines, integrated “microgrids” of small generators (sometimes in the form of solar cells or fuel cells), and a greater use of wind turbines.

Much of the interest in restructuring has centered around the generation part of the power business and less on expanding the transmission grid itself. About twenty-five years ago, the generation capacity margin, the ability to meet peak demand, was between 25 to 30 percent-- it has now reduced to less than half and is currently at about 10-15%. These “shock absorbers” have been shrinking; e.g., during the 1990s actual demand in the U.S. increased some 35%, while transmission capacity has increased only 18%. In the current decade, the demand is expected to grow about 20%, with new transmission capacity lagging behind at under 4% growth.

In the past, extra generation capacity served to reduce the risk of generation shortages in case equipment failed and had to be taken out of production, or in case there was an unusually high demand for power, such as on very hot or cold days. As a result capacity margins, both for generation and transmission, are shrinking. Other changes add to the pressure on the national power infrastructure as well. Increasing inter-regional bulk power transactions strain grid capacity. New environmental considerations, energy conservation efforts, and cost competition require greater efficiency throughout the grid.

As a result of these “diminished shock absorbers,” the network is becoming increasingly stressed, and whether the carrying capacity or safety margin will exist to support anticipated demand is in question. The most visible parts of a larger and growing US energy crisis that is the result of years of inadequate investments in the infrastructure. The reason for this neglect is caused partly by uncertainties over what government regulators will do next and what investors will do next.

Growth, environmental issues, and other factors contribute to the difficult challenge of ensuring infrastructure adequacy and security. Not only are infrastructures becoming more complexly interwoven and more difficult to comprehend and control, there is less investment available to support their development. Investment is down in many industries. For the power industry, direct infrastructure investment has declined in an environment of regulatory uncertainty due to deregulation, and infrastructure R&D funding has declined in an environment of increased competition because of restructuring. Electricity investment was not large to begin with. Presently the power industry spends a smaller proportion of annual sales on R&D than do the dog foods, leather, insurance, or many other industries—less than 0.3 percent, or about $600 million per year.

Most industry observers recognize this shortage of transmission capability, and indeed many of the large blackouts in recent years can be traced to transmission problems, either because of faults in the lines themselves or in the coordination of power flow over increasingly congested lines. However, in the need to stay “competitive,” many energy companies, and the regional grid operators that work with them, are “flying” the grid with less and less margin for error. This means keeping costs down, not investing sufficiently in new equipment, and not building new transmission highways to free up bottlenecks.

A Stressed Infrastructure

The major outage on August 14, 2003 in the Eastern US and the earlier California power crisis in 2000-2001 are only the most visible parts of a larger and growing US energy crisis from inadequate investments in the infrastructure leading to a fundamental imbalance between growing demand and an almost stagnant supply. The imbalance had been brewing for many years and is prevalent throughout the nation (EPRI, 2001).

From a broader view, the North American electricity infrastructure is vulnerable to increasing stresses from several sources. One stress is caused by an imbalance between growth in demand for power and enhancement of the power delivery system to support this growth. From 1988 to 1998, the US's electricity demand rose by nearly 30 percent, but the capacity of its transmission network grew by only 15 percent. This disparity increased from 1999 to 2009: demand grew by about 20 percent, while planned transmission systems grow by only under 3.8 percent. Along with that imbalance, today's power system has several sources of stress:

- *Demand is outpacing infrastructure expansion and maintenance investments*. Generation and transmission capacity margins are shrinking and unable to meet peak conditions, particularly when multiple failures occur while electricity demand continues to grow.
- *The transition to deregulation is creating new demands that are not being met.* The electricity infrastructure is not being expanded or enhanced to meet the demands of wholesale competition in the industry; so connectivity between consumers and markets is at a gridlock.
- *The present power delivery infrastructure cannot adequately handle those new demands of high-end digital customers and 21st century economy*. It cannot support levels of security, quality, reliability, and availability needed for economic prosperity.
- *The infrastructure has not kept up with new technology*. Many distribution systems have not been updated with current technology including IT.
- *Proliferation of distributed energy resources (DER).* DER includes a variety of energy sources -- micro turbines, fuel cells, photovoltaics, and energy storage devices -- with capacities from approximately 1 kW to 10 MW. DER can play an important role in strengthening energy infrastructure. Currently, DER accounts for about 7 percent of total capacity in the United States, mostly in the form of backup generation, yet very little is connected to the power delivery system. By 2020, DER could account for as much as 25 percent of total U.S. capacity, with most DER devices connected to the power delivery system.
- *Return on investment (ROI) uncertainties are discouraging investments in the infrastructure upgrades.* Investing new technology in the infrastructure can meet these aforementioned demands. More specifically, according to a June 2003 report by the National Science Foundation, R&D spending in the U.S. as a percent of net sales was about 10 percent in the computer and electronic products industry and 12 percent for the communication equipment industry in 1999. Conversely, R&D investment by electric utilities was less than 0.5 percent during the same period. R&D investment in most other industries is also significantly greater than that in the electric power industry (NSF 2003).
- *Concern about the national infrastructure's security* (Amin 2003; EPRI 2001). A successful terrorist attempt to disrupt electricity supplies could have devastating effects on national security, the economy, and human life. Yet power systems have widely dispersed assets that can never be absolutely defended against a determined attack.

Competition and deregulation have created multiple energy producers that share the same energy distribution network, one that now lacks the carrying capacity or safety margin to support anticipated demand. Investments in maintenance and research and development continue to decline in the North American electrical grid. Yet, investment in core systems and related IT components are required to insure the level of reliability and security that users of the system have come to expect.

From a national security viewpoint, in the aftermath of the tragic events of September 11th and recent natural disasters and major power outages, there are increased national and international concerns about the security, resilience and robustness of critical infrastructures in response to evolving spectra of threats. Secure and reliable operation of these networks is fundamental to national and international economy, security and quality of life.