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powering the 21st century

we can—and must—modernize the grid

THE MASSIVE POWER OUTAGE OF August 2003 underscored the vulnerability of our nation's power grid and the fact that this vital yet complex infrastructure underpins our society and quality of life. The cover story in the August 2004 issue of the *IEEE Spectrum* "The Unruly Power Grid," as well as a subsequent *Washington Post* op-ed piece of 10 August 2004, "Blackouts Are Inevitable—Coping, Not Prevention, Should Be the Primary Goal," missed the mark on the real issues at all levels—technological, political, and economic, as well as urgent, tactical, and strategic—of the energy and infrastructure security challenges facing our nation.

Those authors realistically believe that most human decision-making is based on emotions and perceptions rather than a true understanding of the fundamental mathematical underpinnings, allowing for structured open decisions with risk and cost-benefit inputs. Although coping is useful for both limiting panics and for having some low-level backups, to focus mainly on coping is unwisely defeatist.

As an energy professional and an electrical engineer, I cannot imagine how anyone could believe that in the United States we should learn to "cope" with 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. I do not believe the American people would—or should—settle for a substandard electricity infrastructure.

We absolutely can meet the needs of a pervasively digital society that relies on microprocessor-based devices in vehicles, homes, offices, and industrial facilities. We can reduce grid congestion and atypical power flows and meet customers' reliability expectations. 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. It will require an extensive, prolonged commitment by the federal government and the industry to provide research funding and to reduce red tape. It will take a renewed commitment on the part of industry to modernize and invest in new technology. And it will take continuing collaboration among economists, scientists, and engineers to slowly but surely transform the power grid into what we know it can be—and what it must become.

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Evaluating the Power Grid's Evolution

The U.S. power grid that has evolved now underlies every aspect of our economy and society. The power grid was hailed by the National Academy of Engineering as the 20th century's engineering innovation most beneficial to our civilization. This network represents an enormous investment, including over 15,000 generators in 10,000 power plants and hundreds of thousands of miles of transmission lines and distribution networks with an estimated worth over US$800 billion. In 2000, transmission and distribution alone were valued at US$358 billion.

The electric power grid was historically operated by separate utilities; each independent in its own control area and regulated by local bodies to deliver bulk power from generation to load areas reliably and economically. Competition and deregulation have now created multiple energy entities that must share the same regulated energy-delivery network.

Traditionally, new delivery capacity would be added to handle load increases, but because of the current difficulty in obtaining permits and the uncertainty about achieving an adequate rate of return on investment, fewer total circuit miles are being added. Meanwhile the nation's economy, population, and technological achievements have continued to grow.

Several cascading failures during the past 40 years highlighted our need to understand the complex phenomena associated with power network systems and the development of emergency controls and restoration; that number continues to rise in North America.

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In My View

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Beginning in 1995, the amortization/ depreciation rate has 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.

Analyses of data collected for the U.S. Department of Energy (DOE), which requires electric utilities to report system emergencies that can affect the reliability of bulk power delivery systems, 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. 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. The conclusion was that the complex systems required to mitigate problems during periods of great demand and restoration are at great risk of serious disruption, creating a critical need for technological improvements.

Power Grid Modernization and Challenges

As electricity's share of the nation's total energy continues to grow, a key to modernizing the power grid must be the improvement in the system's ability to respond to threats, whether natural or deliberate. Today's grid relies far too heavily on narrowly programmed protection devices that have contributed to worsening the severity and impact of power outages. These devices, which came into play during last year's blackout, typically perform with a simple "on/off" logic, which acts locally while destabilizing a larger regional interconnection. With its millions of relays, controls, and other components, the parameter settings and structures of the protection devices and controllers in the electricity infrastructure can be a crucial issue. It is analogous to the poem "for want of a nail . . . the kingdom was lost." That is, relying on an inexpensive 25-cent chip and narrow control logic to operate and protect a multibillion dollar machine is folly when so much is at stake. While seemingly expensive, redundancies and the ability to detour needed power around problems are absolutely essential to the modern grid.

From a national perspective, a key challenge is how to redesign, retrofit, and upgrade the nearly 200,000 miles of electromechanically controlled transmission capacity into a smart, self-healing grid driven by a well-designed market approach. As technology progresses, and the economy becomes increasingly dependent on markets, infrastructures such as electric power, oil/gas/water pipelines, telecommunications, and financial and transportation networks become increasingly critical and complex. To meet the challenge, collaboration among engineers, policy makers, and economists are critical to providing and supporting the design and management of complex technological, societal, and economic systems in the long term. The electric power industry offers an immediate opportunity for launching such collaboration, as new ways are being sought to improve the efficiency of electricity markets while maintaining the reliability of the network. Creating a "better" grid with self-healing capabilities is no longer a distant dream as considerable progress is being made.

But considerable technical challenges as well as several economic and policy issues remain to be addressed, including industry and government responsibilities, the role of the market in a modern, strategically secure power system, and funding issues, e.g., economic incentives for infrastructure investment and research. To address these and other questions, the electric power industry and all pertinent public and private sectors must work together with other critical infrastructure stakeholders.

Catastrophes, Risks, and Solutions

On a related note regarding natural disasters and risk management, the eye of Hurricane Charley went directly over our home on Bokeelia (the northern tip of Pine Island near Fort Myers in Florida). We have family and many friends who live on Pine Island; fortunately they were not hurt but their houses have sustained considerable damage. Our own unit was spared the worst damage, thanks to the reinforced concrete foundation/pillars and the automatic hurricane shutters (which only our unit has). Neighbors' units were badly damaged, but we are very grateful that the people were not physically hurt.

The electric shutters were the primary reason our unit suffered very minimal damage from the hurricane. Also, upon structural analysis, by sealing off our unit from the winds on the lanai side—and thereby preventing the creation of a vacuum within our unit—the shutters helped stabilize the entire building from the center and mitigated the risk of further structural damage to the other units. While the initial cost of the shutters was considerable, they saved our unit when it really mattered, in a "low-probability but high-consequence" event. Technology does indeed help mitigate risk—perhaps not always as desired but hopefully when critical.

From a broader viewpoint, judicious investments in pertinent technologies and the development of human capital can help enhance the quality of human life and serve our society. During the past ten millennia, fundamental understandings gained through scientific discovery and enabled by innovation and its management—sometimes planned!—have provided us the tools to ascend from savagery to civilization.

The 20th century in particular marked a period of technology triumphs. Electrification, telecommunications and the Internet, fast and efficient transportation, modern medicine, scientific agriculture, and other advances changed—and continue to change—the conditions of human life all around the globe. In little more than 100 years, the average human lifespan nearly doubled. Many times greater still have been the new opportunities and possibilities afforded by technology to each individual during that longer life. It is clear that technology and its effective management is a major driving force in shaping global society. A reliable, secure, and efficient electricity system is the lifeblood of development, and its impact on societies around the globe is immense.

A balanced approach to investments in technology and its use can make a sizable difference in mitigating the risk. There are many vulnerabilities to the grid—and it *is* imperfect—and with the diminished shock absorbers of the business-as-usual environment of recent years, we must be prepared for more outages and the increased cost of outages at the consumer level. We can—and must—reverse this trend.

On the one hand, electricity shall prevail at the quality, efficiency, and reliability that customers demand and are willing to pay for; the question is who provides it. On the other hand, it is important to note that achieving grid performance, security, and reliability is a national profitable investment, not a cost burden on the taxpayer. The economic payback is three to seven times—and in some cases an order of magnitude greater—than the money invested. Furthermore, the payback starts with the completion of each sequence of grid improvement. The issue is not merely who invests money; that is ultimately the public, whether through taxes or kilowatthour rates. Considering the impact of regulatory agencies, they should be able to induce the electricity producers to plan and fund the process. That may be the most efficient way to get it in operation.

In conclusion, it is important to note that some of the failures identified by the U.S.-Canada Power System Outage Task Force that investigated the 14 August 2003 blackout were not technological at all. Rather, many were human-operator training issues and failures to perform simple, but time-consuming and expensive, tasks such as trimming trees along transmission right-of-ways. Such failures are readily remedied through greater awareness, improved training, and adequate monetary resources. p&e