Pacific Northwest National Laboratory

Operated by Battelle for the
U.S. Department of Energy

REDUCING THE COST OF ENERGY DELIVERY DISRUPTIONS: THE ROLE OF ADVANCED TECHNOLOGY

M.L. Brown

March 1997

RECEIVED
FEB 26 1998
OSTI

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

RECEIVED**DEC 30 1997****OSTI****97525**

Reducing the Cost of Energy Delivery Disruptions: The Role of Advanced Technology

Merwin L. Brown
Pacific Northwest National Laboratory
902 Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
(509) 372-6323
(509) 375-3778 fax

ABSTRACT

In July and August 1996, the electric grid in the western United States experienced widespread power outages from southern California to western Canada. These large disruptions reminded us of the vulnerability of our energy delivery systems. While these disruptions may have been isolated events, there are a growing number of threats to the security, stability, reliability and safety of our national energy delivery systems. For a fraction of the billions of dollars a year these outages cost our economy, technologies could be developed that would reduce the threats and consequences of such disturbances. Many of these same developments also would better enable our energy delivery systems to accommodate the demands of pending competition in the energy marketplace.

CAUSES OF DISRUPTION

Acts of Nature and Accidents

Electric grid reliability has always been susceptible to acts of nature and accidents. Hurricanes on the East Coast, earthquakes on the West Coast, and ice storms in the Pacific Northwest and elsewhere in the U.S. have disrupted energy services for weeks or even months at a time. High winds, high water, and lightning from thunderstorms frequently cause only brief local outages, but their collective damage can extract a huge economic toll. Gas and liquid pipelines are less susceptible to acts of nature, but are especially vulnerable to earthquakes that cause pipes to break, leading to explosions, fires, and delivery disruptions. However, accidental excavations are the largest disruption factor in pipelines, and are not insignificant in underground electric distribution disruptions. Above ground systems are susceptible to vehicular collisions, and electric especially can be disrupted by shorts caused by wires contacting vegetation or even animals.

In the last couple of decades, however, expansions of network interconnections have increased customer exposure to disruptions by spreading them over a greater geography. Therefore, in August 1996, an electric line sagging into a tree in the Pacific Northwest caused blackouts in the Southwest. In turn, a January 1994 earthquake in southern California shut down electric systems in the Pacific Northwest. Fortunately, the nature of

pipeline delivery systems is such, especially given the compressibility of gas, that disruptions do not usually promulgate far from the break, nor very fast.

Acts of Terrorism and Vandalism

Terrorists and vandals also pose threats to the security of our energy delivery systems. Remotely located infrastructures for pipes and wires, like gas compressor stations and storage, electric substations and towers, and liquid products pumps, have always provided tempting targets for physical assaults. Fortunately, we have not yet experienced a major act of sabotage in the U.S. that resulted in a substantial power outage or fuel shortages. On the other hand, sabotage in South America, Africa, and Europe has been much more frequent and has caused outages of several weeks (Office of Technology Assessment, 1989). Recent events in the U.S., however, have caused speculation that physical terrorism might be on the rise in this country.

A growing dependence on communications and information management in energy delivery systems, however, has added a new terrorist-related risk. "White collar" saboteurs wielding electronic and computer-based "weapons" pose an even greater threat of disruption than physical assaults on our energy delivery systems and associated electronic commerce. Information has always been important to managing electric transmission systems--less so for distribution. To give some perspective on this dependence, one utility reported in 1993 of having 20,000 PCs, two mainframes, 460 LANs and a corporate database of 1.45 terabytes (Danielson, 1993). But the volume of data, the speed with which it must be handled, and its importance to maintaining secure and stable systems have all been growing, especially in electric transmission and distribution systems and, to a lesser degree, in gas and liquid pipeline SCADA systems. Control systems are becoming increasingly reliant on electronic and computer-based devices and systems. While these control systems are isolated from the general public, making access relatively difficult, they are probably not immune to attack. Plans by some utilities calling for the use of the Internet for energy brokering, communicating with customers in "real-time" (Hoffman, 1996), and other forms of electronic commerce will likely increase the vulnerability to this form of disruption.

Simultaneous attacks on control systems throughout a regional grid could be made by electronic and physical terrorists. Unfortunately, grid operators do not have the same degree of sophistication in tools and experience to deal with these forms of disruptions as for those caused by weather, for example. The consequences of disruptions caused by electronic tampering, especially in electric grids, have the potential to dwarf those from more conventional causes, like losing a line to a tree.

Open Access and Competition

Perhaps the most pervasive, yet subtle, factors in energy delivery systems reliability are the impending pressures of competition and new regulatory requirements. While electric loads have increased at about 2% annually over the last decade, very little capacity has been added to the transmission systems during this time. This construction hiatus has been attributed in

part to siting difficulties, but at costs approaching million dollars a mile, money has also been a factor (Hoffman, 1996). Consequently, the desire to increase asset utilization and cut costs can cause delivery systems to be operated much closer to their design limits and raise the exposure to disruptions. This exposure is compounded because, with current technology, one rarely knows where the limit truly is.

In hindsight, the California/Oregon AC Intertie might have been operating near such a limit prior to the August 1996 outage because the amount of power being transferred from north to south through it was afterwards cut back to 67% of previous limits (Hoffman, 1996) of 4800 MW (Taylor, 1996). This action taken to increase the system reliability was a tradeoff that effectively raised the cost of energy to customers in the south. But the economic pressures to send more lower cost energy through that intertie are sure to increase once California energy markets truly open up to competition. Indeed, similar wheeling transactions are already fairly common. Bulk power transfers have increased four-fold from 1980 to 1990, to where 40% of the electricity generated in the U.S. is now sold on the wholesale market (Balzhiser, 1996). This fraction is expected to grow significantly, but only if the transmission bottlenecks are removed.

Furthermore, open access and competition are expected to require these assets to accommodate business transactions and delivery configurations, including distributed power generation, for which they were not designed. In the past, utilities planned, built, and operated new generation and transmission and distribution systems. They had a considerable degree of control for maintaining reliability. Under competition, however, the market will determine when and where new generation will be built. Energy customers, or their brokers, will be purchasing energy from preferred providers who can change frequently once retail wheeling becomes reality. The energy delivery system will be expected to accommodate these transactions reliably and economically. Grid operators will not only need new tools to successfully provide reliable service, they will need them to determine the market value of that service.

Competition, or its threat, has also resulted in reduced O&M in energy delivery systems, a practice that contributes to disruptions. For example, the 300,000 miles of pipeline in the United States are aging. Pipelines are deteriorating and, defects, if not properly located, identified, and mitigated, will grow. Yet, safety and environmental impacts cannot lessen and will clearly continue to add to future operating costs. Therefore, technology development must deal with this aging infrastructure of pipelines (Thomas, *et al*, 1996).

THE COSTS

The August 1996 Western grid outage left about 4 million customers without electricity (for several hours in some cases) during the heat of summer. It demonstrated that energy delivery disruptions are, at a minimum, inconvenient and uncomfortable, but they also can be unsafe and directly expensive. The adverse economic consequences are compounded if the responses to

threat of disruptions are conservative operating policies. Assets will be relatively underutilized and the cost of energy delivery will increase. Furthermore, our energy delivery systems will be unable to conduct the transactions that could provide the full economic potential of open access and retail wheeling.

Outages cause direct costs in the form of lost production and sales. Businesses, like restaurants and retail stores, lose revenues during outages. Businesses, like grocery stores, not only lose business, but they can lose inventory through spoilage if the outages last long enough. Banks and other financial institutions have become dependent on computer-based data handling and electronic communications that are very vulnerable to even very brief outages lasting only seconds. Some manufacturing processes, like those used in the semiconductor industry, can also experience product losses amounting to millions of dollars from disruptions of only a few seconds. Sensitive electronic equipment can be damaged, a growing concern with the increased use of computers.

Power outages can adversely affect public safety through disabling air and ground traffic control, sewage systems, and the like. Power outages caused by downed lines have started forest or grass fires, and have even directly threatened life. The breaks in pipelines can release hazardous liquids and cause explosions and fires. Beyond the threats to health and safety, there are the costs of cleanup and compensation for damages.

In all, electricity outages in the U.S. are estimated to cost over \$26 billion a year (Hof, 1991). Blackouts of a few hours have been estimated to cost between \$1 and \$5 per kilowatt hour (Office of Technology Assessment, 1989). One estimate puts the cost of the New York City Blackout of 1977 -- one of the most extensively studied outages from a cost point of view -- at almost \$350 million dollars (Office of Technology Assessment, 1989). Today, that cost would likely be much higher. As another data point, until the derating of the California/Oregon Intertie, energy customers in southern California were saving, on the average, \$1 million per day by purchasing Pacific Northwest energy (Hardy, 1996). Disruptions in natural gas pipelines result in similar costs. Based on data from the U.S. Department of Transportation, property losses from gas pipeline incidents from 1984 through 1994 were about \$340 million. Data on collateral damages are not known, but there is anecdotal evidence of businesses that have been shut down during natural gas delivery disruptions. Ironically, there is also a compounding effect among energy delivery systems. Liquid fuels pipelines are dependent on the electric grid for powering its motor-pumps. With the increasing deployment of natural gas-fired generation, the production of electricity is dependent on a natural gas pipeline system. These factors provide considerable incentive to the energy providers, the consumers, and the public in general, to take steps to improve the reliability of energy delivery systems.

THE SOLUTIONS

Fortunately, there are a number of potential technology solutions for mitigating many energy delivery system reliability problems. The list includes enhanced systems monitoring, analysis, sensors and control devices; advanced O&M; improved

and hardened information systems; new energy storage and generation (including on-site applications); expanded energy load management, and new materials.

The solutions can be grouped in the following three themes (Donnelly, et al, 1996):

- Data and Information Systems: collection, storage, retrieval, and communication of data and information
- Operations: wide-area control, distributed (decentralized) control, 'hardening' the power system and materials
- Policy and Implementation: Policy and implementation issues associated with reliability in the new utility environment; requires the development of metrics for monitoring reliability and standards for reliability technologies.

While some of their benefits are near term, each of these themes requires technology development and technical expertise from a broad range of sciences to realize their full potential. Each requires coordination across a broad range of stakeholders, and each must find champions within the energy industry and the public sector in a time of declining investment in R&D.

Data and Information Systems Technical Theme

Data and information have become progressively more important to energy delivery systems as they have expanded to meet new loads and find new resources. The advent of customer choice and open access is expected to cause a significant jump in the quantity and importance of data and information required in support of energy commerce. For example, the frequency of communications between the energy provider and the customer will shrink from about once every 30 days to perhaps as often as every 15 minutes. Not only will this increase in communication frequency expand the amount of data and information, but so will its growing content. In addition to communicating the amount of energy used per month and what is owed for it, there will potentially be information related to energy use profiles; what devices are using how much energy and when, and how efficiently; what are the prices of various forms of energy from what suppliers; and even non-energy related items, such as home security.

Shifting our perspective to the national grid infrastructure, its reliability and quality of service will need to rely heavily on wide-area information as we move toward higher asset utilization and, perhaps, independent operation of the grid system.

A technology development program for this theme would deal with the collection, storage, retrieval, and communication of data and information. Due to the distributed nature of energy delivery systems--especially the electric power grid--both in geographical terms and in ownership, this information technology problem is formidable. Some of the data will be sensitive to the contributing party. Security measures will need to be implemented to ensure the privacy of the data. Other pieces of information will be

critical to operations. This data will require different security measures to prevent tampering. Still other forms of data may need to be prioritized so that communications channels are not clogged during emergencies (Donnelly, et al, 1996).

To complicate the issue, energy system data requirements vary widely by application and form. Much of the status information only needs to be reported when an event has occurred. Therefore, a certain piece of equipment may only report a change in status once in a two-year period. Metering information need only be reported monthly for many residential customers. Other metering applications may require hourly information. The data requirements continue well into the radio spectrum (for fault location applications, as an example). Much of the dynamic information required to enhance reliability is collected at 40 to 100 samples per second. This information will have the highest likelihood of being transmitted long distances in real time (Donnelly, et al, 1996).

It is clear that the grid operators of the future will be faced with having to resolve terabytes of data from diverse sources into useful information that can be used to reconfigure and control the grid to prevent blackouts, such as the recent western system outages (Donnelly, et al, 1996).

Operations Technical Theme

Operational solutions to energy delivery grid reliability problems are approached from four different perspectives: (1) wide-area control, (2) distributed (decentralized) control, (3) 'hardening' the system, and (4) materials. A combination of these approaches is probably the only cost-effective means to achieve an acceptable level of reliability.

Currently, system reliability is the primary responsibility of control center operators. For example, there are over 3,000 electric utilities; however, there are only 140 control centers in the continental United States. Research efforts to date have centered on enhancing the ability of these control centers to reliably operate the interconnected grid. One example of this research was embodied in the Department of Energy's Real-Time Power System Control program. Addressing issues at the regional control centers is only one part of the preferred solution. Three areas of inquiry are suggested for improving electric power system reliability through operational measures (Donnelly, et al, 1996):

1. Wide-area (centralized) control, including Real-Time Power System Control, FACTS, and remedial action;
2. Distributed (decentralized) control, which involves expanding reliability control systems to encompass distribution and end-use devices; and
3. Hardening the power system, which involves activities that would extend the operating range of critical power system components for short periods of time due to weather emergencies or to facilitate more graceful failures.

The first area of inquiry deals with regional control. In order to effectively implement the level of regional control required to maintain or improve today's level of reliability in tomorrow's environment, two things must happen: (1) Local controllers must become more autonomous, and (2) regional operators must be provided with "over-the-horizon" information on system condition and advanced decision support tools. To do these two things, we must see R&D in the areas of large-scale modeling, monitoring and information systems, grid security assessment tools, multi-objective optimization tools, visualization tools, and integration of energy marketing and grid engineering decision support systems (Donnelly, et al, 1996).

In the second area of inquiry, a new realm of power system control would be developed. The regional control centers mentioned above rely on a comparatively small base of resources to manage the power system when compared to the population of installed electrical equipment. Although this simplifies control, it tends to magnify the consequences of system failure. Modern communications and control technologies could be distributed more widely in the electrical system, including at the end-use and distribution system level, to provide more options for system control and restoration. This program thrust would evaluate options for distributed controls for reliability (Donnelly, et al, 1996). A primary distinction between the distributed controls for reliability and conventional demand-side management is that the former would only need to be turned on and off for a second or two several times over a few minutes. Such control action would be transparent to the consumer and could provide significant benefit to wide area dynamics. It is envisioned that several classes of end-use load could be similarly controlled using technology for distributed controls for reliability; particularly, thermostatically-controlled loads (Dagle, J.E., et al, 1997). A simple example of such distributed control may be a water heater thermostat that monitors system frequency and disconnects, and subsequently reconnects the heating element during periods of power system instability to help stabilize the system.

The third area of inquiry deals with 'hardening' the power system. The power delivery system generally fails during periods of stress that are predictable; typically, during climatic extremes or when components are down for maintenance (especially very large units). FERC's Order 888 essentially divides responsibility for system reliability between generation and transmission providers at the boundary between spinning reserve and stand-by power. The Order requires transmission providers to make available spinning reserves that cover power shortages for roughly ten minutes as a service ancillary to transmission. Reserves beyond that period are deemed by FERC to be generation related. This policy sets a functional limit on the responsibility of the transmission system of ten minutes. It implies transmission providers could implement a curtailment strategy after that period. A major cause of failure is overheating of components. Selected cooling of critical components and

other preventative measures could be taken to guard against failure and/ or to extend the range of system operations. This approach would require the development of new technologies and revisions to operating practices (Donnelly, et al, 1996).

While improved materials would find application in both wires and pipes, the gas and liquid pipelines would benefit the most. Corrosion and material/construction defects account for almost a third of the property loss in natural gas pipeline incidents. Improved methods for corrosion mitigation, pipeline inspection and repair, and *in situ* refurbishing could be significant to an aging system.

Policy and Implementation Technical Theme

This theme addresses policy and implementation issues associated with reliability in the new utility environment. It is suggested that there might be a suitable federal role in treating the reliability issue to set policy and to establish a framework for providing incentives for stakeholders to meet the policy goals. Examples of federal involvement in enhancing grid reliability could take the form of treating reliability as a tradable commodity and/or setting standards and metrics for adapting to new reliability expectations. A program centered on this theme could consist of two areas of inquiry:

- Policy issues, including consideration of reliability as a tradable commodity that may vary.
- Implementation issues, including setting standards and metrics for adapting to a flexible reliability environment.

Typically, reliability is treated as a binary variable in policy and regulatory discussions; either the system is up or it is down. The ideal is a system that never goes down. Deviations from this high standard are viewed as failures. Nevertheless, sophisticated buyers in wholesale markets are able to use otherwise idle generation and transmission capacity by purchasing non-firm power and non-firm transmission to significantly reduce delivered power costs for some fraction of their total power requirements. To ensure a reliable retail power supply, these buyers contract for emergency supplies, rely on local generation, or curtail retail loads (Donnelly, et al, 1996).

These same approaches could be extended to retail markets to expand the benefits of increased asset utilization; however, retail markets and retail distribution systems would need to be adapted to these new delivery options and to local generation, energy storage, and load control technologies. The costs and benefits associated with a change of this magnitude are currently undocumented, although utility research in distributed utilities suggests the potential benefits outweigh the costs. This program thrust would take a fresh look at reliability and alternative ways of proving energy service that better utilize existing energy infrastructure, including electricity and gas distribution systems. The outcome would be an assessment of the most appropriate path to take to ensure an economically optimal reliable power supply for the future (Donnelly, et al, 1996).

The second program thrust complements the first. Establishing national policies regarding reliability or facilitating the development of new reliability technologies will require the development of metrics for monitoring reliability and standards for reliability technologies. The need for metrics is especially pressing as reliability standards are expected to be adopted during the current industry restructuring process. Many of the events associated with system failure have origins that are unknown or climate based. These may be uncontrollable and, thus, should not be included in performance measures; however, there is no systematic or agreed-upon way to classify events at present. This program would work with regulators, utilities, and power system users to review current operating standards and develop appropriate metrics and measurement protocols for reliability. If distributed reliability measures are adopted, or if retail access includes reliability as an ancillary service, standards will need to be established to ensure that devices perform as expected and that uncontrolled electrical equipment doesn't interfere with reliability control and restoration operations. This program would also work with representatives of the utility and electrical equipment manufacturing industries to review current electrical system operating criteria and develop appropriate standards for new equipment (Donnelly, *et al*, September 1996).

On-site or distributed power generation, expected to be a relatively new component in the value chain of energy delivery, probably deserves some special consideration. While it can provide valuable backup for critical functions, it also can contribute to the reliability of the wider grid system. During the 1989 earthquake in northern California, the numerous and widespread independent power producers were credited with helping support many power areas after some key utility generation was knocked off line.

Yet, for on-site or distributed generation to become more useful, a number of grid integration stability, reliability, power quality and safety issues, and opportunities need to be addressed. Codes and standards are needed. New algorithms and system models are needed. While some work has been done in the national labs and in private industry, more is needed.

While speaking of codes and standards, the gas pipeline industry has been moving to a risk management approach for pipeline safety at a national (FERC) level. Currently, there are a number of local gas distribution companies who would like to see the same approach applied to local pipeline systems under state and local regulation. Such a shift in regulation could result in safe pipelines at lower costs. There is a need for model development and testing to assist the export of the national approach to meet local requirements.

The R&D Players

Expenditures for energy products and services in the U.S. totaled nearly \$500 billion. The costs of energy delivery disruptions probably exceeds 5% of those expenditures. Yet, while the benefits of reducing energy delivery disruptions might be substantial, the current business and regulatory climates are

not conducive to technology development. Regulatory reform, or at least the uncertainty created in the reform process, in electric and natural gas markets is changing the incentives for energy utilities to invest in R&D. A March 1996 study by the Department of Energy reports that real spending for R&D in 1995 fell for the third consecutive year. Total investment for all forms of energy R&D in the United States was \$6.5 billion in 1993, of which \$3.5 billion was from private industry. These private sector expenditures are down 33% in real terms, from 1983 levels (Thomas, *et al*, 1996).

CONCLUSION

The widespread geography of energy delivery systems and the strong interactions of various subsystems having different owners create a special situation for identifying the roles and responsibilities for R&D support that does not exist in energy production or energy services. It is argued that the operation of an interconnected energy grid requires a certain degree of openness in communicating information. Yet, tomorrow's utilities will have little financial incentive to provide their competitors with this information. The concept of an independent system operator (ISO) has been proposed for the electric industry as one way to resolve this dilemma, but is not clear that its responsibilities will include investing in the development of new technology for system-wide application. Despite the pressures of competition, the likelihood that the energy delivery systems will remain regulated and, therefore, rate-based, does suggest that some collaborative technology development will take place in the industry as it has in the past. In the interests of national security and global competitiveness, there does appear to be an important role for the federal government in the development of policy, codes and standards, and some technologies, such as modeling, monitoring, analysis, etc. Finally, given the expectations of a highly competitive industry, there are bound to be private proprietary developments by vendors and, perhaps, individual system owners. In short, the situation is complex and will require a coordinated approach. What is probably most lacking at the moment is clear leadership.

References

Balzhiser, Richard E., "The Electricity Industry and Technology: The Coming Transformation," presented at the Energy Daily Conference, Profiting from Distributed Electric Generation, Improving the Bottom Line for Utilities and Customers, Washington, DC, September 30 - October 1, 1996.

Dagle, J.E., D. W. Winiarski, and M. K. Donnelly, PNNL-1148, "End-Use Load Control for Power System Dynamic Stability Enhancement," Pacific Northwest National Laboratory, for the U.S. Department of Energy, February 1997.

Danielson, John, panel member at the Energy Daily and Pacific Gas and Electric Company conference, 'Electric Utilities' Computational Needs: Real Time Pricing and Distribution in the 1990s, San Francisco, CA, 1993.

Donnelly, Matthew K., J. E. Dagle, J. G. DeSteele, D. J. Hammerstrom, and W. M. Warwick, "Reengineering Reliability" internal planning paper, Pacific Northwest National Laboratory, Richland, Washington. September 1996.

Hardy, Randall, Administrator, Bonneville Power Administration, U.S. Department of Energy, before the Subcommittee on Water and Power Resources of the House Committee on Resources, November 7, 1996.

Hof, Robert D., "The 'Dirty Power' Clogging Industry's Pipeline," *Business Week*, p 82, April 8, 1991.

Hoffman, Steve, "Enhancing Power Grid Reliability," *EPRI Journal*, pp 6-13, November/December 1996.

Office of Technology Assessment, Congress of the United States, "Physical Vulnerability of Electric Systems to Natural Disasters and Sabotage." 1989.

Taylor, Carson W., "The July 2, 1996 Breakup of the Western North American Power System," presented at the 1996 IEEE Power Engineering Society Summer Meeting.

Thomas, C. M. (Tina), State Regulatory Counsel, LaVerne A. Tedeski, Coordinator, GRI Advisory Council, "Summary of the 1996 Gas Research Institute Joint Panel on Energy Issues for the GRI Board of Directors and Advisory Council," August 20, 1996.