# Introduction and Summary

## INTRODUCTION

The reliability of U.S. electric power systems has been so high that the rare occurrences of major blackouts have been prominent national and even international news items. The most notable incidents—in South Carolina after Hurricane Hugo, in Seattle after the 1989 cable fire, New York City in 1977, or almost the entire Northeast in 1965—have demonstrated that blackouts are very expensive and entail considerable disruption to society.

As damaging as these blackouts have been, much worse events are possible. Under several different types of circumstances, electric power ***systems*** could be damaged well beyond the level of normal design criteria for maintaining reliability. Seismic experts expect that several parts of the country could experience significantly larger earthquakes than the one that hit California in 1989. Hurricanes even more damaging than Hugo could move along the Gulf of Mexico or up the Atlantic coast, maintaining their strength rather than losing it inland. Either type of natural disaster could damage many electric power system components, causing widespread outages over a long period of restoration and recovery. Even more ominously, terrorists could emulate acts of sabotage in several other countries and destroy critical components, incapacitating large segments of a transmission network for months. Some of these components are vulnerable to saboteurs with explosives or just high-power rifles. Not only would repairs cost many millions of dollars, but the economic and societal damage from serious power shortages would be enormous.

Electric utilities normally plan for the possibility of one, or occasionally two, independent failures of major equipment without their customers suffering any significant outage. If the system can be better protected, or made sufficiently resilient to withstand greater levels of damage, then the risk of a major, long-term blackout will be reduced. However, any such measures will cost money. Utilities are taking some steps, but apparently, generally consider the risk to be too low to warrant large expenditures, which would ultimately be borne by their customers, or by stockholders if the State utility commission did not approve inclusion of these costs in the rate base.

However, the consequences of a major, long-term blackout are so great that there is a clear national interest involved. Steps that may not be worthwhile for individual utilities could make sense from the national perspective. The purpose of this report is to explore the options for reducing vulnerability and place them in context. It first reviews the threat from both natural disasters and sabotage to determine what damage might occur. However, an analysis of the probability of any of these threats materializing is beyond the-scope of this study. Chapter 3 reviews the impact of major blackouts that have occurred, in order to help understand the costs of an even greater one that might be experienced eventually. Chapter 4 estimates the effect on the system when various critical components are damaged, and how the system can be restored. Chapters 5 and 6 describe present and potential efforts to reduce vulnerability. Finally, chapter 7 suggests how Congress could act, depending on how seriously the problem is viewed.

## SUMMARY

### *Causes and Costs of Extended Outages*

A variety of events, both natural and manmade, can cause power outages. Widespread outages or power shortages lasting several months or more are unlikely unless significant components of the bulk power system—generation and transmission-are damaged. The most probable causes of such damage are sabotage of multi-circuit transmission facilities, and very strong earthquakes or hurricanes.

The bulk power system is vulnerable to terrorist attacks targeted on key facilities. Major metropolitan areas and even multi-state regions could lose virtually all power following simultaneous attacks on three to eight sites, though partial service might be restored within a few hours. Most of these sites are unmanned, and many are in isolated areas, with little resistance to attack. Powerplants can also be disabled by terrorists willing to attack a manned site, or isolated from the transmission network by high-power rifle fire outside the site.

None of the attacks on electric power systems in the United States has been large enough to cause widespread blackouts, but there are reasons for concern that the situation may worsen. Small-scale, unsophisticated attacks on power systems have occurred here. Power systems in other countries, especially in Latin America and Europe, have suffered much worse and more frequent damage. Latin American and African countries have suffered outages of several weeks. Terrorist attacks in this country have not been a major problem over the past decade, but that could change rapidly. Terrorists could select power systems as targets if they want to cause a large amount of economic disruption with a relatively small effort. Efficient selection of targets would require more sophistication than has yet been shown by terrorist groups in the United States, but the required information and expertise are available from public documents as well as from foreign terrorist groups. In addition, some foreign groups might want to strike directly at the United States.

Hurricanes and earthquakes can also have a devastating effect on power systems, but the pattern of destruction would be much different than after a large-scale attack by saboteurs. Hurricanes affect distribution systems much more than generation and transmission. The relatively low lines are vulnerable to falling trees, flooding, and flying debris. Restoration may be a monumental task lasting several weeks or even months, but replacement parts are readily available, and utilities are experienced in the type of tasks required. However, the lingering blackouts following Hurricane Hugo demonstrated that greater advanced planning may be warranted. For instance, some types of transmission towers failed in the high winds, suggesting that more resilient designs should be used in vulnerable areas. Utilities along the Gulf and Atlantic coasts, areas vulnerable to hurricanes, should be studying the lessons learned from Hugo.

Earthquakes are quite capable of destroying generation and transmission equipment as well as distribution systems. However, where facilities have been constructed to withstand earthquakes, as in California, it is unlikely that more than a few key pieces of equipment would be damaged. The greatest concern is when an earthquake hits an area where seismic disturbances have not been considered in the design of equipment. The central Mississippi valley, the southern Appalachians, and an area centered around Indiana have the highest potential for earthquake damage. No plausible natural disaster should damage the bulk power system so badly as to cause widespread power outages for more than a few days if utilities have taken adequate precautions. Utilities normally can restore power fairly quickly unless multiple circuits are interrupted.

However it might occur, a long-term blackout is extremely expensive. Direct impacts include lost production and sales by industrial and commercial firms, safety (e.g., incapacitated traffic and air system controls), damage to electronic equipment and data, inconvenience, etc. Indirect costs include secondary effects on firms unable to conduct business with blacked-out firms, public health (e.g., inoperable sewage treatment plants), and looting. Table 1 summarizes the costs of the 1977 blackout in New York City, which lasted for about 25 hours. Blackouts of a few hours or days have been estimated to cost $1 to $5 per kilowatt-hour not delivered, far greater than what the power would have cost had it remained uninterrupted. Predicting costs for any specific longer-term outage is very uncertain because costs depend on many factors including the customers affected, the timing and duration of the outage, and the degree of adaptation customers and utilities can achieve to mitigate the outage.

Unless the damage is extremely severe, at least partial power could be restored in a matter of hours. Full restoration may take many months if a large number of key pieces of equipment have been destroyed. In the interim, customers would be faced with rolling blackouts, voltage reductions, or lower reliability. An additional impact is that the cost of the power that is available will be high if some of the most economical generating stations are damaged or isolated from loads by transmission system damage and therefore idled.

## Component Vulnerability and Impact on System

Three factors determine the importance of any individual component—its susceptibility to damage; the effect on the power system of its loss; and the difficulty of its replacement or repair. These factors vary with particular circumstances. For example, generating stations can be destroyed by saboteurs willing to enter the plant, but the presence of utility employees performing their normal functions is a deterrent. However, if an insider is involved, sabotage becomes much easier. Similarly, the vulnerability of generating stations to earthquakes is low if they have been designed to withstand them and high otherwise.

Widespread, long-term blackouts could only be caused by damage to several circuits isolating

**Table I-Cost of the New York City Blackout—1977[a]**

| Impact areas | Direct ($million) | | Indirect ($million) | |
|---|---|---|---|---|
| *Businesses* | Food spoilage | $1.0 | Small businesses | $155.4 |
| | Wages lost | 5.0 | Emergency aid (private sector) | 5.0 |
| | Securities industry | 15.0 | | |
| | Banking industry | 13.0 | | |
| *Government* (Non-public services) | | | Federal Assistance Programs | 11.5 |
| | | | New York State Assistance Program | 1.0 |
| *Consolidated Edison* | Restoration costs | 10.0 | New capital equipment (program and installation) | 65.0 |
| | Overtime payments | 2.0 | | |
| *Insurance*[b] | | | Federal crime insurance | 3.5 |
| | | | Fire insurance | 19.5 |
| | | | Private property insurance | 10.5 |
| *Public Health Services* | | | Public hospitals-overtime, emergency room charges | 1.5 |
| *Other public services* | Metropolitan Transportation Authority (MTA) revenue: Losses | 2.6 | MTA vandalism | 0.2 |
| | MTA overtime and unearned wages | 6.5 | MTA new capital equipment required | 11.0 |
| | | | Red Cross | 0.01 |
| | | | Fire Department overtime and damaged equipment | 0.5 |
| | | | Police Department overtime | 4.4 |
| | | | State Courts overtime | 0.5 |
| | | | Prosecution and correction | 1.1 |
| *Westchester County* | Food spoilage | 0.25[c] | | |
| | Public services equipment damage, overtime payments | 0.19 | | |
| Totals | | $55.54 | | $290.16 |

[a]Based on aggregate data collected as of May 1,1978.
[b]Overlap with business losses might occur since some are recovered by insurance.
[c]Lotting was included in this estimate but reported to be minimal.
Note: These data are derivative, and are neither comprehensive nor definitive.
SOURCE: Systems Control, Inc., Impact ofAssessrnent *of the* 1977 New York City Blackout (Washington, DC: US Department of Energy, July 1978), p. 3.

generating capacity from loads. No single failure should have a significant effect on power flow to customers since most utilities maintain sufficient generating and transmission reserves to accommodate such failures. If more damage occurs, either to generating stations or the transmission system connecting them to loads, the system can separate into islands. When these islands form, some have too much or too little generating capacity for their loads and lose all power. Other islands with approximate balance can maintain power, disconnected from the remainder of the system. The pattern of break up is not predictable, depending on the location of loads, which units are operating, the configuration of the transmission system, and the nature of the initiating event. Under extreme contingencies, substantial outages will occur. Modern protective circuitry should prevent the type of cascading failures across an entire system that occurred in the Northeast blackout of 1965, but there are many uncertainties over system behavior under untested conditions.

Power systems can be constructed to ride out almost any earthquake or hurricane with only minimal damage to components that would require months to replace. Most customers of an adequately prepared system will have their power restored within a day or two, though extensive damage to transmission and distribution lines may mean some outages for a few weeks. As noted above, however, a major earthquake east of the Rocky Mountains would cause major problems because few facilities are designed to withstand such an event.

Sabotage could cause the most devastating blackouts because many key facilities can be targeted. Substations present the greatest concern. The transmission lines themselves are even easier to disrupt because they can be attacked anywhere along the line, but they are also much easier to repair. Generating stations are somewhat more difficult than substations to attack because they are manned and often guarded.

Substations are used at generating plants to raise the low voltage of the generator to the level of the transmission system, and near load centers to reduce the voltage for the distribution network. The former are partially protected by the routine activity at powerplants, but few of the latter have any more defense than a chain-link fence. In some cases, an attack can be carried out without entering the facility.

The destruction of two or three well-selected substations would cause a serious blackout. In many cases, most customers would be restored within 30 minutes, but this damage would so reduce reliability that some areas would be vulnerable to additional blackouts for many months. Virtually any region would suffer major, extended blackouts if more than three key substations were destroyed. Some power would be restored quickly, but the region would be subject to rolling blackouts during peak demand periods for many months. The impact would be less severe at night and other times when demand is normally less than peak, because utilities then would have a better balance of supply and demand. The greater the generating and transmission reserve margin, the less would be the impact on customers, because it is easier for utilities to find ways to get power delivered despite the damage.

## *Current Efforts To Reduce Vulnerability*

Utilities historically have expended great efforts to ensure reliability, but only over the past few years have they started to take seriously the possibility of massive, simultaneous damage on multiple facilities. Awareness of the threat, however, has not yet led to the implementation of many measures to counter it. Few if any utilities plan their system and its operation to accommodate multiple, major failures, and key facilities are still unprotected.

Most of the actions the industry has taken have been instigated by the North American Electric Reliability Council (NERC) and the Edison Electric Institute (EEI). NERC completed a major study of vulnerability in 1988. Some of the recommendations have been adopted, while others are still under review. EEI has a large and active security committee which facilitates information exchange on physical protection of facilities.

The Federal Government's role for the most part has focused on national security issues—how to keep facilities operating which are vital to the United States during times of crisis. There has been less concern over the damage to the civilian economy that a major power outage would cause. The National Security Council is the lead agency for emergency preparedness, with the Federal Emergency Management Agency serving as adviser. Both of these agencies consider many vulnerabilities in addition to energy. Energy concerns are included in the new Policy Coordinating Committee on Emergency Preparedness and National Mobilization (PCC-EP/NM).

The Department of Energy (DOE) has prime responsibility for energy emergencies. DOE's Office of Energy Emergencies (OEE) was created to ensure that industry can supply adequate energy to support national security and the Nation's economic and social well-being. Most of OEE's activities have been directed at national security issues, but other efforts have included information exchanges with State governments, disaster simulations, and contingency planning. OEE also operates the National Defense Executive Reserve Program, which recruits civilian executives from the electric power industry among others to provide information and assistance in case of national emergency. DOE also has established a threat notification system to alert energy industries to potential problems.

The Department of Defense administers the Key Assets Protection Program. The Program's purpose is to protect civilian industrial facilities essential for national defense from sabotage during a crisis. The Program has identified electric power facilities required for vital military installations and defense manufacturing areas and coordinated plans for their protection with the owners.

Two trends that may increase vulnerability should be noted. First, the U.S. electrical equipment manufacturing industry has declined with the slowdown in utility growth. Many production facilities have closed and the skills of their work forces have been largely lost. In addition, imports of equipment have risen to about 20 to 25 percent of the total market, and most U.S. production capability is controlled by foreign companies. The concern regarding vulnerability is that in a major emergency, say if all the transformers at several substations are destroyed, foreign companies may lack the incentive U.S. companies would have in expediting the restoration of service. If a worldwide resurgence of growth has filled their order books, will foreign companies accord adequate priority to U.S. emergency needs? There is no definitive answer to this question. Some observers see no problem while others are quite concerned.

Second, power systems reserve margins are dropping as growth in demand exceeds construction. Reserve margins have been unusually high and still are in some areas, so utilities find this trend economically beneficial. If a major disaster such as discussed in this report occurs, however, extra reserve margin would be extremely valuable in restoring service to some customers. Utilities would have additional options in finding ways to generate and transmit power. These options are disappearing as margins return to planned levels.

### *Policy Options To Further Reduce Vulnerability*

Measures to reduce vulnerability can be grouped according to whether they prevent damage to the system, limit the consequences of whatever damage does occur, or speed recovery. An obvious way to prevent damage is to improve physical security and earthquake resistance for key facilities. The most problematic sites can be fairly well-protected against casual or unsophisticated attacks. The initial cost for walls around the transformers, crash-resistant fences, and surveillance systems would be a few percent of the replacement cost of the facility. Protection against a sophisticated attack would be extremely expensive, and probably not very effective unless response forces are near.

However, even if key facilities are protected, there is little that can be done to protect transmission lines against a saboteur with a high-power rifle. It is easy to destroy insulators on a transmission tower or the line itself, either of which will incapacitate the entire line. Such damage can be repaired quickly if sufficient replacements are on hand, but the saboteur can repeat it even more quickly in a different portion of the line or on other lines. Key transmission lines can thus be kept out of service (or at least kept unreliable) for long periods.

Protection of key facilities can also be enhanced by improved planning and coordination with the FBI to provide warning, and police or military forces to provide rapid response. Utility employee training can also be expanded to include greater awareness of suspicious activities and recognition of sabotage, so warning can be given to other facilities. These suggestions also have been made by NERC's National Electric Security Committee and have been adopted by NERC's Board of Trustees in October 1988.

Measures to limit the consequences of damage include improved training of system operators to recognize and respond to major perturbations, improved control centers and other system modifications, and increased spinning reserves. The intent of these steps is to isolate the damaged areas and keep as many customers as possible on-line. Rapid action can prevent the disruption from spreading as far as it otherwise might.

Measures to speed the recovery focus on the large transformers. The recovery period could be greatly reduced if more spares can be made available. One way would be to use those spares that utilities normally consider necessary for their own reliability but which are not actually in service at the moment. Legislation to relieve utilities of liability over potential blackouts in their own areas resulting from the absence of this equipment may be necessary. Alternatively, utilities could purchase spares for key equipment and store them in secure locations, or a stockpile of at least the most common transformers could be established.

A stockpile might entail initial costs of about $50 to $100 million for the step-down transformers used to lower voltage from the transmission system for use on a distribution network. Step-up transformers at generating stations are less standardized than step-down transformers. They employ a greater variety of voltages and different physical layouts for the high current bus from the generator. There is much less likelihood of finding a suitable spare, and a stockpile would have to be sizable. A less expensive alternative would be to stockpile key materials (copper wire, core steel, and porcelain) and, in an emergency, to use preexisting designs instead of custom designing for the particular application. Under these conditions, manufacturing time could be reduced from over 12 months to about 6 months for four prototype units and two to three per month thereafter. However, the product would lack the optimization and state-of-the-art improvements of a custom-designed unit. Suboptimal transformers, whether stockpiled or manufactured generically, would be less efficient, resulting in significantly higher operating costs. Hence these expedited transformers might have to be replaced when better ones can be produced.

In addition to the measures intended to reduce the vulnerability of the existing system, the evolution of the electric power system can be guided toward inherently less vulnerable technologies and configurations. In particular, a system that emphasizes numerous small generators close to loads is, overall less vulnerable to sabotage. However, the total relative costs of moving toward dispersed systems are not clear, and substantial government incentive might be necessary to expedite the trend toward smaller units. Another step would be to improve standardization of system components to make stockpiling, equipment sharing, and emergency manufacturing easier. However, there are good reasons for the diversity of components, and standardization would result in some loss of efficiency of the system. Greater use of underground cables would also offer some advantages compared with overhead lines, though if damage does occur, replacement of cables is much slower and more costly.

These measures are listed in table 2. Some measures are already being addressed to some degree by the industry and government. Policymakers can accept this level of progress if present trends seem adequate for the level of threat. Alternatively, a more activist approach can be taken to enhance these steps and add others. Some of the steps listed would be quite expensive, but others would have nominal costs. Considering the present budget constraints, funding new costly initiatives will be justified only if the threat is seen as serious. Therefore table 2 notes whether the activity is being addressed under present trends, whether it can be implemented at low cost, or whether it would be relatively expensive. Several items appear in two categories, indicating differing levels of implementation, or planning in one and implementation in another. Utilities can be mandated to make these investments without government financial assistance, but that will make implementation more difficult unless they are assured of passing the costs on to their customers.

The appropriate level of government intervention is a matter of value judgment and opinion. The level of threat, both sabotage and natural disaster, cannot be quantified, and the costs of a major outage are highly dependent on the exact nature of the outage. If a worst case scenario is experienced, the costs would be much greater than all the measures discussed here. If a very strong earthquake occurs and suitable reinforcements avert major damage to the power system, or if terrorism increases in this country, then even very large investments will have been justified.

However, it is also impossible to quantify the degree to which these measures would reduce vulnerability. It is relatively easy to counter low-level threats, including almost all natural disasters, or prevent them from causing massive damage. It is much harder to counter any threat more serious than a small, unsophisticated terrorist group, though the recovery from the damage can be expedited. Furthermore, even greatly increased resistance to sabotage might just move the problem elsewhere. As noted above, if saboteurs can't destroy substations, they can still cause blackouts by shooting power lines. Alternatively, they can turn to other parts of the infrastructure, such as telecommunications or water supplies. Thus, it is questionable how much protection society would be buying.

It is possible to reduce vulnerability, but at a cost. Any of these measures can be justified if the threat is estimated to be sufficiently serious. Not taking any action is an implicit decision that no action is worthwhile. With the level of terrorism in this country as low as it is, many people will be skeptical of the need for any action, especially major investments such as increased reserve margins or stockpiles. However, terrorism could increase much faster than the measures to counter it could be implemented. If this seems plausible, then at least planning and other low-cost measures should be started earlier. If a rapid increase in terrorism seems at all likely, then even expensive measures are reasonable insurance. There is no "correct' answer as to which is the most appropriate approach.

## Table 2—Options To Reduce Vulnerability

| | Present trends | Low cost | Moderate to major investments |
|---|---|---|---|
| A. *Preventing damage* | | | |
| Harden key substations-protect critical equipment with walls, toughen equipment to resist damage, etc. | | | x |
| Surveillance (remote monitoring) around key facilities (coupled with rapid-response forces). | | | x |
| Maintain guards at key substations. | | | x |
| Improve coordination with law enforcement agencies to provide threat information and coordinate responses. | X | | |
| *B. Limiting consequences* | | | |
| Improve emergency planning and operator training. | x | x | |
| Modify the physical system; improve control centers, increased reserve margin, etc. | | | X |
| Increase spinning reserves. | | x | X |
| *C. Speeding recovery* | | | |
| Contingency planning for restoration of service. | x | x | |
| Clarify legal/institutional framework for sharing reserve equipment. | x | | |
| Stockpile critical equipment (transformers) or any specialized material. | | | X |
| Assure adequate transportation for heavy equipment. | x | x | |
| Monitor domestic manufacturing capability. | | x | |
| *D. General reduction of vulnerability* | | x | |
| Emphasize less vulnerable technologies. | | | |
| Encourage decentralized generating systems. | x | x | |

SOURCE: Office of Technology Assessment, 1990.