Chapter 2
Causes of Extended Outages

Virtually everyone in the United States has some experience with power outages lasting at least a few minutes. Blackouts that last for a day or more are headline-making news, such as the 1989 storm damage in Washington, D.C. that kept some people without power for several days. Hurricane Hugo, one of the most destructive storms to strike North America this century, caused extensive damage to electric utilities in its path and left many people without power for several weeks. Over the last decade, concerns have begun to be raised about the possibility of extended blackouts due to intentional damage to electric power and other energy systems (e.g., sabotage). U.S. electric power systems have been targets of numerous isolated acts of sabotage. None has been serious enough to cause significant impact, but there is increasing recognition that a concerted effort by saboteurs could blackout major regions of the country.

This chapter focuses on extended outages caused by natural disasters and sabotage and their resulting effects on electric power systems. The impacts of extended outages, including costs, are discussed in chapter 3.

NATURAL HAZARDS

Natural hazards with the potential to cause extended blackouts include earthquakes, hurricanes, tornadoes, and severe thunderstorms. Each affects the power system differently. In general, earthquakes could damage all types of power system equipment, and are the most likely to cause power interruptions lasting more than a few days. Hurricanes primarily affect transmission and local distribution (T&D) systems, but the resultant flooding could damage generating equipment. Tornadoes and severe thunderstorms affect T&D lines directly through wind damage, and indirectly through downed trees, etc. Freak occurrences can cause particularly high levels of damage. In October 1962, for example, the only hurricane in recorded history to hit the west coast of the United States left parts of Oregon and Washington without power for up to 2 weeks, primarily because of the time needed to clear downed trees.

Earthquakes

An earthquake's actual impact depends on the population density and/or level of development in the affected area, the type of soil or rock material, the structural engineering, and advance warnings and preparation. For both loss of life and property damage, the most damaging earthquake of this century was Tangshan, China, in 1976 (Richter 7.8). Over 250,000 people died, and 20 square miles of the city were flattened.[1] The 1988 Armenian earthquake and the recent San Francisco Bay earthquake provide painful reminders of a strong earthquake's capacity to do damage and the importance of good seismic design and construction and emergency preparedness planning to mitigate the impacts (see box A).

Earthquakes sometimes result in compound disasters, in which the major event triggers a secondary event, natural or from the failure of a manmade system. In urban areas, fires may originate in gas lines and spread to storage facilities for petroleum products, gases, and chemicals. These fires often are a much more destructive agent than the tremors themselves because water mains and fire-fighting equipment are rendered useless. More than 80 percent of the total damage in the 1906 San Francisco quake was due to fire.

Most of the United States has some risk of seismic disturbance. The series of earthquakes that struck New Madrid, Missouri were probably the most severe in North America. The tremors were felt as far away as Boston. The first quake, which occurred in December 1811, may have been stronger than the 1906 San Francisco earthquake; it was followed in 1812 by hundreds of after-shocks.[2] According to the American Association of Engineers, it is very likely that a destructive earthquake will occur in the Eastern United States by the year 2010. The central Mississippi valley, the southern Appalachians, and an area centered around Indiana have the highest

[1]Robert Muir Wood, *Earthquakes and Volcanoes* (New York, NY: Weidenfeld & Nicolson, 1987).

[2]Robert Redfern, *The Making of a Continent* (New York, NY: Times Books, 1983).

Box A—The Armenian and San Francisco Earthquakes' Effects on Electric Power Systems

On December 7, 1988, Armenia was struck by a 6.9 magnitude earthquake-the most destructive to hit the region in centuries. Hundreds of buildings, including hospitals, schools, apartments, and industrial facilities, were destroyed. At least 30,000 people were killed and some 500,000 were either left homeless or jobless. Several large cities in the epicentral region sustained massive damage and high casualties. Leninakan, population 290,000, was 80 percent destroyed and Kirovakan, population of 150,000 was also heavily damaged. The city closest to the epicenter, Spitak, was completely destroyed.[1]

The high death toll was caused by the collapse of buildings, many of which were constructed of masonry and precast concrete. Building materials-such as structural steel and wood, which are more flexible than concrete—are in short supply in Armenia. Steel-frame buildings and other steel structures, such as construction cranes, sustained far less damage than concrete structures. Also, the lack of emergency preparedness planning contributed to the catastrophe.[2]

In contrast, the October 17, 1989 San Francisco Bay Area earthquake did not result in the catastrophic loss of life and property that was experienced in Armenia. The 7.1 magnitude earthquake was the strongest to hit the area since 1907. The death toll is at least 66 people and approximately 3,000 injured. The quake caused an estimated $7 billion in damage in northern California.[3] However, the growing California population, particularly in the earthquake-prone areas, could lead to a much greater loss of life and property in the future. Like Armenia, California lies within a large seismically active area. Unlike Armenia, though, California has one of the most comprehensive and up-to-date emergency preparedness plans in the United States and perhaps the world. For example, in June 1989, Pacific Gas & Electric (PG&E), the largest electricity supplier in the area, performed a company-wide earthquake emergency exercise. This exercise proved invaluable in responding to the real thing 4 months later, according to PG&E.[4] In addition, a great deal of attention is given to seismic considerations in structural design, engineering, and construction. These and other factors can mitigate the impacts of a major earthquake disaster.

Armenia[5]-In Armenia, electricity was interrupted for 4 to 7 days in the epicentral area. Two substations were severely damaged or almost totally destroyed. A 220-kV facility in Leninakan sustained damage to capacitor racks, ceramics, and circuit breakers. The 110-kV facility near Nalband was almost totally destroyed. The under-reinforced masonry and precast concrete control house collapsed and struck nearby equipment as it fell. Transformers, circuit breakers, and capacitor banks were severely damaged. Soviet authorities had to bring in a rail-mounted substation to restore power to the region.

The two-unit Armenian Nuclear Powerplant, located 75 kilometers south of the epicenter, continued to operate during and after the earthquake. But, the plant was eventually closed because the units required substantial additional seismic reinforcement to remain safe, and the price was considered prohibitive.

No damage to steel transmission towers throughout the region was reported. Wooden poles also survived intact, except for a few cases where partially rotted poles snapped at their bases.

San Francisco—About 48 hours after the San Francisco earthquake, electricity had been restored to all but 12,000 of the 1 million customers affected. About half were those in the Marina District of San Francisco, which sustained heavy damage.[6]

The Moss Landing powerplant and high-voltage switchyards, located near the earthquake's epicenter, were heavily damaged. PG&E indicated that a 340-ton air preheater was knocked off its pedestal and the bottom dropped out of an 800,000-gallon raw water tank, creating a bog.[7] Only one section of a 230-kV circuit near Moss Landing was knocked down. However, substantial damage was reported to distribution lines, especially in the Santa Cruz area. Damage to distribution lines in San Francisco was limited because most are located underground.[8]

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1 "Real-World Lessons in Seismic Safety," *EPRI Journal*, June 1989, p. 23.

2 Ibid.

3 "California Governor Signs Earthquake Relief Measures," *Washington Post, Nov. 7,* 1989, p. A-14.

4 "PG&E Credits Mock Earthquake Drill in Responding Quickly to Real Thing," *Electric Utility Week,* Oct. *30, 1989,* p. *3.*

5 "Real World Lessons in *Seismic Safety,* " op. cit., footnote 1.

6 "PG&E credits Mock Earthquake Drill in Responding Quickly to Real Thing," Op. cit., footnote 4.

7 "Coping With Loma Prieta: How PG&E's Gas and Power System Fared," *The Energy Daily,* vol. 17, No. 234, Dec. 12, 1989, p. 3.

8 "Earthquake Cuts Off a Million PG&E Customers; Two-Thirds Back in Day," *Electric Utility Week,* Oct. *23,* 1989, p. 2.

potential for earthquake damage.[3] An earthquake similar to the New Madrid series would seriously affect 12 million people in seven States.[4]

Impact on Electric Power Systems

More than any other natural hazard, major earthquakes are capable of producing almost complete social disruption in modern urban areas. Infrastructure, both above and below ground, may be shattered, and quick repair of below-ground items is almost impossible. Earthquakes can destroy all types of power system equipment, but the damage drops off rapidly with distance from the epicenter. Most structural research has gone into multi-story buildings, darns, nuclear powerplants, and storage tanks.[5]

Except for structures located at points of earth slippage, foundations in reasonably firm soil will tend to move with the ground without damage or relative displacement. Above grade, however, natural modes of vibration of the structure may be excited, amplifying the ground motion.[6] Depending on its age or size, a powerplant itself may survive a moderate-to-severe quake, but its stacks might not.

The only large generating plant damaged by the 1989 San Francisco earthquake was the Moss Landing facility, located about 20 miles south of Santa Cruz, the earthquake's epicenter. In addition, two 104-MW generating units at the Hunter's Point powerplant in San Francisco were briefly shutdown manually after the earthquake shed the load, but were returned to service within 24 hours. The quake also knocked out of service five small generating plants, totaling 467 MW, near San Luis Obispo, some 230 miles south of San Francisco, but did not affect the Diablo Canyon nuclear plant.[7]

The increase in transmission voltage over the years has resulted in larger substation equipment whose size makes it more seismically vulnerable. The increased susceptibility to damage is caused by two principal factors: 1) a drop of the frequencies of vibration into a lower and more severe region of the characteristic seismic frequency range, which produces an amplification of the seismic forces in the equipment; and 2) the inherent structural deficiencies—the brittle nature and low-energy dissipation properties-of electrical insulating material such as porcelain.[8]

In the 1971 San Fernando earthquake, failures occurred in many new extra-high-voltage (EHV) substations which had not previously been subjected to a strong seismic event. Subsequent studies by manufacturers and utilities resulted in modification of some of the existing equipment and extensive revision of the specifications for future substation equipment. The design criterion for seismic acceleration increased from 0.2 to 0.5 Gs in the most seismically active areas. The 1972 standard in Japan, where earthquakes are frequent, was 0.3 Gs.[9] The Institute of Electrical and Electronic Engineers has seismic qualification standards for power transformers, lightning arresters, circuit breakers, relays, etc. 10

During the 1989 San Francisco earthquake, PG&E experienced significant internal damage to a 500-kV substation located near the Moss Landing powerplant. Damage to circuit breakers and transformers at the substation isolated two 112-MW units that were operating at the Moss Landing facility at the time of the earthquake.[11]

Performance of transmission lines, towers, and poles under earthquake conditions generally has been excellent. Steel towers move with the ground and the acceleration stresses are well within the

3Coordinating Committee on Energy of the Public Affairs Council, American Association of Engineering Societies, *Vulnerability of Energy Distribution Systems to an Earthquake in the Eastern United States--An Overview,* December 1986.

4U.S. Geological Survey, National Center for Earthquake Engineering Research.

5Gilbert F. White and J. Eugene Haas, *Assessment of Research on Natural Hazards* (Cambridge, MA: The MIT Press, 1975).

6L.W. Long, "Analysis of Seismic Effects on Transmission Structures, " paper presented at the IEEE PES Summer Meeting and EHV/UHV Conference, Vancouver, BC, Canada, July 1973.

7"PG&E Credits Mock Earthquake Drill in Responding Quickly to Real Thing," *Electric Utility Week,* Oct. 30, 1989, p. 3; "Earthquake Cuts Off a Million PG&E Customers; Two-Thirds Back in Day,' *Electric Utility Week,* Oct. 23, 1989, p. 2.

8K.M. Skreiner and L.D. Test, "A Review of Seismic Qualification Standards for Electrical Equipment," *The Journal of Environmental Sciences,* May/June 1975.

9Ibid.

10IEEE 323.1974, standards for safety-related equipment.

11"PG&E Credits Mock Earthquake Drill in Responding Quickly to Real Thing," op. *Cit.,* footnote 7.

margins required for wind resistance. Wood poles are inherently more flexible than steel towers, and the flexibility reduces the seismic stress substantially.[12] However, earthquakes can cause transmission outages when tower foundations are subject to earth slippage. Detailed soil analysis, adequate footing design, and periodic inspection of existing foundations are essential. In the 1971 San Fernando earthquake, tower foundations failed that over the years had their strength reduced by erosion or adjacent excavation for roads or buildings.[13] The only major transmission line damage reported during the 1989 San Francisco earthquake was a section of 230-kV circuit between the Moss Landing powerplant and Watsonville. However, substantial distribution line damage was reported in areas close to the earthquake's epicenter.[14]

Hurricanes

The losses caused by a landfall hurricane are a function of the storm's strength and path and the area's population and economic development. Hurricanes are accompanied by torrential rains, typically 3 to 6 inches but more if the forward progress is slow. Winds can exceed the design of a total structure or its components and cladding, or cause hazards from windborne debris. The winds also produce disastrous sea surges and waves. A large proportion of the damage to coastal areas is caused by the storm surge, an influx of high water accompanying the hurricane. Other hazards include flooding of streams induced by the heavy rainfall and accelerated coastal erosion. Occasionally tornadoes accompany a hurricane.[15]

In the United States, most hurricane damage occurs in a narrow zone along the coastlines of the Atlantic Ocean and Gulf of Mexico. The trend is toward fewer deaths due to improved storm warning and management. However, property loss is increasing because of greater coastal development.[16]

Effects on Electric Power Systems

Hurricanes primarily affect T&D lines. High winds can damage or uproot T&D poles. Poles can also fall when soils become water saturated by accompanying torrential rains, as was the case in 1982 when Hurricane Iwa struck the Hawaiian Islands and in 1989 when Hurricane Hugo hit the Carolinas. Hurricane Hugo knocked out power to more than 1 million customers in the Carolinas. Many people were left without power for several weeks. High winds and flying debris downed transmission towers and several hundred miles of transmission lines, and falling trees knocked out thousands of distribution lines. Four utilities hardest hit by the September 22, 1989 storm have indicated that the cost of restoring service and cleanup may exceed $170 million. Insurers are expected to pay for about 10 percent of the cost.[17] See box B for a discussion of Hurricane Hugo's effect on the largest supplier of electricity in South Carolina.

Tornadoes and Thunderstorms

In the United States, tornadoes are most prevalent in a region known as "Tornado Alley' that extends from the western Texas Panhandle across Oklahoma, Kansas, southern Nebraska, and Iowa, but have been known to occur in all States.[18]

Tornadoes kill hundreds of people and destroy property valued at billions of dollars every year. The combination of high winds and the sudden drop in air pressure causes heavy destruction of everything in a tornado's path.[19] Heavy rain and large hailstones often fall north of the tornado's path. Tornado families occur when up to six tornadoes are spawned from the same thunderstorm.[20]

Severe thunderstorms can produce damaging lightning and high winds with the potential to cause extended blackouts. For example, the 1977 New York blackout began with a series of severe lightning strokes. Also, in 1989, a severe thunderstorm

[12] Long, op. cit., footnote 6.

[13] Albert W. Atwood, Jr., and Kenneth L. Griffing, comments on Long, Op. cit., footnote 6.

[14] "PG&E Credits Mock Earthquake Drill in Responding Quickly to Real Thing," op. cit., footnote 7, p. 3.

[15] White and Haas, op. cit., footnote 5.

[16] Ibid.

[17] "Damage Estimates From Hurricane Hugo Pegged at up to $170 Million," *Electric Utility Week*, Nov. 13, 1989, p. 5.

[18] "Tornado," *McGraw-Hill Encyclopedia of Science a& Technology*, vol. 18, 1987.

[19] "Tornado," *Encyclopedia Americana*, vol. 26, 1986.

[20] "Tornado," *McGraw-Hill Encyclopedia of Science and Technology*, vol. 18, 1987.

Box B—Hurricane Hugo's Effect on South Carolina Electric & Gas Co.[1]

Hurricane Hugo was one of the most powerful hurricanes to strike North America in this century and the most powerful to strike the Carolinas. Property damages in North and South Carolina alone are estimated to be about $6.5 billion.[2] The hurricane caused extensive damage to electric utilities in its path. Hardest hit was South Carolina Electric & Gas Co. (SCE&G), the largest supplier of electricity in South Carolina. Of SCE&G'S 430,000 customers, 70 percent were blacked out during the storm. After 5 days, about 140,000, or 33 percent, were still without power. Full service was restored in less than 3 weeks.[3]

In Charleston and Summerville, transmission and distribution circuits were especially hard hit by high winds, flying debris, and falling trees. The distribution system in these two areas was almost completely leveled. While there was damage to the transmission system, the delay in repair was primarily due to the extent of the damage to the distribution system. No significant damage was reported to generating units or transmission substation equipment. However, a cooling tower at one 600-MW unit was destroyed. Temporary repairs were made and the unit was back in service in less than a week. Only one power transformer, a 115/230-kV unit, which served a distribution station, was damaged in the storm.

There was a lot of damage from trees that were broken and blown into the distribution and transmission systems. Before repairs could be made, roads, lines, and access had to be cleared. Since it had been over 30 years since a major hurricane had struck the area, there was an unusually large amount of debris from wooded areas. The debris, while often not damaging the system, still required crews to physically remove branches, etc. from the transmission towers, distribution poles, and conductors.

Throughout the SCE&G system, two-thirds of the transmission circuits were out of service immediately following the storm. About 300 towers, out of a total 24,000, were either toppled or broken. Contributing factors in the damage to the transmission system were the number of wooden pole transmission towers in the 230-kV and 115-kV systems and the amount of rain that preceded the storm. Soil conditions were especially poor in wet and low-lying areas. Transmission towers in those areas fell because the footing had become too soft and weak from the rain. SCE&G and other coastal utilities are reevaluating the foundation requirements of towers near marshes, swamps, and river crossings.

As many as 3,600 workers labored to restore electric service at SCE&G, with 75 percent of them working on the transmission and distribution systems. Over 90 percent of the workers were from neighboring utilities and private contractors. Line crews came from Alabama, Arkansas, Florida, Georgia, Mississippi, Louisiana, Maryland, Tennessee, Virginia, and Illinois. Many of the crews brought their own vehicles and specialized equipment. This was done as part of mutual assistance agreements among utilities.

1 Casazza, Schultz& Associates, Inc., "Vulnerability of Electric Power Systems to Sabotage and Natural Disasters," contractor report prepared for the Office of Technology Assessment, Nov24, 1989.

2 Edward v. Badolato et al., Clemson University, The Strom Thurmond Institute of Government and Public Affairs, "Hurricane Hugo—Lessons Learned in Energy Emergency Preparedness, " 1990, p. 1.

3 There were still customers without service, but the problem was with the customers, not the utility. Many homes and businesses were too severely damaged to have service restored.

blacked out portions of the Washington, DC area for several days, primarily because of the number of downed trees.

Effects on Electric Power Systems

In general, property damage from tornadoes has declined sharply due to improved prediction and increased public awareness. Tornadoes are more likely to cause damage to transmission and distribution lines over a small geographic area than wipe out a substation or generating plant.

Thunderstorms are more widespread and consequently more disruptive. High winds, torrential rains, and lightning can wreak havoc on distribution lines.

Geomagnetic Storms

Large fluctuations in the Earth's magnetic field caused by solar disturbances are called geomagnetic storms. The Sun continuously emits a stream of protons and electrons called the solar wind. Solar disturbances such as sunspots and solar flares create gusts in the solar wind, with a more intense stream of charged particles emitted. When the solar wind hits the Earth's magnetic field it produces electric currents in the atmosphere, altering the magnetic field (as well as causing the aurora borealis). Both solar activity and geomagnetic storms ebb and flow in an 1 l-year cycle, although large storms may occur at any time. The peak of the current geomagnetic storm cycle, which is expected to be the most violent yet recorded, is anticipated to arrive in approximately 1991.[21]

Effects on Electric Power Systems

Fluctuations in the Earth's magnetic field create electric potentials (differences in voltages) on the Earth's surface. The resulting electric potential differences of 5 to 10 volts per mile fluctuate very slowly and are typically aligned from east to west. Geomagnetically induced currents (GICs) flow wherever a power line connects areas of different electric potential. The magnitude of GIC depends on several factors including a power line's location, length, and resistivity relative to the resistivity of the ground. Areas with long east-west transmission lines and highly resistive geology typical of igneous rock formations are most likely to experience large GICs.

GIC produced in a power system may either damage equipment or merely take it out of service during the course of the geomagnetic storm. Both may lead to system outages. When struck by GICs, EHV transformers may overheat, resulting in permanent damage or reduced life. Voltages in transformers may drop significantly, leading to unacceptable loadings on generators and transmission lines resulting in their being taken out of service by protective relays. Harmonic distortions created in the transformers may cause misoperation of relays, too. Relays may operate when they shouldn't, resulting in equipment being taken out of service unnecessarily; they may also fail to operate when needed, resulting in damage to the attached equipment.

A very strong geomagnetic storm on March 13, 1989 damaged voltage control equipment in Quebec, resulting in the collapse of nearly the entire system for a 9-hour blackout. The same storm tripped protective relays in several areas of the United States and damaged several large transformers. One of these transformers, a step-up unit at the Salem Nuclear Plant in New Jersey, had to be removed from service, forcing the plant to shutdown for 6 weeks.

SABOTAGE

No long-term blackouts have been caused in the United States by sabotage. However, this observation is less reassuring than it sounds. Electric power system components have been targets of numerous isolated acts of sabotage in this country. Several incidents have resulted in multimillion-dollar repair bills. In several other countries, sabotage has led to extensive blackouts and considerable economic damage in addition to the cost of repair.

Some terrorist groups hostile to the United States clearly have the capability of causing massive damage-the loss of so many generating or transmission facilities that major metropolitan areas or even multi-state regions suffer severe, long-term, power shortages. The absence of such attacks has as much to do with how terrorists view their opportunities as with their ability. U.S. electric power systems are only one target out of many ways of striking at America, and not necessarily the most attractive.

This section briefly reviews the range of acts of sabotage against electric power systems and the capabilities of different types of saboteurs. However, an analysis of the motivations and intentions of terrorists is beyond the scope of this study. Several referenced studies have considered this subject. The reader is also referred to a forthcoming OTA study "The Use of Technology To Counter Terrorism.'

Experience With Sabotage

United States

Over the past decade there were few notable acts of sabotage, and apparently none that were intended to cause harm other than to the local utility. The most common cause has been labor disputes. In July 1989, a tower on a 765-kV line owned by the Kentucky Power Co. was bombed, temporarily disabling the line. No arrests have been made. In 1987-88, power line poles and substations were bombed or shot in the Wyoming-Montana border area. Later in 1988, similar attacks were experienced in West Virginia. Such attacks had also occurred in 1985 in West

[21] This discussion is drawn from: ''A Storm From the Sun,'' *EPRI Journal*, July/August 1989, pp. 14-21; V.D. Albertson, "GeomagneticDisturbance Causes and Power System Effects," *ZEEE Power Engineering Review*, July 1989, pp. 16-17; J.G. Kappenman, "Power System Susceptibility to Geomagnetic Disturbances:Present and Future Concerns,"*IEEE PowerEngineering Review*, July 1989, pp. 15-16; and D. Soulier, "The Hydro-Quebec System Blackout of March31, 1989," *ZEEEPower Engineering Review*, July 1989, pp. 17-18.

Virginia and Kentucky. All these attacks occurred during coal mine strikes.[22] Two Florida substations were heavily damaged by simultaneous dynamite explosions in 1981 in one of the most expensive incidents. Damages totaled about $3 million, but no significant customer outages resulted. No arrests have been made, but circumstantial evidence points to a contractor labor dispute.[23]

Incidents stemming from unknown motives include the cutting of guy wires and subsequent toppling of a tower on the 1,800-MW, 1,000-kV DC intertie in California in 1987. There was negligible impact on the power system, because the load on the line was light at the time and it was scheduled for maintenance the next day, so alternate power routes had already been arranged. Damage was repaired in about 4 days.[24] No suspects have been announced. Wooden poles were also cut in Colorado in 1980, bringing down a 115-kV line. The damage was repeated later in the year. Total costs were about $200,000 each time.

Another incident demonstrates that saboteurs can mount a coordinated operation. In 1986, three 500-kV lines from the Palo Verde Nuclear Generating Station were grounded simultaneously over a 30-mile stretch. It happened at a time when none of the nuclear reactors was operating, so no disruption occurred. Under different conditions, the reactors would have shut down. No arrests have been made.[25]

In 1989, several environmental extremists were arrested in the act of cutting a tower on a line in Arizona. The group, which reportedly had been inspired by Edward Abbey's *The Monkeywrench Gang*, had been infiltrated by the FBI. Two members of this group have prepared a manual detailing how to attack equipment and facilities, including power lines, deemed harmful to the environment.[26]

Since 1980, only Puerto Rico has experienced extensive attacks that might be characterized as terrorist, as opposed to labor disputes or vandalism. In 1980-82, many bombings occurred at substations and transmission towers. Some of these incidents have been attributed to Macheteros, a separatist group. Several of the resultant outages lasted for several days.

The FBI and other agencies do not maintain statistics on energy facility sabotage separately from those of other targets. The best available database is that developed from public sources by a private consultant to the Department of Energy, which records a total of 386 attacks on U.S. energy assets from 1980 through 1989, an average of 39 per year.[27] Electric power systems, mostly transmission lines and towers, were the target in a large fraction of these 386. This database may understate the problem because some utilities may not publicize attacks out of concern that more may be inspired.

Other Countries

Terrorist sabotage has been much more extensive and violent in Europe and Latin America than in the United States. Attacks have been made by separatists, radical revolutionaries, and anti-technology and anti-nuclear groups. A few examples will illustrate this:

France has experienced assassinations of energy officials as well as bombings, arson, rocket attacks on energy facilities, and grounding of transmission lines. The saboteurs included anarchic, separatist, and political terrorists, and anti-nuclear extremists.

West Germany also is familiar with bombings and assassinations from the Baader-Meinhof group, Red Army Faction, and other groups. In addition, there has been an intensive campaign to destroy transmission lines by cutting or bombing towers. In 1986 alone, about 150 acts of such sabotage were committed. Much of the violence has been by politically motivated or anti-nuclear extremists. Transmission lines from nuclear reactors have been a major focus, and the nuclear industry itself has been a target.

Attacks on electric power systems have been most severe in El Salvador. The Farabundo Marti National Liberation Front (FMLN) has repeatedly bombed or fired on transmission towers, substations,

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[22] Robert K. Mullen, Consultant t. the U.S. Department of Energy, testimony at hearings before the Senate Committee on Governmental Affairs, Feb. 7-8, 1989, pp. 246-247.

[23] Kenneth Caldwell, Manager of Corporate Security Services, Florida Power& Light Co., personal communication, Feb. 7, 1990.

[24] *Electric Utility Week*, Aug. 10, 1987.

[25] Mullen, op. cit., footnote 22.

[26] Dave Foreman and Bill Haywood (eds.), *Ecodefense: A Field Guide to Monkeywrenching*, 2nd ed. (Tucson, AZ: Ned Ludd Books, 1987).

[27] Robert K. Mullen, personal communication Feb. 7, 1990.

and hydroelectric powerplants. Up to 90 percent of the entire Nation has been blacked out by the FMLN during some sabotage campaigns. The FMLN has even produced a manual detailing how to attack an electric power system. According to official sources, the FMLN has launched over 2,000 attacks on electric systems since 1980. The Sendero Luminosa (Shining Path) revolutionary group has adopted a similar strategy in Peru, frequently leaving Lima, as well as a 600-mile stretch of the country, blacked out or under power rationing for 40 to 50 days.[28]

Countries where insurgents or hostile forces have targeted electric power systems have found it worthwhile to take protective measures. Passive techniques, such as concrete sheaths around transmission tower legs, make them more difficult to topple. Some countries, including South Korea, maintain army conscripts at key facilities. Because of the expense of adequately protecting distributed systems, others simply repair the damage, and may design their systems to be easily repairable.

The Threat

Intentional damage to an electric power system can be caused by a wide variety of actors. Most common are ordinary vandals, typically hunters who shoot at transmission lines or the insulators attaching them to towers. Utilities are experienced with handling vandalism, which is very unlikely to cause massive damage. Hence this report is not concerned with vandalism except to the extent that remedial measures for more serious attacks might have an incidental value in reducing it.

The Single Saboteur

Most of the U.S. incidents noted above could have been caused by one person. The fact that most have been relatively minor suggests that either the saboteurs did not know how to cause greater damage or they did not want to. In sabotage initiated over labor disputes, the perpetrators usually are trying to hurt the utility or their suppliers, not to cause widespread blackouts. The dispute would have to get extraordinarily bitter before anyone would risk antagonizing a large part of the public. A personal grievance might be a more probable motivation for an individual to try to cause widespread damage. A utility employee who felt misused might want to use his expertise to retaliate in a spectacular fashion. Alternatively, any of the motivations of a group, discussed below, might apply to an individual who decides to take matters into his own hands.

The primary difficulty faced by a single saboteur intent on causing a devastating blackout would be to assemble all the necessary information and supplies. He would have to get the idea in the first place; research how electric power systems work and what the vulnerable points are; determine the layout of his target system; physically locate the actual targets; plan the attack in considerable detail; procure explosives; rehearse; and carry out the actual attack. If any of these steps were deficient, the attack would lose effectiveness.

It is unlikely, though not impossible, that an independent individual will combine the motivation, expertise, contacts to procure explosives, tenacity, and nerve to disable as many as eight facilities simultaneously. This would require visiting all the sites over several days and would entail a significant risk of detection. A more probable scenario for the independent saboteur is a one-night series of assaults on as many facilities as he can reach. Such an attack can still cause major problems for a utility, but far fewer than would more widespread damage. Theoretically, the saboteur could continue his attacks, but once utilities are alerted they can post guards to deter an immediate reoccurrence of the rampage.

Terrorist Groups

Organizations initiating terrorist attacks in other countries include separatists, political radicals, and anti-technology and/or anti-nuclear extremists. The only significant separatist movement in the United States in the past 125 years has been in Puerto Rico, and none seems likely to develop. Nor do the anti-technology or anti-nuclear movements seem likely to turn to large-scale, violent extremes, in part because people have peaceful ways to try to implement their views.

This country has had more experience with politically oriented extremism, particularly in the sixties and seventies. The Weathermen and other groups did bomb some transmission towers and might well have wanted to cause more damage. Much of this violence was in reaction to the war in Vietnam It should be noted that current trends, if anything, indicate a lessening of terrorist attacks.

[28] Ibid.

However, under some conditions, this threat might reemerge, possibly by environmental extremists. Electric power systems probably are not the most obvious targets but could become fashionable if terrorists choose to inflict great inconvenience and economic cost on society instead of more dramatic acts such as assassinations or destruction of symbolic targets. The Evan Mecham Eco-Terrorist International Conspiracy (EMETIC) targeted electric system facilities in 1987 -89.[29] Even extortion on a gigantic scale might be considered to raise funds and shake confidence in existing institutions.

Foreign groups could also import violence. American property and individuals abroad have been the targets of attack in many countries. It is not clear why some of the groups hostile to the United States have not carried their struggles here, and therefore it cannot be guaranteed that they won't. Groups in volatile areas such as the Middle East and Central America might want to hurt the United States directly. Separatists might want to pressure this country to influence events in their country, even if they have no direct conflict with us. Drug cartels in Colombia could hope to make our drug wars too costly. Environmental extremists concerned over potential global climate change might see the U.S. electric power system as symbolic of the refusal to curb production of carbon dioxide. The logic does not have to be sound for an attack to be damaging.

A group is much more likely than an individual to be able to mount a major assault on sufficient facilities to cripple a power system. A group combines all its members' skills and contacts and can share tasks. In particular, international contacts among terrorist groups multiply the expertise and resources available to any group. The knowledge gained by destroying substations and power lines in Germany and El Salvador is available in the United States. In fact several "how-to" sabotage manuals are available for sale here. Weapons and explosives are also widely available here and abroad. If foreign terrorist groups wish to attack the United States, they can probably find assistance herein obtaining target information and in camouflaging their activities.[30] However, a group is also much more likely to be detected than an individual.

Military Attacks

Commandos with special training and essentially unlimited resources and support could mount a far stronger attack than could even the most sophisticated subnational terrorist group that has yet emerged. The Soviet Union is reported to have such forces, called spetsnaz, available for operations in the United States.[31] The object would be to create havoc and demoralization before overt hostilities commence. While this risk is diminishing, it has not disappeared. Alternatively, a hostile country might take this approach if it were unable or unwilling to declare war but wanted to take some military action against the United States.

The ultimate attack would be an overt military operation. The vulnerability of electric power systems can have serious national security implications. For example, in World War II, Germany's highly centralized electric system was not attacked until late in the war. German officials, surprised at this omission, commented after the war that ''The war would have finished two years sooner if you (the Allies) had concentrated on the bombing of our powerplants earlier. . . " When the Allies finally did destroy Germany's electric generating and synthetic fuel facilities, the German economy was crippled.[32] This experience will not be ignored in any future hostilities.

For defenses to be effective against military assault, either commando or overt, they would have to be extraordinarily strong and expensive, well beyond anything that might be justified against subnational terrorists. Since even a limited terrorist attack could have extremely serious consequences, this report focuses on responses to that threat. Actions necessary only to counter military threats are beyond the scope of this report, but it notes potential benefits of a few of the counterterrorism steps.

[29] Robert K. Mullen, *personal* communication Apr. 2, 1990.

[30] Yonah Alexander, "International Network of Terrorism," *Political Terrorism and Energy,* Yonah Alexander and Charles K. Ebinger (eds.) (New York, NY: Praeger Publishers, 1982).

[31] Victor Suvorov, *SPETSNAZ, The Inside Story of the Soviet Special Forces* (New York, NY: W.W. Norton & Co., 1987) and as partially reprinted *in the* Hearings Record of the Senate Committee on Governmental Affairs, "Vulnerability of Telecommunications and Energy Resources to Terrorism," Feb. 7 and 8, 1989.

[32] Federal Emergency Management Agency, ''Dispersed, Decentralized and Renewable Energy Sources: Alternatives to National Vulnerability and War," December 1980.