Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack

Critical National Infrastructures

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Dr. Lowell L. Wood, Jr.

Dr. Joan B. Woodard

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Just as in the case involving power plants, the first critical issue is the proper functioning of the protective elements, specifically relays, followed by the local control systems. These elements protect the high-voltage breakers and transformers that are high-value assets. High-value assets are those that are critical to system functioning and take a very long time to replace or repair. Other protected devices, such as capacitors and reactive power generators, are also high value and nearly as critical as the transformers. E1 is likely to disrupt and perhaps damage protective relays, not uniformly but in statistically very significant numbers. Left unprotected, as would likely result from E1 damage or degradation to the protective relays, the high-value assets would likely suffer damage by the transient currents produced during the system collapse, as well as potentially from E2 and E3 depending upon relative magnitudes. Commission testing of some typical protective relays with lower than expected EMP levels provides cause for serious concern.

The high-value transmission equipment is subject to potentially large stress from the E3 pulse. The E3 pulse is not a freely propagating wave like E1 and E2, but the result of distortions in the Earth's magnetic field caused by the upper atmosphere nuclear explosion. The distortion couples very efficiently to long transmission lines and induces quasi-direct current electrical currents to flow. The currents in these long lines can aggregate to become very large (minute-long ground-induced currents [GIC] of hundreds to thousands of amperes) sufficient to damage major electrical power system components. With respect to transformers, probably the hardest to replace quickly, this quasi-direct current, carried by all three phases on the primary windings of the transformer, drives the transformer to saturation, creating harmonics and reactive power. The harmonics cause transformer case heating and over-currents in capacitors potentially resulting in fires. The reactive power flow would add to the stresses on the grid if it were not already in a state of collapse. Historically, we know that geomagnetic storms, which can induce GIC flows similar to but less intense than those likely to be produced by E3, have caused transformer and capacitor damage even on properly protected equipment (see **figure 2-3**). Damage would be highly likely on equipment unprotected or partially protected due to E1.

Figure 2-3. GIC Damage to Transformer During 1989 Geomagnetic Storm

The likelihood and scope of the E3 problem are exacerbated by the small transmission margins currently available. The closer a transformer is operating to its performance limit, the smaller the GIC needed to cause failure. Moreover, newer transmission substations are increasingly using three single-phase transformers to handle higher power transfer, since the equivalently rated three-phase transformers are too large to ship. The three-phase systems are more resistant to GIC, since their design presumes a balanced three-phase operation. Thus the separate single-phase transformers are more susceptible to damage from GIC.

System Restoration — Transmission

The transmission system is the lynch pin between generation and load. It is also a network interconnecting numerous individual loads and generating sources. To restore the overall power system to get generation to load, as noted earlier, an increment of genera-

Commission has concluded that the electrical system within the NERC region so disrupted will collapse with near certainty. Thus one or more of the three integrated, frequency-independent NERC regions will be without electrical service. This loss is very large geographically and restoration is very likely to be beyond short-term emergency backup generators and batteries. Any reasonable EMP event would be much larger than the Texas region so basically the concern is the Eastern and Western regions with Texas either included or not depending upon the location of the weapon. The basic threat to U.S. society that moves an EMP event from a local or short-term adverse impact to a more prolonged and injurious event is the time it takes to restore electrical and other infrastructure service.

The early time EMP, or E1, is a freely propagating field with a rise time in the range of less than one to a few nanoseconds. E1 damages or disrupts electronics such as the SCADA, DCS, and PLC as well as communications and to some extent transportation (necessary for supplies and personnel). This disrupts control systems, sensors, communication systems, protective systems, generator systems, fuel systems, environmental mitigation systems and their related computers, as well as the ability to repair. SCADA components, in particular, are frequently situated in remote environments and operate without proximate human intervention. While their critical electronic elements are usually contained within some sort of metallic box, the enclosures' service as a protective Faraday cage is inadequate. Such metallic containers are designed only to provide protection from the weather and a modicum of physical security. They are not designed to protect the electronics from high-energy electromagnetic pulses, which may infiltrate either from the free field or from the many antennae (cable connections) that compromise electromagnetic integrity.

The E1 pulse also causes flashovers in the lower voltage distribution system, resulting in immediate broad geographic scale loss of electrical load and requiring line or insulator replacement for restoration.

The intermediate time EMP, or E2, is similar in frequency regime to lightning, but vastly more widespread, like thousands to millions of simultaneous lightning strikes, even if each strike is at lower amplitude than most naturally occurring lightning. The electrical power system has existing protective measures for lightning, which are probably adequate. However, the impact of this many simultaneous lightning-like strike disruptions over an extremely large geographic area may exceed those protections. The most significant risk, however, is synergistic because the E2 pulse follows on the heels of the E1. Thus where E1-induced damage has circumvented lightning protection, the E2 impact could pass directly into major system components and damage them.

The late time EMP, or E3, follows E1 and E2 and may last for a minute or more. The E3 pulse is similar in a great many respects to geomagnetic effects induced by solar storms. Solar storms and their impacts on electrical systems with long lines have been thoroughly evaluated and are known to cause serious damage to major electrical system components at much lower levels than the reasonably possible E3 impact. This damage has been incurred in spite of functioning, in-place protective systems. Given the preceding E1 and E2 pulse damage to the protective systems and other system components, damage from E3 to unprotected major system components is virtually assured.

EMP is inimical to the continued functioning of the electrical power system and the reliable behavior of electronics. Each of the three EMP modes of system insult is sufficient by itself to cause disruption and probable functional collapse of large portions of the interconnected electrical power system at EMP threat levels. In every EMP attack, all three assaults (E1, E2, and E3) are delivered in sequence and nearly simultaneously. It is the Commission's assessment that functional collapse of the electrical power system region within the primary area of assault is virtually certain. Furthermore, widespread functional collapse may result even from a small weapon with a significant E1 component. While stopping electrical supply over a broad geographical area nearly instantaneously is damaging, it is the time it takes to restore service that is important, assuming restoration is possible, which itself may be questioned in some instances.

System Collapse Scenarios

NERC was one of several key advisers on the EMP impact assessment discussed above although the conclusions and emphasis are the Commission's alone. NERC also informed the Commission that there is no modeling capability extant, either deterministic or statistical, that can assess with confidence the outcome of simultaneous, combined subsystem failures. Putting together a coherent picture of the projected system collapse scenario must rely on expert judgment.

Large-scale load losses in excess of 10 percent are likely at EMP threat levels. Instantaneous unanticipated loss of load, by itself, can cause system collapse. This is possible at 1 percent loss, and is very likely above 10 percent. At similar percentage levels, loss of generation can also cause system collapse. Both the load loss (normally from a transmission system failure) and generation loss resulting in system collapse have been experienced. At the levels of loss for each, collapse is highly likely if not certain. Systemwide ground-induced currents in the transmission grid can by themselves cause system collapse. They did so in March 1989 in Quebec. At the levels expected in an E3 event, collapse would be much more likely and widespread.

Loss of computer control of substation switchyard equipment could, by itself, lead to system collapse. Manual operation is possible only with adequate communication and the ability of personnel to physically get to the right substations, a problematic question in the event of an EMP attack. Adequate numbers of trained and experienced personnel will be a serious problem even if they could all be contacted and could make themselves available. Thus manual operation would be necessary and might not be timely enough or have sufficient skilled personnel to deal with a broad-scale, instantaneous disruption and dynamic situation. Loss of manual control of switchyard equipment would, in short order, lead to line and transformer faults and trips. Several substations tripping nearly simultaneously would lead itself to system collapse.

Loss of telecommunications would not, by itself, cause immediate system collapse except as needed to address issues caused by the above disruptions. However the lack of telemetered control data would make the system operators effectively blind to what is going on, but personnel at substations, if they can get there and communicate with the system operators, could overcome much of that. Malfunction of protective relays could cause system collapse by contributing to several of the above scenarios through misinformation or by operating incorrectly.

All of these collapse mechanisms acting simultaneously provide the unambiguous conclusion that electrical power system collapse for the NERC region largely impacted by the EMP weapon is inevitable in the event of attack using even a relatively low-yield device of particular characteristics.

besides EMP that must be addressed, which can have serious to potentially catastrophic impacts on the electrical system. Common solutions must be found that resolve these multiple vulnerabilities as much as possible. For example, in the course of its work, the Commission analyzed the impact of a 100-year solar storm (similar to E3 from EMP) and discovered a very high consequence vulnerability of the power grid. Steps taken to mitigate the E3 threat also would simultaneously mitigate this threat from the natural environment. Most of the precautions identified to protect and restore the system from EMP will also apply to cyber and physical attacks. The Commission notes that the solutions must not seriously penalize our existing and excellent system but should enhance its performance wherever possible.

The time for action is now. Threat capabilities are growing and infrastructure reinvestment is increasingly needed which creates an opportunity for the investment to serve more than one purpose. Government must take responsibility for improvements in security. As a general matter, improvements in system security are a Government responsibility, but it may also enhance reliability if done in certain ways. For example, providing spare parts, more black start capability, greater emergency back-up, nonsynchronous interconnections, and more training all will do so. Yet, EMP hardening components will not increase reliability or enhance operation. Conversely improving reliability does not necessarily improve security, but it may if done properly. For example, adding more electronic controls will not enhance EMP security, but electronic spare parts and more skilled technicians will help improve security and reliability. Finding the right balance between the utility or independent power producer’s service and fiscal responsibility with the Government’s security obligation as soon as possible is essential, and that balance must be periodically (almost continuously) reexamined as technology and system architecture changes.

Recommendations

EMP attack on the electrical power system is an extraordinarily serious problem but one that can be reduced below the level of a catastrophic national consequence through focused effort coordinated between industry and government. Industry is responsible for assuring system reliability, efficiency, and cost effectiveness as a matter of meeting required service levels to be paid for by its customers. Government is responsible for protecting the society and its infrastructure, including the electric power system. Only government can deal with barriers to attack — interdiction before consequence. Only government can set the standards necessary to provide the appropriate level of protection against catastrophic damage from EMP for the civilian sector. Government must validate related enhancements to systems, fund security-only related elements, and assist in funding others.

It must be noted, however, that the areas where reliability and security interact represent the vast majority of cases. The power system is a complex amalgamation of many individual entities (public, regulated investor-owned, and private), regulatory structures, equipment designs, types and ages (with some parts well over one hundred years old and others brand new). Therefore, the structure and approach to modifications must not only recognize the sharply increased threat from EMP and other forms of attack, but improvements must be accomplished within existing structures. For example, industry investment to increase transmission capacity will improve both reliability and system security during the period when transmission system operating margins are increased.