Written Testimony

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"Examining Vulnerabilities of America's Power Supply"

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The Electric Power Research Institute (EPRI) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, non-profit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety, and the environment. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the US, and international participation extends to more than 30 countries.

EPRI's testimony focuses on: 1) the threat of high-impact, low-frequency events to the grid including Electromagnetic Pulse and other electromagnetic threats including Geomagnetic Disturbance and Intentional Electromagnetic Interference; and 2) risk management approaches to address EMP threats. These remarks are based upon EPRI research as well as industry knowledge and public domain documents.

1) High-Impact, Low-Frequency Events

High-impact, low-frequency (HILF) events are of growing concern in the power industry. HILF events include severe weather and other natural events; cyber, physical, or coordinated attacks; pandemics; unanticipated severe shortages of fuel or water for power generation; and electromagnetic pulse (EMP) and intentional EM interference (IEMI) attacks. There are inherent vulnerabilities in the transmission grid system to these threats because their severity is generally greater than the design basis for the system. To eliminate these vulnerabilities would be cost prohibitive, and would defeat the industry's objective to provide reliable, safety, environmentally responsible *and* affordable power.

The prudent approach is to assess the vulnerabilities, understand the impacts should these types of events occur, and develop cost-effective countermeasures to reduce the risk by increasing system resiliency. In the context of the transmission system, "resiliency" is the ability to harden the system against – and quickly recover from – HILF events, which include both severe weather, including space-weather, and man-made attacks. HILF events can disrupt generation, transmission, and distribution systems, as well as interdependent systems such as natural gas pipelines, other fuel transport, and telecommunications. Utilities have a large number of possible mitigating technologies from which to choose to enhance transmission resiliency in the face of HILF events.

Electromagnetic Pulse (EMP) and Geomagnetic Disturbance (GMD) are often discussed together when evaluating potential impacts on the power system and approaches for improving system resiliency. While these events are both in the category of electromagnetic high-impact, low-frequency events (along with physical attacks, severe storms, earthquakes, and other events), there are very important differences between EMP and GMD events that should be understood when evaluating resiliency improvement priorities and investment decisions.

Electromagnetic Pulse (EMP)
EMP refers to a very intense pulse of electromagnetic energy, typically caused by detonation of a nuclear or other high-energy explosive device. High-altitude EMP (HEMP) is a nuclear warhead detonated hundreds of kilometers above the Earth's surface to produce more widespread effects (areas impacted can be hundreds of kilometers in diameter). It is generally accepted that a HEMP will require a high-altitude delivery device (e.g., a missile) which will require a high level of sophistication and logistics. As a result, the HEMP threat is often associated with potential attacks from nation entities.

- EMPs are intentional man-made attacks of electro-magnetic energy specifically for the purpose of disrupting and/or damaging electrical/electronic systems. The three portions of the EMP may have different impacts on the transmission systems (see figure 1).

    - E1 – very fast rise time, may result in damage to electronic components either directly, or by coupling into the attached wires. GMDs do not have this characteristic.
    - E2 – characteristics are similar to lightning and consequently can result in damage to electronics and potential flashover of distribution class insulation. Neither GMD nor IEMI have this characteristic.
    - E3 – characterized by a longer duration and low frequency content similar to GMD but much shorter in duration. EMP has two potential grid impacts similar to geomagnetically-induced currents (GICs): (1) increased reactive power consumption and (b) potential protection system mis-operation from harmonics. A third potential impact of GICs, localized heating in transformers, is considered unlikely from EMP E3 because the duration of an EMP E3 is short in relation to the thermal time constant of power transformers.

- EMPs can occur with little or no warning. With the possible exception of enhanced visibility tools, most operational strategies are inapplicable. Therefore, response to the EMP threat generally comes in the form of hardening assets to reduce initial damage, and recovery to reduce the duration of the interruption.

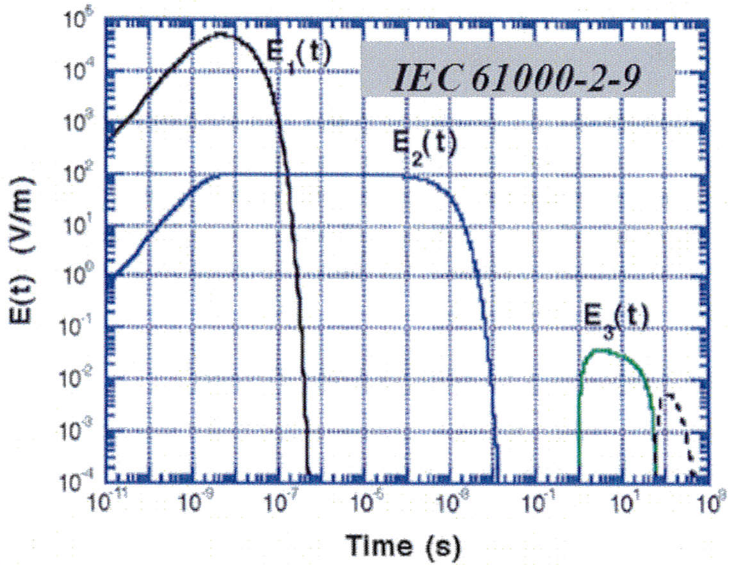

Figure 1: EMP Characteristics: Electric field magnitude as a function of time for an EMP pulse.

Geomagnetic Disturbance (GMD):

- GMDs are natural phenomena which generate slowly changing (quasi-DC) currents. These currents are similar to those created in the E3 portion of an EMP; however the E3 duration of an EMP is much shorter than a significant GMD.
- Locations that are closer to the Earth's poles are more susceptible to GMD than lower latitudes. Space weather warning systems provide a coarse estimate of GMD activity as much as four days before the storm reaches the Earth. These systems use direct observations of the sun. Accuracy of the forecast improves when the storm reaches the DSCOVR satellite, about one hour before the storm reaches the Earth. DSCOVR is a NOAA Earth observation and space weather satellite launched on February 11, 2015. It is positioned at the Sun-Earth L_1 Lagrangian point, 930,000 miles from Earth, to monitor solar wind condition, provide early warning of approaching corona mass ejections and observe phenomena on Earth including changes in ozone, aerosols, dust and volcanic ash, cloud height, vegetation cover and climate.
- Monitoring systems have been installed in multiple locations which measure the GIC currents in transformers across the grid.
- GMD events, many of which are low magnitude, occur on a regular basis which enables grid operators to improve their understanding of the phenomena, determine the impact on the grid, and evaluate trial countermeasures. These small storms can provide an indication of the grid's response to severe storms, and support development of prudent operational strategies.
- Although severe storms can occur any time during the approximately eleven-year solar cycle, more storms occur during the peak of the solar cycle.
- GMD storm duration can be in the order of hours or days while the duration of EMP is considered to be in the order of minutes.
- Utilities have established operational strategies to mitigate risk during GMD events.

Other Electromagnetic Threats

Intentional Electromagnetic Interferences (IEMI)

Like EMP, IEMI generates and delivers electromagnetic energy. IEMI is generated and delivered locally, and employs no nuclear material. IEMI devices have the potential to impact electronic assets in nearby locations such as control centers. Critical electronic equipment in these locations include relays, supervisory communications and data acquisition (SCADA), communications, and energy management systems (EMS).

As stated earlier, there are inherent vulnerabilities in the grid system to these threats because their severity is generally greater than the design basis for the system. Today's power systems are operating in an increasingly complex electromagnetic environment in which large current and voltage components, sensitive electronics, digital signals, and analog waveforms coexist and interact. The widespread proliferation of smart grid systems, including substation automation and syncrophasor systems, are part of this increasing complexity.

2) Risk Management Approaches to Address EMP Threats

EPRI has worked with industry stakeholders to characterize EMP threats, including HEMP attack, EMP, and local IEMI attack. This work has provided the design basis for assessing vulnerability and developing mitigation strategies. EPRI has gathered available data on component vulnerabilities to the benchmark threats. The results, when complete for all critical components, will support calculation of the system impact. EPRI has gathered leading practices by electricity providers who have applied trial implementation of countermeasures to reduce vulnerability.

A number of risk-management approaches can be considered to reduce the impact of EMP on the transmission system. Some of these methods are being considered by various utilities for implementation:

Risk Assessment
Prudent application of scarce resources requires careful countermeasure and site selection. While it may be difficult to identify regions of the grid that are more likely to be attacked by an EMP, it may be possible and prudent to identify and focus resources on the most critical components necessary for the reliable operation of the transmission system.

Hardening of Assets
Hardening for new and existing systems generally focuses on reducing the impact of electromagnetic waves on electronic equipment. Some hardening options include:

- New control rooms with EM shielding in the form of a Faraday Cage are being implemented at some locations. Cable entrances may be considered, including the number and location of penetrations as well as the implementation of surge protection, filtering and grounding strategies. Other challenges include staff entrances/exists and ventilation ducts.
- New relay houses which are EMP hardened are being developed and tested by some utilities. These relay houses utilize metal buildings with special consideration to ensure bonding of metal members, improved grounding, and cable entrances.
- The use of power supply and communication cables with integrated shields, as well as consideration for the grounding strategies for these shields, are being implemented (e.g., individually-shielded twisted pair cables with an overall shield which is grounded).
- Surge protection and grounding of cables entering and exiting the facilities is routine practice due to everyday lightning activity that could affect the electronic equipment.
- Filtering can be applied at cable entry points to reduce high-frequency conducted energy which can impact the attached electronic activity.
- Relocation of unprotected, sensitive control equipment to inside the shielded enclosures.
- Relocation of control cables to a lower EM environment, such as conductive conduit, to reduce induced voltage.

- The use of fiber optic cables rather than metallic cables for communications. Fiber optic cables have much lower susceptibility to EM impacts.
- Utilities are engaging original equipment manufacturers (OEMs) to incorporate EM resiliency into new components, such as relays and communications systems.
- Neutral blockers for transformers to reduce the impact of GMD have been implemented. These blockers may aid in the reduction of induced E3 currents. The impact of neutral blockers on system operation requires consideration.

Recovery

- Because a severe EMP attack can damage key electronic system components, strategic sparing is prudent. Sparing can be considered for relays, which are susceptible to the E1 and E2 component of an EMP. Storing critical spares in shielded EM enclosures is a consideration.
- Other equipment which supports restoration could also be protected from EMP. This includes equipment associated with black start, backup communications systems, transportation, and diagnostics components.
- Asset owners may consider adding the EMP threat to their transformer spares strategy. Lower voltage transformers below 69 kV can be affected by the E1 and possible E2 portions of an EMP. Larger power transformers are unlikely to be impacted directly.
- In addition to spares, mobile systems to support recovery can be considered, such as mobile transmission capacitor banks, mobile substations (typically for distribution), and mobile substation control houses.
- Redundant systems can be applied which are not susceptible to EMP, such as electro-mechanical relays.
- Utilities may consider disconnecting, and possible grounding, redundant relays and communication systems that are installed, so that they are available after an EMP. However, caution is warranted for this approach because system resiliency to traditional threats may be compromised.
- Restoration plans and training can be embellished to incorporate recovery from EMP. Relay technicians will be especially important to EMP recovery.

Conclusion

EPRI looks forward to offering continued technical support to the electricity sector, public policy-makers and other stakeholders to ensure safe, reliable, affordable, and environmentally-responsible electricity.