Written Testimony

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"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

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The subject of today's testimony is EPRI's research efforts related to high-altitude electromagnetic pulse (HEMP) and geomagnetic disturbance (GMD) events. EPRI has been engaged in a focused research effort over the last three years to evaluate the potential impacts of HEMP on the electric transmission system and to identify potential options for mitigating effects. EPRI has also been researching GMD for nearly four decades with significant applications now implemented across the electric utility industry. This testimony provides an overview of EPRI's research activities related to HEMP and GMD.

High-Altitude Electromagnetic Pulse (HEMP) Research

The detonation of a nuclear weapon in space (~ 20 km or more above the Earth's surface) can generate an intense electromagnetic pulse (EMP) referred to as a high-altitude EMP or HEMP that can propagate to the Earth's surface and impact various technological systems such as the electric grid. Depending on the height of the explosion above the Earth's surface and the weapon yield, the resulting HEMP can be characterized by three hazard fields, denoted E1 EMP, E2 EMP and E3 EMP.

The International Electrotechnical Commission (IEC)[1] defines the three hazard fields based on their distinct characteristics and time scales:

- The early-time component (E1 EMP) consists of an intense, short-duration electromagnetic pulse with double exponential waveform characterized by a rise time of 2.5 nanoseconds and amplitude on the order tens of kV/m (up to 50 kV/m at the most severe location on the ground).
- The intermediate time component (E2 EMP) is considered an extension of E1 EMP and has an electric field pulse amplitude on the order of 0.1 kV/m and duration of one μsec to approximately 10 msec. E2 EMP is comprised of two subcomponents, E2A and E2B.
- The late time component (E3 EMP) is a very low frequency (below 1 Hz) pulse with amplitude on the order of tens of V/km or mV/m with duration of one second to hundreds of seconds. Like E2 EMP, E3 EMP is comprised of two subcomponents E3A and E3B that are often referred to as the blast wave and heave wave, respectively.

Potential impacts of HEMP vary depending on the component (E1 EMP, E2 EMP or E3 EMP) that is responsible for damage.

The geographic area exposed to varying levels of E1 EMP fields can be quite large as the area of coverage is defined by line of sight from where the weapon is exploded and the horizon. The incident E1 EMP can couple to conductive objects such as overhead lines and cables exposing connected equipment to voltage and current surges (conducted threat). The resulting E1 EMP can also radiate equipment directly (radiated threat). Potential impacts from E1 EMP on the electric grid range from damage to electronics such as digital protective relays, communication systems and supervisory control and data acquisition (SCADA) systems to more traditional power delivery assets such as insulators and unprotected transformers.

The characteristics of E2 EMP are often compared with nearby lightning strikes. However, it is important to understand that E2 EMP does not couple to conductive objects in the more traditional sense of how lightning strikes a transmission tower or a conductor. Rather, E2 EMP couples to conductive objects through the air like E1 EMP. This coupling mechanism is similar to the way in which the field created by a nearby lightning stroke couples to an overhead distribution line. Because the amplitude of the incident E2 EMP field is quite low (0.1 kV/m), impacts to the bulk power system are not expected to occur.

The resulting E3 EMP induces low-frequency (quasi-dc) currents in the bulk power system. The flow of these geomagnetically induced currents (GIC) in transformer windings can cause magnetic saturation of the transformer core, that is the steel structure that the windings are constructed around, during a portion of the 60 Hz sinusoidal voltage waveform. This phenomenon, often referred to as part-cycle saturation, causes current flow in the transformer to become highly distorted. Additionally, magnetic flux that would under normal operating conditions be primarily confined to the transformer core, induces eddy-currents in windings and structural components resulting in additional hotspot heating. Thus, transformers that are experiencing part-cycle saturation: generate harmonic currents which can affect protection

[1] *International Electrotechnical Commission. "Electromagnetic Compatibility (EMC)–Part 2: Environment, Section 9: Description of HEMP Environment–Radiated Disturbance*. IEC 61000-2-9. Geneva, Switzerland. 1996.

systems and other components, appear as large reactive loads which can depress system voltage levels and lead to voltage collapse (blackout), and experience additional hotspot heating potentially leading to damage in extreme cases. However, due to the short duration of the E3 EMP event, immediate transformer impacts are expected to be minimal.

EMP Research Project Description

When the EPRI EMP research project was launched, publicly available data on the HEMP threat, potential impacts of HEMP on the electric transmission system, and field-tested mitigation options for substations were limited. Additionally, there were differences between the findings of EMP research conducted during the 1980's through early 1990's by the DOE and others and more recent findings communicated by the former Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack (former EMP Commission). Because of these differences and the potential societal impacts of a HEMP attack, EPRI launched a three-year research project in April 2016 to provide electric utilities and other stakeholders with a technical basis for making more informed decisions regarding the potential impacts of HEMP on the electric transmission system and options for mitigating potential impacts. By the conclusion of the project, the research was voluntarily financially supported by more than 60 U.S. utilities.

The EPRI research project sought to answer two important questions:

1. what are the potential impacts of a HEMP attack on the modern electric transmission system?
2. if impacts are severe, can they be mitigated in cost-effective ways, based upon science and technology?

The main goal of this research effort was to provide the electric utility industry and other stakeholders with an unclassified, technical basis for: 1) assessing the potential impacts of a HEMP attack on the bulk power system, and 2) hardening the system against those impacts, should any be found. The research specifically focused on the electric transmission system (overhead lines and substations), and did not consider the potential effects of HEMP on generation facilities, nuclear reactors, distribution systems, loads or other key elements or infrastructure sectors.

Research results were communicated to project members and other stakeholder groups throughout the project. Lastly, an important aspect of this project was the close collaboration with various government entities with extensive expertise and knowledge of the HEMP threat. Key collaborators included: DOE, Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratory (SNL), Los Alamos National Laboratory (LANL) and the Defense Threat Reduction Agency (DTRA). EPRI in close collaboration with the DOE also developed a Joint Electromagnetic Pulse Resiliency Strategy[2] that was published in July 2016.

To address the two fundamental research questions above, the project was broken up into five research areas which included:

[2] https://www.energy.gov/sites/prod/files/2016/07/f33/DOE_EMPStrategy_July2016_0.pdf

- **Environment and Modeling** – Several conservative (bounding) unclassified HEMP environments for use in assessments were identified and/or obtained from the DOE and national labs and software tools and methods for performing assessments were developed. All three hazard fields, E1 EMP, E2 EMP and E3 EMP, were included in the environment and modeling research effort.
- **Testing** –Extensive laboratory testing of critical substation assets such as digital protective relays, supervisory control and data acquisition (SCADA) equipment and communications systems was conducted to provide data on the levels of E1 EMP induced stress that could cause operational disruption or damage of these devices. Testing included free field illumination testing to assess device performance when subjected to radiated threats and direct injection testing to assess performance when subjected to conducted threats. Direct injection testing of instrument transformers, distribution-class transformers and insulators was also conducted to assess the equipment's susceptibility to E1 EMP. Additionally, testing to evaluate potential mitigation options and shielding effectiveness of substation control houses was performed. Testing focused on E1 EMP impacts.
- **Assessment** –Assessment, using bounding HEMP environments obtained from DOE and industry standards, was conducted to improve understanding of the potential impacts of a HEMP attack on the bulk power system. These assessments included: E1 EMP, E2 EMP, E3 EMP and combined effects from E1 EMP and E3 EMP.
- **Mitigation, Hardening and Recovery** –Various mitigation and hardening approaches that could be employed to reduce the potential impacts of HEMP on the electric transmission system were evaluated. Potential unintended consequences of various mitigation and hardening strategies were also evaluated, and system recovery following a HEMP-induced blackout was explored.
- **Decision Support -** A framework for supporting risk-informed decisions regarding the implementation of HEMP hardening and mitigation measures was developed.

EPRI has collaborated with its funders and pertinent government agencies during the course of the work and that collaboration is ongoing. The final report describing this research and its findings is expected to be made available by April 30, 2019.

As the research findings and report are not yet final, this testimony provided at the request of the Committee will focus on the two reports on E3 EMP impacts that were published in 2017.

E3 Assessment of the Continental U.S. Electric Grid

As a part of this research an assessment of the potential impacts that E3 EMP could have on the bulk power system was performed. The assessment included a transformer thermal assessment[3] and a voltage stability assessment[4].

At the time these studies were performed, the Oak Ridge National Laboratory (ORNL) E3 EMP environment[5] was the only unclassified environment available that contained the *minimum* spatio-temporal characteristics[6] necessary to perform interconnection-scale assessments. The environment is based on the Starfish Prime event which was a high-altitude detonation of a 1.4 MT weapon at an altitude of 400 km over a location near Johnston Island. The peak geoelectric field (E3B) associated with this environment is 24 V/km.

Following the initial E3 EMP assessments, LANL provided additional unclassified E3 EMP environmental data for five benchmark scenarios. For comparison with the ORNL E3 EMP environment, the peak geoelectric field (E3B) associated with these environments are provided in Table 1. It should be noted that the benchmark scenarios described, as well as the results from these scenarios, are notional. No actual information about any weapon or weapons platform is contained in these results.

Table 1
E3 EMP Fields for Benchmark Scenarios (LA-UR-17-31106)

Yield (kT)	Height of Burst (km)	Maximum Field (V/km)
25	100	0.85
125	100	1.5
125	400	1.9
1,000	200	9.2
10,000	200	35

Comparing the ORNL E3 EMP environment with the data provided in Table 1 shows that this environment provides a reasonable bounding case for assessments. However, there are known limitations with this environment. First, the environment includes a significant E3A component that covers the entire contiguous United States (CONUS) while also having a strong E3B component over a portion of the same area. It is well established that the maximum E3A field does not exist to any significance over the same geographic area covered by the E3B pulse.

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[3] *Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Geomagnetically Induced Current and Transformer Thermal Analysis*. EPRI, Palo Alto, CA: 2017. 3002009001.
[4] *Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis*. EPRI, Palo Alto, CA: 2017. 3002011969.
[5] *Study to Assess the Effects of Magnetohydrodynamic Electromagnetic Pulse on Electric Power Systems, Phase 1 Final Report*, ORNL/Sub-83/43374/1/V3, May 1985.
[6] These characteristics refer to the time-varying electric field on the ground over a large geographic area. These electric fields are used to compute time-varying geomagnetically-induced currents (GIC) that are used in the assessments.

Secondly, the direction of the geoelectric field vectors for both the E3A and E3B environments remained fixed throughout the duration of the event. This behavior is not consistent with data observed during high-altitude tests over land. Third, only a single waveform was available to represent the temporal effects which is also known to be inconsistent with test data. These limitations led the EPRI research team to explore options for obtaining additional unclassified data that could be used to improve the fidelity of previous studies. To fill this gap, EPRI obtained the full spatio-temporal environment associated with the 10 MT scenario shown in Table 1 from LANL. Additional E3 EMP assessments, with results expected to be released in April 2019, are being performed using the LANL 10 MT E3 EMP environment.

An overview of assessments that have been published and based on the ORNL E3 EMP environment is provided below.

Transformer Thermal Assessment

As discussed previously, the potential for GIC generated by E3 EMP to cause additional hotspot heating in windings and structural parts of bulk power transformers is well recognized. If heating is of sufficient magnitude and duration, it can cause damage to windings or result in bubble formation in the oil which can lead to dielectric breakdown and failure of the transformer; on a large scale, loss of numerous bulk power transformers could result in long-term blackout. Thus, one of the first steps in this three-year research effort was to evaluate the potential impacts of E3 EMP alone on bulk power transformers.

Because of the potential impacts of E3 EMP on bulk power transformers such studies have been included in prior government-sponsored research activities. Findings from one such study are documented in a final research report published by Oak Ridge National Laboratories (ORNL) in 1993[7] and another is documented in a U.S. Federal Energy Regulatory Commission (FERC) Interagency Report prepared by Metatech and published in 2010[8]. The results presented in these two research reports have diverging conclusions. The earlier ORNL report concluded that E3 EMP would not result in significant damage to bulk power transformers while the Metatech study concluded that transformer damage was likely, and that up to 100 transformers could be damaged depending on the target location.

The purpose of the EPRI study was to determine, using high-fidelity power system and transformer thermal modeling that was not available at the time of the previous studies, whether or not a significant number (hundreds) of bulk power transformers would experience thermal damage from a single E3 EMP event. More simply, the study sought to answer the question, "if a system were exposed to the nominal E3 EMP environment, would there be enough bulk power transformers available to facilitate system recovery?"

The EPRI study evaluated the potential impacts of the ORNL E3 EMP environment centered over eleven locations within CONUS. Each location was evaluated separately as a single high-

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[7] Electromagnetic Pulse Research on Electric Power Systems: Program Summary and Recommendations. Oak Ridge National Laboratories, Oak Ridge, TN: 1993. ORNL-6708.

[8] Meta-R-321, The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid. Metatech Corporation, January 2010.

altitude detonation event. The study found that although a significant number of transformers (hundreds to thousands depending on target location evaluated) could experience GIC flows greater than the 75 amps/phase screening criteria adopted from North American Electric Reliability Corporation (NERC) TPL-007-1[9], only a small number (3 to 14 depending on the target location evaluated) of these transformers were found to be at potential risk of thermal damage. In addition, the at-risk transformers were found to be geographically dispersed. The principle reason for this finding is the short duration of the E3 EMP event; thus, these findings should not be used to extrapolate potential impacts of GMD events of the same magnitude. The research also found that transformer condition was an important factor indicating that proper transformer maintenance is an important mitigating factor.

The results of this study are in agreement with earlier work performed by ORNL which concluded that direct immediate damage to bulk power transformers from E3 EMP is unlikely. Results from additional analysis using the LANL E3 EMP environment is expected to be made available in the final report.

Voltage Stability Assessment

The EPRI voltage stability assessment was based on the same ORNL E3 EMP environment and evaluated the same 11 target locations across CONUS. As with the previous study, each location was evaluated separately as a single high-altitude detonation event.

The voltage stability assessment was conducted using a time-domain modeling approach (transient stability model) to compute the GIC flows and the response of the bulk power system to those GIC flows. The magnetic response of bulk power transformers to the flow of GICs (that is, the additional reactive power absorption resulting from part-cycle saturation) was included in the power system model as well as dynamics of generators, controls and loads. Generic protection systems for lines and generators were also included. The effects of system topology changes due to protection system operations (lines and generators) were included in both the GIC calculations and dynamics simulations. The effects of harmonics resulting from part-cycle saturation, and the potential damage or disruption to critical electronic systems or other assets caused by the preceding E1 or E2 pulses, were beyond the scope of this initial study.

This initial study found that voltage collapse (or blackout) due to E3 EMP alone was possible for several of the scenarios that were simulated. Although it is difficult to precisely determine the geographic area that would be impacted by voltage collapse it is estimated that the impacts could be regional and on the order of several states or larger, but smaller than either the Eastern or Western Interconnections. None of the scenarios that were evaluated resulted in a nation-wide grid collapse. The results of this study are in agreement with earlier work performed by ORNL which indicated that voltage collapse is possible, but nation-wide blackout is unlikely.

Although study results indicate that regional voltage collapse from E3 EMP is possible, the impact of E3 EMP on the bulk power system can potentially be mitigated by reducing or blocking the flow of GICs in bulk power transformers. Mitigation could potentially be accomplished with neutral grounding resistors, capacitive blocking devices, series capacitors, or a combination of these approaches. Designing protection and control systems so that they are

[9] NERC TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events

immune to the effects of power system harmonics, and utilizing automatic switching and load shedding schemes, may also help to mitigate the impact of E3 EMP events. Because transmission operators are not currently provided with warning of an impending HEMP attack and voltage collapse due to E3 EMP occurs rather quickly, manual operator actions are not expected to be timely enough to help mitigate voltage collapse.

Because transformer damage is expected to be minimal, recovery times following a E3 EMP induced blackout are expected to be consistent with prior events *if* damage from E1 EMP and E2 EMP is minimal. The ability of E1 EMP to damage communications systems, supervisory control and data acquisition (SCADA) systems, and protection and control systems is a major concern since loss of these functions can adversely affect system recovery efforts. Therefore, hardening of critical electronic systems within transmission control centers, black-start units, and substations included along cranking paths should be considered.

Results from additional E3 EMP analysis using the LANL E3 EMP environment is expected to be made available by April 30, 2019, as part of the final report.

Next Steps

EPRI's EMP research results are being finalized, and are expected to be made available in a final report by April 30, 2019. The final report is expected to include:

- additional unclassified (bounding) HEMP environments provided by DOE and LANL;
- results from extensive E1 EMP testing of substation equipment such as digital protective relays, SCADA and communications equipment;
- results from E1 EMP, E2 EMP, E3 EMP and combined E1 EMP + E3 EMP assessments;
- approaches for mitigating the effects of HEMP (E1 EMP and E3 EMP) on the electric transmission system with focus on substations; and
- considerations for system recovery following a HEMP-induced blackout.

GMD Research

A geomagnetic disturbance (GMD) or solar storm occurs when the magnetic cloud, called a coronal mass ejection, that is emitted from the sun as part of a solar eruption collides with the Earth's shielding magnetic field. This collision generates currents in the magnetosphere and ionosphere of the Earth's outer atmosphere which in turn induces GIC in transmission lines and transformer windings at the Earth's surface.

Because the primary energy source that drives the flow of GIC in the power grid is typically located nearer the geographical poles, power grids in northern latitudes tend to experience greater impacts. Additional considerations include system voltage level and topology, local deep Earth conductivity and proximity to large bodies of salt water.

The potential bulk power system impacts from GIC generated by a severe GMD event are similar to those described previously regarding E3 EMP. However, there are some important distinctions. First, the geoelectric fields associated with severe GMD events, and hence the GIC flows, tend to be considerably less than those generated by a nominal (bounding) E3 EMP environment. For example, the geoelectric field in Quebec during the March 1989 GMD event has been estimated as approximately 2 V/km as compared with the nominal E3 EMP environments of 24 V/km (ORNL) or 35 V/km (LANL). Additionally, GMD events can last for several days as compared to E3 EMP which only last a few minutes. Lastly, severe GMD events can expose continental-scale areas to varying levels of geoelectric fields whereas exposure from a nominal E3 EMP environment is more regional.

The potential impacts of severe GMD events on the bulk power system are real, and have been observed in the past. For example, during the March 1989 geomagnetic storm, Hydro-Quebec experienced a blackout resulting from the effects of GMD-related harmonics, and a generator step-up unit (GSU) at Salem Nuclear Power Plant in New Jersey was damaged from resulting hotspot heating. Damage to several bulk power transformers resulting from voltage transients associated with system collapse (not to be confused with thermal damage from GIC) was also experienced in Canada. A number of other effects were observed in the United States and Canada, for example tripping of capacitor banks, but these did not result in any significant reliability impacts[10].

EPRI recognizes the potential for severe GMD events to impact the bulk power system, and has been involved in GMD-related research for nearly four decades[11]. Some of EPRI's research activities in this area have included:

- prototype development of GIC blocking devices;
- developing sensors and a support network for measuring geomagnetic fields and GIC flows in transformers;
- developing software tools, models and guidelines to assess the impacts of severe GMD events on the bulk power system;
- evaluating and improving the fidelity of existing models (e.g. earth conductivity);
- improving understanding of potential impacts of GMD events on bulk power system components;
- laboratory/field testing of high-voltage transformers to inform the development of magnetic and thermal models for use in assessments;
- evaluating mitigation options and their application; and
- supporting the development of benchmark GMD events (1-in-100 year solar storms) used in assessments.

Because EPRI's research in the GMD area is expansive, only current activities will be addressed.

[10] North American Electric Reliability Corporation (NERC), March 13, 1989 Geomagnetic Disturbance: www.nerc.com/files/1989-quebec-disturbance.pdf
[11] *Investigation of Geomagnetically Induced Currents in the Proposed Winnipeg-Dulluth-Twin Cities 500 kV Transmission Line.* EPRI, Palo Alto, CA: 1981. EL-1949

Monitoring and Sensors

A critical component of GMD research is measurement of geomagnetic fields and GIC flows in the power grid. Measurements can be used to improve understanding of the phenomenology of an event as well as improve and/or validate models that are used in assessments. Thus, one of the important aspects of EPRI's GMD research program is centered around monitoring and development of advanced sensor technologies.

In order to improve geomagnetic field observations throughout the United States, EPRI currently has research underway to locate 13 next-generation magnetometer sensors (sensors that measure the local geomagnetic field) between existing magnetic observatories operated by the U.S. Geological Survey (USGS). Measurement data will be used to improve deep earth conductivity models and understanding of local geological factors that can potentially impact GIC flows in the network.

The EPRI SUNBURST GIC measurement network consists of a consortium of member utilities through which near-real-time continuous monitoring of the GIC flowing in the neutral of large power transformers is performed. Over the last decade, EPRI has accumulated a body of data and experience about correlations between space weather and GIC flows in the grid. While the primary focus of this research is operating the monitoring network, the data collected in this project is being used to inform model validation efforts and prediction models such as the NASA Solar Shield project.

One of the limitations of measuring GICs using more traditional technology (e.g. SUNBURST sensor) is that the monitoring location must be the neutral of the transformer. Depending on the type of transformer, for example an autotransformer, a neutral connected GIC node may not provide the observability necessary to determine the GIC flows that could affect power system operation and performance. To fill this research gap, EPRI developed an advanced sensor capable of measuring GIC flows in energized conductors. Measurement of GIC in energized AC transmission lines and transformer windings improves observability of the behavior and effects of GIC on the bulk power system. In addition, GIC flows to other parts of the network and in some cases remote transformers can be measured directly. The results from this research is expected to lead to developing more effective network boundary models, and closer representation of actual GIC conditions when assessing impact to transformers.

Research in Support of FERC Order 830 and NERC

In response to the R&D gaps identified in FERC Order 830, EPRI initiated a two-year, collaborative research effort in January 2018 to help address the gaps presented in the Order and to inform future revisions of NERC TPL-007. The intent of this research is to help the electric utility industry and stakeholders advance the collective understanding of the potential impact of extreme GMD events on the bulk power system as well as identify options for mitigating effects. The main objectives of this research effort are to:

- advance the science of defining extreme events on bulk power systems to perform GMD vulnerability assessments;
- evaluate the accuracy of ground conductivity models used for geomagnetically induced current (GIC) studies;
- further study the impacts of GIC currents on power system assets; and
- develop software tools and methods needed to assess the potential impacts of extreme GMD events on the bulk power system.

Currently, this research effort is voluntarily financially supported by 26 utilities and the North American Electric Reliability Corporation (NERC).

Research in Support of Executive Order 13744

EPRI is supporting the U.S. Department of Energy (DOE) in fulfilling the directives outlined in Executive Order 13744 "Coordinating Efforts to Prepare the Nation for Space Weather Events." This Executive Order has several directives for the DOE, including developing a plan and implementing a pilot program to field test and evaluate available technologies that mitigate the effects of GMD on the electrical power grid. In phase 1 (completed), EPRI developed a pilot project plan to implement GMD mitigation equipment on the electrical power grid. EPRI has begun Phase 2 of the pilot project, which will include field deployment of mitigation equipment (and associated monitoring systems) and then monitor, evaluate, and report on the performance of the installed GMD mitigation equipment including adverse system impacts (if any) that may be observed.

Concluding Remarks

The potential impacts of GMD and HEMP are real; however, evaluating the effects of such events on existing and future power grid infrastructure is complicated and requires concrete, scientifically-based analysis. Once the true impacts are known, including the potential unintended consequences of some mitigation options, cost effective mitigation and/or recovery options can be developed and employed.

Significant progress has been made over the course of EPRI's three-year HEMP research project. The final report, which will be made available to the public for free, is expected to be delivered by April 30, 2019. The forthcoming final report will provide the technical basis and findings from a broad array of studies including: interconnection-scale E1 EMP and E3 EMP assessments, an assessment that evaluated the synergistic effects of E1 EMP and E3 EMP, and an E2 EMP assessment. The final report will also provide design options for mitigating the potential impacts that were observed during this research effort and discuss considerations for recovering from HEMP-induced blackouts.

GMD research is ongoing to provide a technical basis for informing future revisions of NERC TPL-007-1. Advancements in power system modeling and description of the 1-in-100 year GMD event have been made and will continue over the next year. This research is expected to advance the state-of-the-art in GMD assessments, and improve industry's ability to predict and mitigate the potential impacts of severe GMD events on the bulk power system.

EPRI is committed to developing science-based solutions to these difficult problems, and will continue to offer technical leadership and support to the electricity sector, public policymakers, and other stakeholders to enable safe, reliable, affordable, and environmentally responsible electricity.