Description of document: Electromagnetic Pulse Risk to the Tennessee Valley Authority (TVA) Bulk Power System; Initial Review of the Impact of Extreme Geomagnetic Storms to TVA Operations, Findings and Recommendations, 2010

Requested date: 10-November-2018

Release date: 20-November-2018

Posted date: 04-February-2019

Source of document: TVA FOIA Officer
400 West Summit Hill Dr. WT 7D
Knoxville, TN 37902-1401
Fax: (865) 632-6901
Email: foia@tva.gov

Tennessee Valley Authority, 400 West Summit Hill Drive, Knoxville, Tennessee 37902-1401

November 20, 2018

This responds to your request under the Freedom of Information Act (FOIA) 5 U.S.C. 552 received November 10, 2018. You requested a copy of the report Initial Review of the Impact of Extreme Geomagnetic Storms to TVA Operations: Finding and Recommendations, December 2010 and any follow on report regarding Electromagnetic Pulse Risk to the Tennessee Valley Authority Bulk Power System. This request was processed under tracking number #5371.

Enclosed is a copy of the report responsive to your first request. We had released a redacted copy of this report in response to previous FOIA requests, but due to the passage of time have determined the report may be released without redactions.

We do not have a follow on report to provide you. Information about what TVA is currently doing in the area of electromagnetic pulse may be found on the TVA website at this address https://www.tva.com/Energy/Transmission-System/Protecting-the-Grid.

If you have questions about this response, you may contact me at (865) 632-6945. In addition the Office of Government Information Services (OGIS) and TVA offer FOIA mediation services. Enclosed is contact information for those services.

You may appeal this initial determination of your FOIA request by writing to Ms. Janet J. Brewer, Senior Vice President, Chief Communications & Marketing Officer, Communications & Marketing, Tennessee Valley Authority, 400 W. Summit Hill Drive (WT 7C), Knoxville, TN 37902-1401. Any appeal must be received by Ms. Brewer within 90 days of the date of this letter.

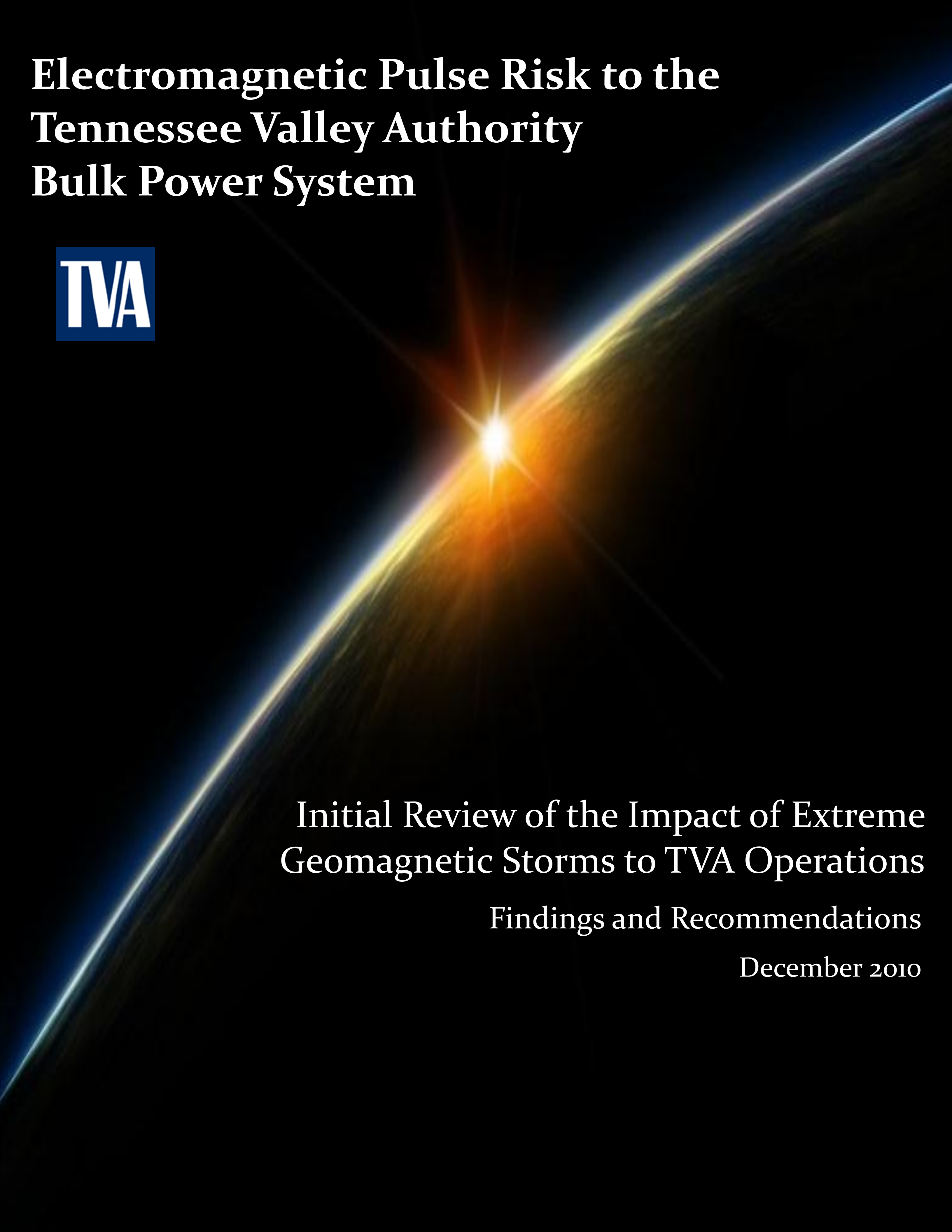
Sincerely,

Denise Smith

Denise Smith
TVA FOIA Officer

Enclosures

Electromagnetic Pulse Risk to the Tennessee Valley Authority Bulk Power System



TVA

Initial Review of the Impact of Extreme Geomagnetic Storms to TVA Operations

Findings and Recommendations

December 2010

Electromagnetic Pulse (EMP) Risk to the Tennessee Valley Authority Bulk Power System

Initial Review of the Impact of Extreme Geomagnetic Storms to TVA Operations

Table of Contents

List of Figures ... ii

List of Tables ... ii

Executive Summary ... 1

- Primary Recommendations ... 1

Understanding the Risk ... 2

- Introduction ... 2
- Risk Posed to TVA Systems Due to Electromagnetic Pulse ... 3
- Coordinated Attack Risks ... 4
  - High Altitude Electromagnetic Pulse (HEMP) ... 4
  - Improvised Nuclear Device (IND) ... 5
  - Intentional Electromagnetic Interference (IEMI) ... 6
  - Mitigation of Risk Associated with Coordinated Attack ... 6
- Naturally Occurring Risk ... 7
  - Geomagnetic Disturbance (GMD) ... 7

Impact to TVA ... 12

- System Vulnerabilities ... 12
  - Description of TVA TRO-TO-SOP-30.188 ... 14
- Improving Reliability Resiliency ... 17
- TVA Reliability Coordinator ... 17
- TVA Reliability Coordinator Responsibilities ... 18
  - TVA Control Centers ... 18
  - TVA Reliability Coordinator Data Exchange ... 18
  - GMD Event Notification is the Foundation of GMD Risk Mitigation ... 19
  - EPRI SUNBURST GIC Monitoring Program ... 20
- Role of TVA Emergency Management ... 20
  - Related Emergency Plans ... 21
- The Time to Put a TVA GMD Program in Place is Now ... 22

Recommendations ... 24

Recommendation Number 1: Identify Geomagnetic Disturbance as a naturally occurring Electromagnetic Pulse risk that warrants priority in the TVA risk management process. 24

Recommendation Number 2: Perform a systems based analysis including research and development to identify and mitigate Geomagnetic Disturbance and Geomagnetically Induced Current vulnerabilities to high value assets. 26

Recommendation Number 3: Incorporate early warning notification and awareness of Geomagnetic Disturbances into emergency and system operational policies and procedures. 30

Appendix A: Crosswalk of Federal and TVA Recommendations for EMP 33

Appendix B: The TVA EMP Working Group 34

Glossary of Related Terms 35

Acronyms 38

References and Additional Sources of Information 41

List of Figures

Figure 1: Time Components of HEMP (Metatech Report Meta-R-321, Jan 2010) 4
Figure 2: Visible Solar Filament of Magnetism 7
Figure 3: Solar Cycle Indicators for the Next Occurrence of GMD 8
Figure 4: GMD Regional Disturbances (Metatech Report Meta-R-319, Jan 2010) 10
Figure 5: 100 Year Geomagnetic Storms - 45 degree Geomagnetic Disturbance Scenario 10

List of Tables

Table 1: Historical GMD Events of Significance 9
Table 2: NOAA Space Weather Scale for Geomagnetic Storms 11
Table 3: EMP Impacted Assets 12
Table 4: Critical Assets Specifically Affected by HEMP and GMD 12
Table 5: EMP and GMD System Vulnerability Description 13
Table 6: TVA Roles and Responsibilities 15
Table 7: Power Systems Risks and Causes 15
Table 8: Operating Instructions 16
Table 9: Vulnerable Reactive Reserve Regions 16
Table 10: Current GMD Notification Flow 20
Table 11: Relationship of Existing TVA Emergency Plans and Procedures to GMD 21
Table 12: How Taking Steps Now Aligns to the Solar Cycle 22
Table 13: Estimated Cost to Install Instrumentation Devices on GMD Vulnerable TVA Critical Assets 29
Table 14: Crosswalk of Federal and TVA Recommendations 33
Table 15: TVA EMP Working Group and Special Acknowledgements 34

Executive Summary

The U.S. economy and national security posture is reliant upon stable critical infrastructures, and all 17 U.S. critical infrastructure sectors[1] are reliant on access to electricity. The North American power grid is one of, if not the most, reliable in the world. While few threats have the ability to catastrophically impact the power grid, Electromagnetic Pulse (EMP) risk has been identified as one of those threats.

EMP events are classified as high-impact, low-frequency (HILF) events and are divided into two categories. Man-made EMP includes the pulse produced by weapons designed specifically to disrupt or destroy electronic equipment. Naturally occurring EMP, which is produced by solar activity, is referred to as geomagnetic disturbance (GMD). Without proactive risk mitigation actions, "100 year" type GMD events could cause major, permanent damage to Tennessee Valley Authority (TVA) power system components and result in a partial or total shutdown of transmission operations.

Effectively mitigating the effects of an EMP event on TVA infrastructure requires a combination of preventative measures, analysis, and system design considerations as well as a proactive risk management strategy that incorporates advanced notification and adjusts existing emergency management plans, processes and procedures. For the United States, the cost of damage from the most extreme solar event has been estimated at $1 to $2 trillion with a recovery time of four to ten years, while the average yearly cost of installing equipment to mitigate an EMP event is estimated at less than 20 cents per year for the average residential customer.[2] This report presents solutions that are low cost and can be readily integrated into existing TVA risk management programs.

Primary Recommendations

This report provides recommended actions that can be used by TVA to protect infrastructure, manage risks, and mitigate impacts. The actions are varied, ranging from increasing operator awareness to interagency outreach and coordination. Listed below are the major recommendation topics to the TVA Risk Steering Group that are further detailed in the Recommendations section of this report:

- Recommendation Number 1: Identify Geomagnetic Disturbance as a naturally occurring Electromagnetic Pulse risk that warrants priority in the TVA risk management process.
- Recommendation Number 2: Perform a systems based analysis with additional research and development to identify and mitigate Geomagnetic Disturbance and Geomagnetically Induced Current vulnerabilities to high value assets.
- Recommendation Number 3: Incorporate early warning notification and awareness of Geomagnetic Disturbances into emergency and system operational policies and procedures.

[1] Homeland Security Presidential Directive 7 (HSPD-7): Critical Infrastructure Identification, Prioritization, and Protection identifies 17 critical infrastructure sectors and key resources.

[2] Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report, National Academy of Sciences, 2008.

Understanding the Risk

Introduction

The threat of an electromagnetic pulse (EMP) attack or a severe "once every 100 years" geomagnetic disturbance (GMD) presents many challenges and risks to energy infrastructure. These challenges and risks have been identified by a number of official U.S. government sources. In 2010, the North American Electric Reliability Corporation (NERC) completed the "High-Impact, Low-Frequency (HILF) Event Risk to the North American Bulk Power System" report which specifically identified the potential cause of long-term, catastrophic damage to bulk power systems from EMP events. Additionally, two reports produced by the presidentially mandated EMP Commission outlined energy sector vulnerabilities to EMP. These reports are the "Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume 1: Executive Report" of 2004, and the "Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Critical National Infrastructures" of 2008.

While the official reports provide insight into the problem, their recommendations do not include specific actions for an operational organization like TVA to implement, nor do they outline the scope of the impact to Tennessee Valley Authority (TVA). As a result, TVA leadership chartered a working group to determine if TVA operations were at risk from EMP and, if so, which components of EMP would have the most impact on TVA operations. To understand the situation, the working group assessed the range of impact of four different types of EMP threats:

1. Geomagnetic Disturbance (GMD)
2. High-altitude Electromagnetic Pulse (HEMP)
3. Improvised Nuclear Device (IND), and
4. Intentional Electromagnetic Interference (IEMI).

The working group concluded that of these four types, IND and IEMI threats are more apt to be localized in impact. These localized attacks could affect a portion of TVA operations and be quite catastrophic to the impacted area, but the overall impact is not of the type that would devastate TVA operations. The system and emergency plans, processes and procedures that TVA currently has in place would be adequate to maintain power system reliability in the face of most IND or IEMI events.

However, the working group agrees that the GMD and HEMP components of EMP could rapidly and completely interrupt TVA's ability to deliver power to its customers. The impact from either of these events is so potentially devastating that the capability to transmit bulk power may not be restored for many months, if not longer. Either of these events could severely damage or completely decommission EHV transformers and capacitor banks within seconds, thereby making bulk power transmission unreliable, if not disrupted. The immediate impact is, at a minimum, cascading outages, and at worse, a complete blackout with no viable restart capability. There are no system or emergency plans, processes and procedures that currently exist that can manage the scope of the impact from these two threats. In terms of impact, even a few weeks of power loss to the 9 million users served by TVA would be disastrous.

The working group carefully examined these two catastrophic risks, HEMP and GMD, and determined that of the two, TVA was in an exceptional position to implement a risk management strategy for GMD. The decision to focus on GMD was due to several factors:

1. TVA already receives severe space weather forecasts that provide warning and notification of potential GMD.
2. TVA has been impacted by GMD and the resulting geomagnetically induced current (GIC) in the past.
3. TVA has known system vulnerabilities and has initiated a set of preliminary procedures for system operation.
4. TVA is establishing a "Tailored Collaboration" to participate in the Electric Power Research Institute (EPRI) SUNBURST geomagnetically induced current (GIC) monitoring program.
5. TVA critical assets affected by GMD will have some resiliency to HEMP if the right analysis, design changes, and advanced warning procedures can be implemented.
6. TVA is not well positioned to make operational changes to harden and shield against specific HEMP-related pulse impacts to micro-electronics and other sensitive electrical components.

This report presents findings and makes relatively low cost recommendations on steps TVA can take to become more operationally resilient to catastrophic forms of EMP. The three specific recommendations presented in this report serve as the foundation for a holistic risk mitigation strategy TVA can implement for the GMD component of EMP. The recommendations within this report will serve not only as a strategic risk mitigation roadmap for TVA, but also provide a platform to open dialogue with TVA stakeholders and critical infrastructure partners.

Risk Posed to TVA Systems Due to Electromagnetic Pulse

EMP is a burst of electromagnetic radiation resulting from a nuclear explosion or from a rapidly fluctuating magnetic field occurring in nature such as in a Geomagnetic Disturbance (GMD). Whether the EMP originates from a nuclear detonation or from a natural event, the resultant rapid spike in electromagnetic energy can couple to electrical/electronic systems causing minor to extensive system damage or disruption. Using the NERC HILF classifications[3], the primary EMP threats to TVA have been placed into two categories: Coordinated Attack Risk and Naturally Occurring Risk. This section will discuss both categories and provide insight into the components of these threats.

[3] NERC "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," June 2010.

Coordinated Attack Risks

There are three main types of EMP threats that are man-made and come as the result of a coordinated attack from an adversary. High Altitude Electromagnetic Pulse (HEMP) and Improvised Nuclear Device (IND) threats are a result of nuclear detonations. Intentional Electromagnetic Interference (IEMI) is caused by radio frequency pulses, high powered microwaves, or other interference from a directed energy weapon.

High Altitude Electromagnetic Pulse (HEMP)

A High Altitude Electromagnetic Pulse is the result of a nuclear warhead detonated hundreds of kilometers above the earth's atmosphere. A HEMP device placed at the optimum altitude and geographic position by an adversary can have a devastating effect on nearly every electrical component within pulse range of the detonation. Unlike nuclear detonations closer to the earth's surface, the danger is not from radioactive fallout, but rather in the ability to rapidly affect unshielded electrical components as well as create geomagnetically induced current (GIC) on the systems providing bulk power transmission.[4]

The HEMP pulse can be thought of as being composed of three "component" pulses:

- E1 (early-time), from times below one nanosecond after detonation to one microsecond;
- E2 (intermediate-time), from one microsecond to one second; and
- E3 (late-time), later than one second.

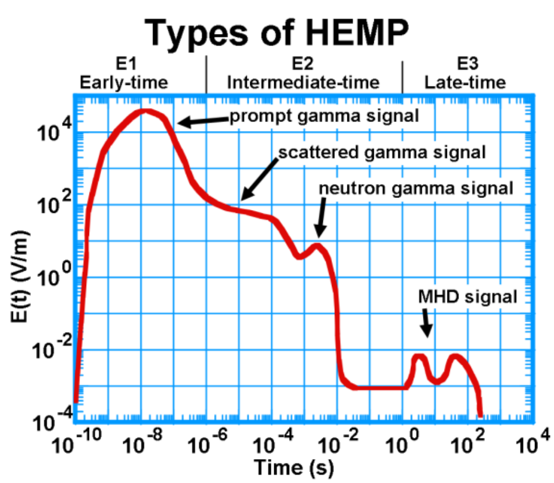


Figure 1: Time Components of HEMP (Metatech Report Meta-R-321, Jan 2010)

[4] Comprehensive information regarding HEMP effects and impacts to the power grid is provided in NERC "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," June 2010 , Meta-R-320 "The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid," January 2010 and Meta-R-321 "The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid," January 2010.

E1 Pulse Early-Time Component

The E1 component is the very fast component of nuclear EMP and is only produced by a nuclear weapon. The pulse is the result of free electrons stripped by gamma radiation from a nuclear explosion interacting with the Earth's magnetic field. The E1 pulse peaks after 5-10 nanoseconds and is over within 1 microsecond after the explosion occurs. The maximum field strength is dependent on several factors (including weapon yield, height of burst (HOB), weapon design, geography, and latitude), but is limited to about 50,000 volts/meter (V/m) at Ground Zero.[5] The primary pathway for the E1 HEMP to reach the electronic equipment that control the operation of the grid is through the coupling of the E1 HEMP fields to cables and wiring, producing conducted transients that can exceed the withstand capability of the connected electronics. In addition, the distribution line insulators and transformers connect to the aboveground electric wires and are thus also influenced by the coupled E1 HEMP fields.[6] An E1 pulse will cause integrated circuits with cables connected to overheat and give false readings, resulting in damage to or destruction of the device.

E2 Pulse Intermediate-Time Component

The E2 pulse bears many similarities to the electromagnetic pulses produced by lightning, but is more similar to thousands of lightning strikes hitting power lines simultaneously. It is the least dangerous type of EMP because of the widespread use of lightning protection. It is important to be aware that damage from the earlier E1 pulse could partially degrade existing lightning protection measures.

E3 Pulse Late-Time Component

The E3 EMP component is a much slower pulse. The time delay is caused by the Earth's magnetic field being pushed out of the way by the plasma produced by the nuclear explosion or solar storm followed by the field being restored to its natural place. This phenomenon can produce geomagnetically induced current (GIC) in long electrical conductors (like power lines) which can damage or destroy power transformers. The E3 pulse lasts from tens of seconds to several minutes, and produces GIC in conductors, particularly in long distance electrical power transmission lines. The longer the conductor and the lower its resistance, the easier the GIC can flow. Direct currents of hundreds to thousands of amperes (Amps) will flow into transformers, potentially causing overheating and fires. Windings capable of carrying up to 3,000 Amps of alternating current can be destroyed by geomagnetic direct currents of only about 300 Amps. This third pulse from a HEMP nuclear device is very similar to the pulse generated by a naturally occurring GMD, and so damage prevention measures are, in theory, identical.

Improvised Nuclear Device (IND)

An Improvised Nuclear Device is a nuclear weapon possessed by terrorist group or other adversary. Components for the weapon are usually bought, stolen, or fabricated from illegally obtained fissile material. The IND would typically be detonated on the ground in a strategic location such as a large city or other population center. Unlike a dirty bomb, this is not an explosive device with radioactive material

[5] Extensive information on E1 can be found in Meta-R-320 "The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid," January 2010.

[6] Page 82, NERC "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," June 2010.

added to it. Rather its method of detonation is from a nuclear sequence and there is an actual nuclear explosion.

An IND of fairly modest explosive yield (i.e., 5-10 kiloton) successfully detonated in a populated area would release blast, thermal, radiation, and EMP effects causing catastrophic damage to infrastructure, buildings, and communications, and large numbers of casualties in a range of 1-10 miles from the explosion. In addition, radioactive fallout from the event would lead to further loss of life and damage to property. EMP will be produced by the ionization and acceleration of electrons from the air and other materials by the intense radiation of the detonation, including a sharp, high-voltage spike radiating outward from the detonation site. The EMP from this attack has the potential to disrupt telecommunications networks, other electronic equipment, and associated systems within approximately a 5-kilometer (~ 3-mile) range from ground zero. Although these EMP effects would be disabling to systems within the blast area, the combined impacts of the physical infrastructure damage and casualties caused by this type of attack will stress local and regional response systems. However, the potential impact to TVA bulk power systems is negligible and isolated, depending on where the device is detonated.

Intentional Electromagnetic Interference (IEMI)

Intentional Electromagnetic Interference is a portable directed energy weapon. The weapon produces electromagnetic fields using either high powered microwaves or ultra-wide-band pulses. An IEMI directed at a telecommunications or control center can have a deleterious, although localized, effect on electronic systems. Rapid advances in radio frequency (RF) sources and antennae have made possible an increasing variety of equipment capable of generating very short RF pulses that can disrupt sophisticated electronics. These devices take advantage of the fact that electronic components and circuits, such as microprocessors, are working at increasingly higher frequencies and lower voltages – and thus are increasingly more susceptible to electromagnetic interference (EMI). Pulse radiation devices may consist of two main types. High power microwave (HPM) devices produce high power in a narrow frequency band, which could cause “front door” damage. Ultra-wide-band (UWB) devices produce a narrow time-domain pulse, and are more likely to cause “back door” disruption or damage. EM field power density decreases with the square of the distance from the source, so the proximity of an EM generator to the targeted equipment is clearly a major factor in causing damage. Although the type of electronic disruptions caused by these devices would be of concern should they be used, the effects are of short range and limited in scope as compared to either GMD or HEMP.

Mitigation of Risk Associated with Coordinated Attack

Coordinated attacks conducted by adversaries, including terrorists armed with nuclear weapons is credible and real. However, system level mitigation strategies to survive a catastrophic HEMP attack is beyond the resources of most regional power generators, including TVA. EMP Coordinated Attack scenarios require cooperation, analysis and resources at the national level and will involve all sectors of the critical infrastructure as well as the Department of Defense (DoD).

Naturally Occurring Risk

Geomagnetic Disturbance (GMD)

Geomagnetic disturbance (GMD) events originate in large solar flares (coronal mass ejections) and result in a rapid displacement of the earth's magnetic field, leading to an EMP event similar to the E3 pulse from a HEMP device as described in the previous section. These events impact power grids by causing slowly varying electric fields in the atmosphere that induce currents known as geomagnetically induced current (GIC) in long power transmission lines. GIC can potentially cause damage or failure of generation equipment and transformers, leading to complete loss of transmission or a cascading grid failure. These solar storm events have occurred on a regular and fairly predictable basis and have affected power distribution systems globally. Although severe events affecting lower latitudes occur infrequently, the impact to transmission systems can be devastating as explained in the Systems Vulnerability section of this report. Figure 2 shows a specific solar event occurring at the time of this report.

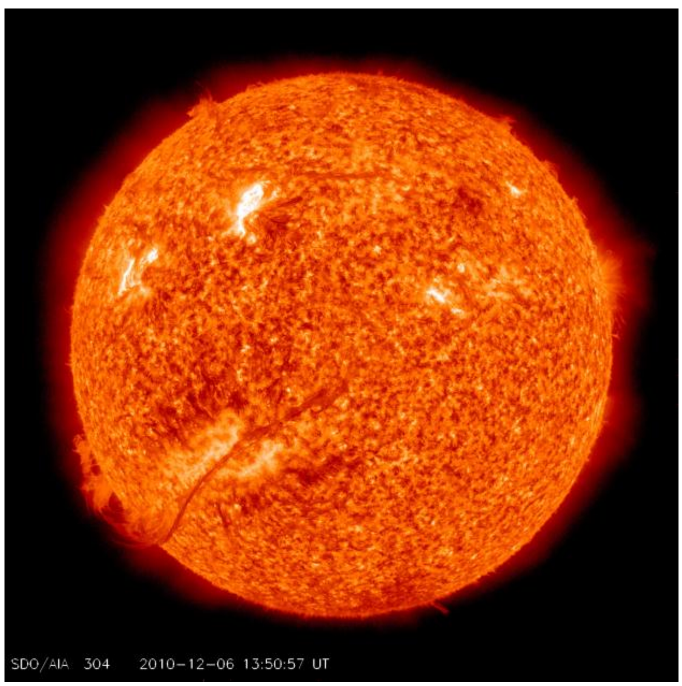


Figure 2: Visible Solar Filament of Magnetism[7]

In contrast to the threat posed by a coordinated attack HEMP event, GMD events can and do occur on a cycle. There is a solar cycle with a period of about 11 years (the current Solar Cycle is #24). Solar flare activity reaches its peak during the solar maximum, and the next "solar max" is expected to occur in 2013. The solar cycle drives variations in space weather, and is observed by counting the frequency and

[7] A spectacular filament of magnetism is snaking around the sun's southeastern limb. From end to end it stretches more than 700,000 km--a full solar radius or almost twice the distance from Earth to the Moon. Space Weather News, December 6, 2010. http://spaceweather.com

placement of sunspots visible on the sun. Large and potentially damaging geomagnetic storms are predicted for the height of the next solar sunspot cycle during the 2012-2013 timeframe. Likewise, there is a period of time following this cycle of approximately 3 to 5 years following the peak, placing the range of activity into the year 2018.

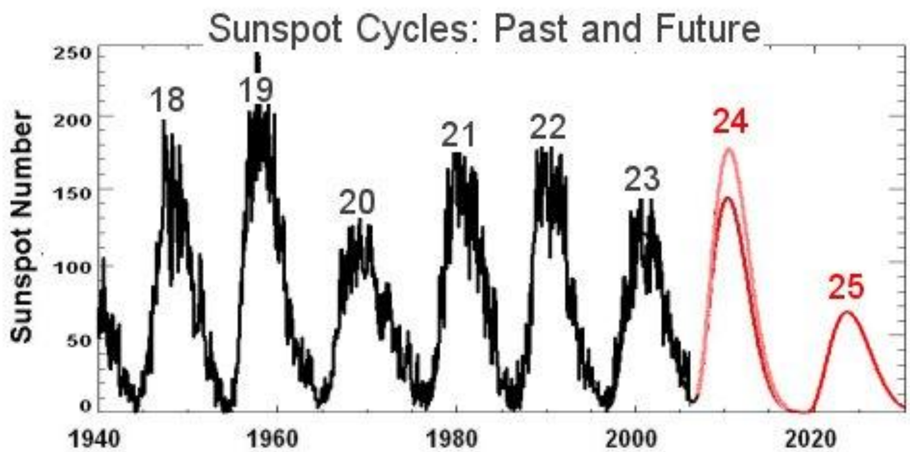


Figure 3: Solar Cycle Indicators for the Next Occurrence of GMD

(Metatech Report Meta-R-319, Jan 2010)

Table 1 provides a highlight of historical GMD events that have impacted infrastructure on Earth's surface.

Table 1: Historical GMD Events of Significance

Event	Impact
1859: Carrington Event	Largest geomagnetic storm on record; caused damage to telegraph systems in North America and Europe. Heralded the advent of space weather and the impacts on human technology systems. • Using the Dst (an alternative storm index) as an estimate of the storm intensity, the 1859 storm is estimated to have reached a level of -1760, a level that is ~3 times larger than the March 13-14, 1989 Great Geomagnetic storm.
1882: Transit of Venus Storm	All telegraph systems in the Northeastern US were disrupted.
1921: New York Railroad Storm	Disturbance levels are nearly 10 times larger than levels that precipitated the North American power system impacts of 13 March 1989. The large ~5000 nT/min observed in May 1921 has occurred before and is therefore likely to occur again. • Switching systems of the New York Central Railroad were put out of operation as well as interfering with telephone and telegraph operations throughout North America and Europe.
1940	First reported power system problems associated with a geomagnetic storm occurred during a GMD.
1989: Hydro Quebec Storm	The 1989 storm affecting Quebec Hydro left 6 million people without power. Quebec Hydro is especially susceptible to GMD and GIC due to: • Location in the northern latitudes, near the frequent location of the auroral electrojet current. • Geographic area of relatively high resistive igneous rock. • Operation of very high voltage 735 kV transmission network that experiences higher magnitudes of GIC flow than lower voltage networks. • Population of 735 kV transformers that are predominantly single-phase units, which readily saturate and, because of the high voltage rating, consume proportionately higher reactive power demands. • Has transmission transfer capability that is highly dependent upon intermediate shunt capacitive compensation devices (in this case, multiple SVCs) to maintain proper voltage regulation at all times.
1992	Observations were recorded of neutral GIC and tank wall temperature near the known hot-spot on the transformer.
2001	Sudden onset of a geomagnetic storm with a transformer failure in New Zealand which occurred on Nov. 6, 2001.
2003	October 2003. Eskom, the power utility that operates the power grid in South Africa (geomagnetic latitudes -27 to -34 degrees) , reported damage and loss of 15 large, high voltage transformers (400 kV operating voltage) due to the geomagnetic storms of late October 2003. This damage occurred at peak disturbance levels of less than 100 nT/min in the region.

Growth in the high-voltage grid over the past 3-4 solar cycles has caused a dramatic increase in the size of the “antenna” for “collecting” GMD disturbances. As the grid has grown in size, it has also become more complex. Changes in the technology base have evolved the grid to higher operating voltages from the 115-230 kV levels of the 1950’s to networks that operate at 345 kV, 500 kV, and 765 kV. Modern design attributes tend to collect and concentrate GIC flows in the higher-voltage portions of the bulk power system. Were a large enough storm to occur, it could result in the simultaneous loss of multiple major transmission corridors, which could cause widespread outages. Operational procedures to reduce loading on heavily loaded lines and more evenly distribute the flow of power across the system during a GMD could help to mitigate this risk. A strong geomagnetic disturbance will directly impact the southeast region. An event centered at 45° geomagnetic latitude covers nearly the entire TVA operating area as seen in Figure 3.

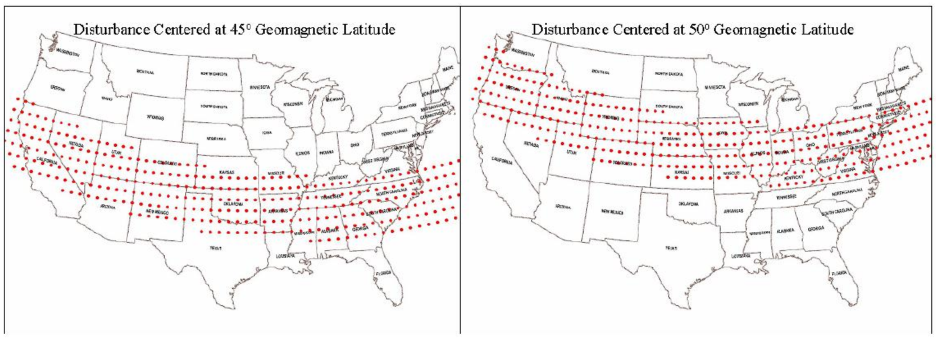


Figure 4: GMD Regional Disturbances (Metatech Report Meta-R-319, Jan 2010)

Susceptibility to GMD-induced failure is complex and depends on geographic influences. According to a study done by Oak Ridge National Laboratory, the southeast region is in a zone which is highly vulnerable as shown in the figure below.

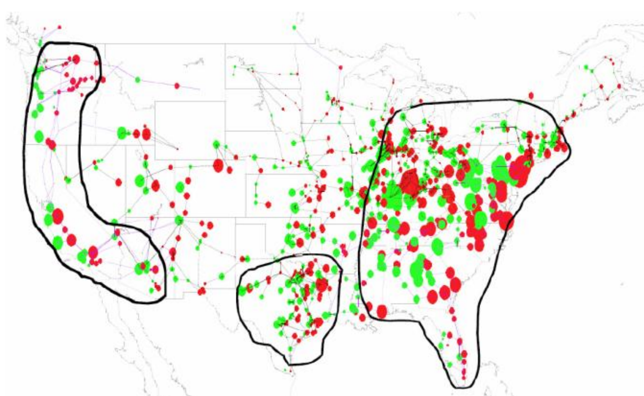


Figure 5: 100 Year Geomagnetic Storms - 45 degree Geomagnetic Disturbance Scenario (Metatech Report Meta-R-319, Jan 2010)

The National Oceanic and Atmospheric Administration (NOAA) issues advance notification of pending solar events. These events are measured based on the Kp Index, an indication of the severity of GMD in near-Earth space. Kp is based on the average of measurements at 13 ground magnetic field observatories. The values of the Kp range from 0 (very quiet) to 9 (very disturbed) in 28 discrete steps, resulting in values of 0, 0+, 1-, 1, 1+, 2-, 2, 2+, ... 9. The index data are distributed by NERC via the Reliability Coordinator Information System (RCIS). Analysis of the records of contemporary and historical GMD events that cause large GIC flows indicate that significant impacts to the power grid infrastructure have been observed on at least three occasions since 1972 at latitudes of concern for the North American bulk power system. In an extreme scenario, available data suggests that disturbance levels as high as 5000 nT/min may have occurred during the geomagnetic storm of May 1921, intensity roughly 10 times larger than the disturbance levels observed in the Hydro Quebec Storm of 1989. If a storm were to occur with these intensity levels, it is reasonable to expect that the TVA bulk power system would experience major impacts.

TVA uses the NOAA scale for determining the severity of solar events. A correlation between the NOAA scale and the Kp index with a description of effects is listed in Table 2.

Table 2: NOAA Space Weather Scale for Geomagnetic Storms

Scale	Descriptor	Effect (Duration of Event will influence severity of effects)	Kp values	Number of storm events when Kp level was met (number of storm days)
G5	Extreme	**Power Systems:** widespread voltage control problems and protective system problems, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other Systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).	9	4 per cycle (4 days per cycle)
G4	Severe	**Power Systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other Systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).	8	100 per cycle (60 days per cycle)
G3	Strong	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).	7	200 per cycle (130 days per cycle)
G2	Moderate	**Power systems:** high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).	6	600 per cycle (360 days per cycle)
G1	Minor	**Power systems:** weak power grid fluctuations can occur. **Spacecraft operations:** minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).	5	1700 per cycle (900 days per cycle)

Impact to TVA

System Vulnerabilities

The three EMP pulse components each have a different impact on power system infrastructure and assets. E1 and E2 pulses are specific to nuclear explosions, but both HEMP and GMD create an E3 pulse that put certain assets at risk. Table 3 outlines which critical bulk power assets are typically impacted by each component of an EMP pulse.

Table 3: EMP Impacted Assets

E1	E2	E3
• Electronics-based control systems • Sensors • Communication systems • Protective systems • Computers • SCADA, DCS, PLC • Generator systems • Fuel Systems • Environmental mitigation systems	• Protective and control features • Major systems components	• Electrical Supply Systems • Electrical Distribution Systems • Long electricity transmission lines • Power Line Transformers

The E3 pulse created from HEMP or GMD event can damage or destroy critical bulk power assets. The effect is the same and therefore, establishing a program at TVA to improve resiliency to GMD will also increase system resilience to HEMP. Table 4 identifies the common assets.

Table 4: Critical Assets Specifically Affected by HEMP and GMD

HEMP	GMD
500 kV Single Phase Transformer 500 kV Three Phase Transformer Static Var Compensators (SVC) Protective Relays 161 kV Capacitor Banks Communications Emergency Generators	

Techniques to mitigate or reduce damage to high value assets have been investigated by NERC, FERC, the EMP Commission, Metatech, TVA, and numerous other sources. Based on a review of industry research documents and TVA TRO-TO-SOP-30.188, single-phase and three-phase transformers, static VAR compensators, relays, capacitor banks, communications systems, and emergency generators are high value assets that are vulnerable in the event of an EMP event.

Each asset is uniquely vulnerable having different impacts to the power system thus requiring specific mitigation techniques shown in Table 5.

Table 5: EMP and GMD System Vulnerability Description

Item Name	Description	Impact Description	Mitigation Technique	Document
500 kV Transformer (Single Phase Design)	Handles electrical power within the transmission system and its interfaces with the generation and distribution systems. Single phased designs are more susceptible to GIC.	Single-phase transformers are more responsive to GIC than most 3 phase designs. The transformer suffers high current, with extreme peaks on the saturated half-cycle, overheating the unit and increasing internal losses.	Supplemental transformer neutral ground resistors (Metatech Press Release 1/11/09)	TRO-TO-SOP-301 188, Metatech Press Release (1/11/09), Oak Ridge - 2010 GMD Events_Meta-R-319
500 kV Transformer (Three Phase Design)	Handles electrical power within the transmission system and its interfaces with the generation and distribution systems. Three phased designs less susceptible to GIC.	TVA has 39 Substations and 28 Generator Step-Up (GTU), 9 are base load generators. GIC monitoring is present on 9 500 kV substation transformers, but no active monitoring. All 39 substation transformers are single-phase designs (each bank made up of three single-phase transformers). Of the 28 GSUs, 7 are single-phase design, with the remaining 21 banks being three-phase designs (one three-phase transformer)	Supplemental transformer neutral ground resistors (Metatech Press Release 1/11/09)	TRO-TO-SOP-301 188, Metatech Press Release (1/11/09), Oak Ridge - 2010 GMD Events_Meta-R-319
Static Var Compensators (SVC)	Provides fast-acting reactive power on high-voltage electricity transmission networks, regulating voltage and stabilizing the system.	GIC flows into transformers causing increases in power demand due to half cycle saturation effects causing SVC's to turn themselves on to supply the increased reactive demand.	Revise the relay settings on the SVCs and make other modifications to allow higher levels of harmonic current loading before initiating a trip.	Oak Ridge - 2010 GMD Events_Meta-R-319
Protective Relays	Calculates operating conditions on an electrical circuit and trip circuit breakers when a fault is detected.	Harmonics from transformer saturation in a capacitor bank can be sensed as an overload causing protective relays to trip. The loss of reactive support combined with increased reactive demand from power transformers can degrade network reliability.		Oak Ridge - 2010 GMD Events_Meta-R-319
161 kV capacitor banks	A collection of individual capacitor units used to support system voltage.	Harmonic currents can cause tripping of 161 kV capacitor banks by neutral ground overcurrent relays with flat frequency response causing damage to EHVs. TVA has 71 161 kV capacitor banks. Of these, 18 installations have GE SFC or DSFC relays for ground overcurrent protection making them susceptible to tripping during GIC/GMD.	Replace the GE SFC/DSFC relays on 161 kV capacitor banks with those that will operate only on 60Hz quantities.	TRO-TO-SOP-301 188
Communications	Electronic transmission of signals and data at a distance. Telecommunication is the systems used in transmitting such signals.	Communications and control systems are at risk of disruption and damage to EMP. Minimal communications capability is needed for immediate responses, to isolate parts for continued operation, and to implement measures to restore the electrical system. Radios (mostly the bands below 30 MHz) are disrupted. Some cell phone tower antennas impacted. Cellular networks are less robust to EMP than landline networks due to the higher susceptibility of cellular network equipment to damage and limited backup power capacity at cell sites.	Perform tests to determine the coupling and propagation characteristics of cables and the withstand levels of the sensors and circuit breakers. Tests should determine cost effective ways of improving high frequency grounding characteristics at the j-boxes inside control buildings.	Threat EMP Report 2008 - EMP Commission Report - FINAL REPORT - EMP Commission.
Emergency Generators	Emergency Generators may include lighting, generators, fuel cells and other apparatus, to provide backup power in a crisis or when regular systems fail.	Generators that are connected to the grid to switch to generator power immediately upon a failure making them susceptible to GIC interference. Backup generators may not function after an EMP event if they contain sensitive electronic components such as electronic control units resulting in the inability to produce short term power.	Evaluate generators for coupling of E1 HEMP into control cables. Evaluate standard high-frequency protection methods to determine the most effective application to the actual generation facility.	Release (1/11/09), Oak Ridge - 2010 GMD Events_Meta-R-319, Threat EMP Report 2008 - EMP Commission Report - FINAL REPORT - EMP Commission.
SCADA Systems	SCADA systems provide System Operators with control and monitoring of the power system so that power is directed where it is needed, frequency is maintained, and the system is operated reliably.	The E1 pulse can upset the protection and control system, damaging control and protective system components, and cause the plant to trip or trigger emergency controlled shut down. SCADA vulnerability is focused on the early time E1 component of the EMP signal because SCADA systems generally are not directly coupled to the very long cable runs that might be expected to couple to a late-time E3 signal.	Measurement of shielding effectiveness should be done based on the design and geometry of control centers. Geometry of cables with power communications entering the facilities should be analyzed. Assessments of the vulnerability and the need for hardening will be completed.	Threat EMP Report 2008 - EMP Commission Report - FINAL REPORT - EMP Commission.

In terms of TVA power grid assets, the primary risk involves damage to EHV (500 kV) transformers from half-cycle saturation and the loss of reactive support due to tripping of capacitor banks and/or static reactive devices. TVA has 39 substation and 28 Generator Step-Up (GSU) EHV level transformer banks that are susceptible to GIC. Nine TVA GSU locations are base load generators that are continuously loaded close to maximum capacity. Customer and Independent Power Producer (IPP) locations also have similar transformer banks at risk on TVA's EHV system.

Taking action to prevent the failure of one or two transformers, or investing in the ability to quickly replace a key system component can make the difference between seamless recovery and a long-term outage. While unrelated to GMD, nonetheless, the worst outage event in U.S. history, a blackout on Aug. 14, 2003, was triggered by the failure of two 345 kV lines and the outage of a 597 MW power plant.

As a result of geomagnetic activity in 1989 and 2000 that caused damage to high value transmission assets in neighboring power grids and capacitor bank tripping within the TVA infrastructure, TVA has developed a procedure to deal with the effects of GMD. TVA TRO-TO-SOP-30.188 outlines roles and responsibilities of system operators and engineers, power system risks and causes, and operating instructions. A synopsis of this procedure has been created to represent the information contained within TVA TRO-TO-SOP-30.188.

Description of TVA TRO-TO-SOP-30.188

Purpose: This document describes the phenomenon of solar magnetic disturbances (SMD)[8], their effects on and potential risks to the power system, and recommended operating responses on receiving warnings of an impending SMD.

Scope: The document covers transmission and generating plant assets, both TVA and non-TVA owned, within the TVA service area.

Background:

- Geomagnetically-induced current can flow through the neutrals of wye-grounded windings of EHV power transformers, resulting in half-cycle saturation that can damage the transformer core (e.g., March 1989 event resulted in destruction of a GSU and a substation transformer in PJM area).
- Power transformers affected by half-cycle saturation generate harmonic currents that can flow in 161 kV capacitor bank neutrals. These harmonic currents can cause tripping of the 161 kV capacitor banks by neutral ground overcurrent relays with flat frequency response (e.g., GE SFC & DSFC).
- Static VAR compensating devices are also susceptible to damage caused by voltage distortion which can result in commutation failure and shutdown.

[8] TVA has utilized the term solar magnetic disturbance (SMD) in both written documentation and verbal discussions during information gathering session conducted to produce this report. For the purposes of this report, it is the same as geomagnetic. NERC utilizes the term geomagnetic.

TVA engineers and operators have actions that they can perform to mitigate the effects of GMD on the infrastructure. Planning for loss of reactive support and knowing load shedding procedures are important steps to deal with the effects of a GMD event which are detailed in Table 6.

Table 6: TVA Roles and Responsibilities

Roles	Responsibility
TRO Engineering Analysis	Using off-line models, study/plan for the simultaneous loss of reactive support as described above.
TRO Grid Operator	Using Areva STNet, study/plan for the simultaneous loss of reactive support as described above.
Transmission Operator	Be familiar with and follow procedures outlined in TRO-TO-SOP-10.168 which deals with Voltage Control, Reactive Reserve, and Load Shedding.

TVA has compiled a specific list of power system risks that contains assets vulnerable to GMD and the causes of damage or disruption from GMD shown in Table 7.

Table 7: Power Systems Risks and Causes

Power System Risks	Cause
Damage to EHV power transformers	Half-cycle saturation and loss of 161 kV reactive support due to tripping of capacitor banks and/or static reserve devices
39 substations and 28 GSU transformer banks at the 500 kV EHV level	Susceptible to GIC, especially at 9 base load generators continuously loaded close to capacity
GIC effects on 67 EHV transformers	GIC monitors installed on 9 500 kV substation transformers but no active monitoring of the devices
71 161 kV capacitor banks	18 of the installations have GE SFC or DSFC relays for ground overcurrent protection that make them susceptible to tripping during GIC/SMD
100 MVAR STATCOM at Sullivan, TN	Has GE SFC or DSFC relays for ground overcurrent protection that makes it susceptible to tripping during GIC/SMD

Operating instructions have been developed for operators to follow during a GMD event and are listed in Table 8. The seven Reactive Reserve Regions (RRR) shown in Table 9 warrant special focus and action regarding loss of 161 kV reactive support.

Table 8: Operating Instructions

Operating Instructions
On learning of the possible threat of a severe GIC/SMD event, operators should be aware of the slightly elevated risk of loss of reactive support during a GIC/SMD event, and be familiar with and follow procedures outlined in TRO-TO-SOP-10.168 which deals with Voltage Control, Reactive Reserve, and Load Shedding.
Operators should ensure on-line generators are operating at minimum MVAR levels necessary to maintain machine stability, to keep as much dynamic reactive available as possible.
Consider bringing available hydro units on-line that can condense. (Appendix A of TRO-TO-SOP 10.168)
Study/plan for the simultaneous loss of susceptible 161 kV reactive support, including (units in MVAR):

Table 9: Vulnerable Reactive Reserve Regions

Reactive Reserve Region (Total MVAR)	GIC Susceptible Generator Locations (MVAR)
RRR 4 (439)	• Burnsville MS (72) • Coffeeville MS (72) • McGregor's Chapel MS (72) • Miller MS (120) • Tupelo MS (103)
RRR 6 (174)	• East Bowling Green KY (126) • Franklin KY (48)
RRR 8 (524)	• Cullman AL (108) • Farley AL (180) • Huntsville AL (74) • Jetport AL (108) • Pulaski (54)
RRR 9 (114)	• Crossville TN (90) • Huntsville TN (24)
RRR 10 (168)	• Charleston TN (168
RRR 11 (244)	• Pigeon Forge (144) • Sullivan TN STATCOM (100)
RRR 14 (168)	• Alcoa TN (168)

Improving Reliability Resiliency

TVA is the nation's largest public power company, providing electric power to over nine million customers in the Tennessee Valley. It acts primarily as an electric power wholesaler, selling to 158 retail power distributors and 58 directly served industrial or government customers. Power comes from dams providing hydroelectric power, fossil fuel plants, nuclear power plants, combustion turbines, wind turbines and solar panels. Transmission is the mechanism to take the power generated by these facilities and distribute it to the retail and direct customers.

There is a delicate balancing act involved to keep the power generation output matched to the consumer load. If the ability to transmit power is reduced or lost, then generation is immediately impacted as the system becomes unstable. The HEMP and GMD components of EMP can have this impact on transmission assets and the generation step-up units. The geomagnetically induced current (GIC) has the ability to render critical transmission system components incapacitated within a matter of seconds. In operational terms, this would lead to cascading outages or to a complete blackout across the TVA’s area of responsibility. Recovery from this type of system failure is difficult. These transmission assets have limited spares, have long manufacture lead times, are mostly manufactured overseas, and are not easy to transport and install. Also, depending on the event, other portions of the North American power grid, and other global power grid systems could also be simultaneously impacted. This risk scenario is one of the most complicated to resolve; it requires a specific approach.

How does an organization like TVA begin to approach a problem of this magnitude, particularly when the frequency of this type of event is considered rare? Like power generation and transmission, there is a need to balance the risk of the threat against the reward of implementing mitigation strategies. A significant component of the ability to manage this risk is that TVA receives advanced notification of severe GMD events. While there is not yet a process in place to take specific system actions, TVA has many plans and procedures that are related. This section of the report will discuss the areas of TVA operations that have a significant role in establishing a level of resiliency to this threat.

TVA Reliability Coordinator

The Tennessee Valley Authority (TVA) serves as the Reliability Coordinator (RC) for the TVA Balancing Authority and Transmission Operator. TVA has also entered into Reliability Coordination Agreements with other Balancing Authorities and Transmission Operators to perform the NERC required RC function. The TVA RC area consists of the transmission and generation facilities within the metered boundaries of the Balancing Authorities listed in the NERC registry and referenced in the TVA Reliability Coordinator Reliability Plan. It is important to note that many of these agreements are with utilities that have systems in more northerly latitudes, which increases the vulnerability to GMD (due to underlying geology). These include:

- SERC Balancing Authorities and Transmission Operators
    - Associated Electric Cooperative, Inc. (AECI)

  - East Kentucky Power Cooperative (EKPC)
  - Electric Energy, Inc. (EEI)
  - Louisville Gas and Electric Company (LGEE) and Kentucky Utilities Company
    - Transmission Operators within LGEE Balancing Authority Area
    - Owensboro Municipal Utility (OMU)
- Tennessee Valley Authority (TVA)
  - Transmission Operators within TVA Balancing Authority Area
  - Alcoa Power Generating, Inc. - Tapoco (APGI)
  - Systems Operation Center

Additional agreements exist with the following:

- TVA, Midwest ISO, and PJM have a Joint Reliability Coordination Agreement.
- TVA RC has Coordination Agreements in place with all of its other neighboring Reliability Coordinators. Those are Integrated Coordinator of Transmission - Entergy (ICTE), Southwest Power Pool (SPP), Southeastern RC (SOCO), and VACAR South.

TVA Reliability Coordinator Responsibilities

The TVA Reliability Coordinator (RC) is responsible for the TVA Reliability Coordinator Area bulk transmission reliability and power supply reliability.

- Bulk transmission reliability functions include reliability analysis, loading relief procedures, re-dispatch of generation and ordering curtailment of transactions and/or load.
- Power supply reliability entails monitoring Balancing Area performance and directing the Balancing Authorities and Transmission Operators to take actions, including load curtailment and increasing/decreasing generation in situations where an imbalance between generation and load places the system in jeopardy.
- TVA RC ensures its Members are aware of Geomagnetic Disturbance (GMD) forecast information and assists as needed in the development of any required response plans.

TVA Control Centers

TVA operates two control centers, one for the Reliability Coordination functions and one for the Balancing Authority and Transmission Operator functions. The Regional Operations Center (ROC) is the main facility for the RC and TVA Transmission Provider/Interchange Authority functions. The System Operations Center (SOC) is the main facility for the TVA Balancing Authority and Transmission Operations. The SOC backs-up the ROC and the ROC backs-up the SOC. Both facilities are in a hot standby mode at all times. These two facilities serve as the focal point for TVA awareness of GMD events and actions to take to prevent damage to the vulnerable systems.

TVA Reliability Coordinator Data Exchange

TVA RC monitors Bulk Electric System elements (generators, transmission lines, buses, transformers, breakers, etc.) that could result in System Operating Limit (SOL) or Interconnection Reliability Operating

Limit (IROL) violations within its Reliability Coordinator Area. TVA's Reliability Coordinator monitors both real and reactive power system flows, and operating reserves, and the status of Bulk Electric System elements that are, or could be, critical to SOLs and IROLs and system restoration requirements within its Reliability Coordinator Area.

TVA RC has adequate analysis tools, including state estimation, pre-and post-contingency analysis capabilities (thermal, stability, and voltage), and wide-area overview displays. TVA RC has detailed monitoring capability of the TVA Reliability Area and sufficient monitoring capability of the surrounding Reliability Areas to ensure potential reliability violations are identified. TVA RC continuously monitors key transmission facilities in its area. TVA RC receives Supervisory Control and Data Acquisition (SCADA) information at a four second per scan update rate and Interregional Security Network (ISN) data that updates at least every thirty seconds. TVA RC Area Members and other RCs provide data (via ISN and RCIS) as requested to support reliability coordination.

GMD Event Notification is the Foundation of GMD Risk Mitigation

The TVA RC has an existing process to receive notification from NERC and NOAA of severe GMD events. This notification process is a routine practice for reliability operators and system operators. The challenge is that there is no system level process or procedure to be implemented at different GMD severity levels. The notice is received, customers are contacted, but nothing is done to change how TVA conducts operations.

As reported in 2008, Michael Stills of United Airlines has this to say about advanced notification: "…it is extremely important to have an accurate prediction…It is very important to have it in a timely fashion and as far in advance as possible…there are limitations, but to have advanced notification, from an infrastructure standpoint, a forecast 6 to 10 hours in advance would be wonderful, but from an operational and planning standpoint, we are probably looking at a minimum of 3 to 4 hours in advance, where we can make a tactical decision and still feel confident in the operation." [9]

If TVA had 3 to 4 hours of advanced warning and had incorporated the recommendations of this report, then in theory, TVA would have adequate time to implement procedures designed to avert the disastrous effect to the bulk power system. The ability to receive advanced notification of severe GMD is the foundation of how to mitigate the risk of impact of a severe GMD event.

The current GMD notification process begins with NOAA issuing an advance notification of pending solar events based on the Kp index. In many cases, these warnings provide up to twelve hours of advanced awareness of the threat which is ample time to make operational decisions concerning critical assets. The current notification process and the mode in which these notifications are distributed are listed in the Table 10.

[9] Michael Stills of United Airlines participated as a panelist in the 2008 National Research Council Workshop: Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report. Committee on the Societal and Economic Impacts of Severe Space Weather Events.

Table 10: Current GMD Notification Flow

GMD Notification Flow	Mode of Information Flow
NOAA	Issues notification via FTP
NERC	Distributes information to power organizations through RCIS
MISO	Receives the information from NERC and sends it to TVA RC via phone.
TVA RC	Issues notification to its customers through an email and phone
TVA RC Customers •TVA SOC •EKPC •LGE KU •SIEEI •AECI	Monitor the situation for any additional information

EPRI SUNBURST GIC Monitoring Program

TVA has submitted a Tailored Collaboration request in December 2010 to participate in the EPRI SUNBURST Program. This program will collect GIC data from energy companies and transmit this collective data back to all SUNBURST participants allowing real-time GIC data to be viewed from reliability stations across the grid. The SUNBURST system components will handle applications from ultra-smart sensors to a worldwide Internet-connected, near-real-time, GIC monitoring system. In conjunction with this program, TVA is looking to have two GIC monitoring devices, on at Paradise Fossil Plant on Unit 3 GSU, and one at the Sullivan TN 500 kV Substation on 500/161 kV bank #1. As aligned to Recommendation 2 of this document, this does not encompass the overall need for GIC monitoring across the TVA enterprise.

Role of TVA Emergency Management

If a severe GMD event occurs and transmission capabilities are constrained or lost, many TVA emergency plans would be activated. In general terms, TVA has an extensive emergency management capability. Each major business unit has its own Emergency Operation Center (EOC) for the use of sustaining operations in the case of a local emergency. If the emergency is large enough, then the Agency Coordination Center (ACC) is activated in accordance with the Agency Emergency Response Plan. The ACC is the focal point for agency level direction and control during a significant emergency. The ACC makes sure all organizations are providing situational awareness, establishing priorities between incidents, and allocating resources. The ACC and all the EOCs have adequate backup fuel supplies for major emergencies. Although this capability may be effective for these types of emergencies, a catastrophic GMD event could leave TVA in the dark for longer than current planned fuel levels will allow. This type of event would damage the nation's fuel supply chain causing extended lag times for fuel distribution. In these circumstances, TVA would be challenged in sustaining operations past the current level of stored backup fuel.

Related Emergency Plans

TVA has multiple plans designed to address threats to operations and TVA typically has a level of self-sufficiency. Yet, these emergency plans and procedures do not account for the potential of an extended duration outage that a severe GMD event could cause. The following TVA plans are not specifically designed to address the EMP/GMD risk, but could be utilized in the design of an EMP Emergency Operations Plan or set of procedures.

Table 11: Relationship of Existing TVA Emergency Plans and Procedures to GMD

TVA Plan	Description	GMD Relationship
Agency Emergency Response Plan	Coordinates agency wide response for major emergencies.	A Catastrophic GMD event could cause cascading outages or a complete blackout which would activate the Agency Emergency Response Plan.
Transmission Emergency Plan	Designed to address an effective response for restoration of the TVA transmission system in the event of a major system interruption or natural disaster.	GMD could cause uncontrolled islanding, single or multiple transmission line outages, frequency disturbances, and major critical asset damage.
Continuity of Operation Plans	Provides the logistical and operational framework for emergencies that render critical facilities unable to support mission essential functions.	A catastrophic GMD event would activate the TVA COOP plan and would rely heavily on the long duration and essential personnel and facility components of the COOP plans.
Emergency Load Curtailment Plan	Program designed to manage power load and is a core part of the cascading outage mitigation strategy.	GMD impacts transmission and causes imbalance between load and generation due to primary impacts to EHV transformers and capacitor banks.
Blackstart Procedures	Allows for the recovery of power generation and transmission following a significant system wide outage.	GMD would follow the same restart principles, however, the primary assets required for transmission may be significantly damaged and would require repair or replacement before blackstart procedures could be fully implemented.
TVA Operating Response to Solar Magnetic Disturbances	Identify the key roles and responsibilities for a GMD event at the power system operations level and identify vulnerable assets.	Currently the only specific procedure or process in place at TVA for GMD, but does not yet address specific mitigation actions to employ advanced warning if it is received.

TVA RC Member Related Emergency Plans

In addition to TVA emergency plans, TVA RC members maintain plans that would be considered a focal point in outreach and coordination. The member plans and procedures include:

- AECI Emergency Operating Plan and AECI System Restoration Plan
- EEI Imminent Station Blackout
- EKPC Blackstart Procedures, EKPC Restoration Plan, and EKPC Underfrequency Load Shed Program
- LGEE Blackstart Guidelines and LGEE Energy Emergency Plan
- Kentucky Utilities System Blackstart and Restoration Plan
- OMU System Restoration Procedure and OMU Synchronization Procedure
- Tapoco (Alcoa) Emergency Operations Plan

The Time to Put a TVA GMD Program in Place is Now

Solar cycles drive variations in space weather. Large and potentially damaging geomagnetic storms are predicted for the height of the next solar sunspot cycle during the 2012-2013 timeframe, followed by an approximate five year window in which a major GMD could occur.

TVA currently has a lack of situational awareness regarding their posture toward GMD. Deficiencies exist in the areas of impacts to critical assets, advanced notification, operating plans, and recovery plans regarding GMD. In 2010, at the beginning of the solar maxima, TVA has an opportunity to adjust its operational response to catastrophic events caused by GMD. By addressing the issue now, work completed before the upcoming solar maxima can help TVA systems more resilient to GMD caused during peak solar activity.

Table 12: How Taking Steps Now Aligns to the Solar Cycle

	Peak Solar Activity		Post Peak Severe GMD Activity				
2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	System Analysis				Advanced Notification		
	GIC Monitoring				Situational Awareness		
	Capacitor Bank Protection				GMD Operating Procedures		
	Research and Development				Emergency Response Procedures		
	Training and Outreach				GMD Resiliency		

Action taken before peak solar activity will help make TVA more resilient to upcoming GMD activity.

It will take significant time and effort to implement a robust program to address GMD risk. Analysis, testing, training are required to develop system plans and procedures to address GMD threats. Many of these steps can be done concurrently allowing TVA to implement advanced warning and operational procedures that will increase situational awareness.

By acting now and initiating steps to address GMD, TVA can be more securely positioned to manage GMD to ensure continued operations. Results from immediate actions taken to protect critical TVA assets could be seen in less than two years which coincides with the next solar maxima.

Recommendations

Recommendation Number 1: Identify Geomagnetic Disturbance as a naturally occurring Electromagnetic Pulse risk that warrants priority in the TVA risk management process.

Background

Electromagnetic Pulse (EMP) risk to critical infrastructure and the bulk power industry has been a subject of research by many U.S. Government organizations over the past decade. Many aspects of EMP are related to nuclear weapon detonation or directed energy weapons, and have varying degrees of catastrophic impacts to electronic components and power assets (extra high voltage (EHV) transformers, Generator Step-Up (GSU) transformers, capacitor banks, relays, etc.) depending on where the weapons are employed and on their strength. Of these, a High Altitude Electromagnetic Pulse (HEMP) from a high yield upper atmosphere nuclear detonation would have catastrophic impacts on electrical assets as outlined in the body of this report.

TVA is not positioned correctly to address hardening and shielding of sensitive electrical components to the E1 pulse of a HEMP event. The need to harden and shield these assets is under consideration by various national and international organizations. TVA could support specific research and development programs on this topic as an operational platform within the industry. Beyond making recommendations in regards to usage of hardened and shielded assets, it is not the mission of TVA to propose large scale changes to the small electronics industry. For the moment, TVA should rely on formal electrical industry recommendations and employ standards as they are developed by the formal regulatory bodies that govern TVA's operations and engineering.

However, TVA is in a position to address Geomagnetic Disturbance (GMD), which carries an impact to critical operational assets similar to the E3 pulse of a HEMP event. GMD has the potential to debilitate TVA transmission assets, which could lead to either a complete loss of transmission, or a cascading grid failure. Likewise, the ability to restart generation and transmission utilizing blackstart procedures is ineffective due to the lasting and direct damage to 500 kV EHV transformers and 161 kV capacitor banks. Spares for replacing impacted systems exist in varying quantities, and likewise some transformers are more resilient to GIC than others.

TVA receives notification of potential GMD risk via the TVA Regional Reliability Coordinator through National Oceanic and Atmospheric Administration (NOAA) sources. At this time, there are no specific programs to measure the impacts of the naturally occurring events, nor triggered actions to take for load curtailment, taking assets offline, or other preventative steps if provided advance warning of a significant solar storm.

This is the equivalent of a "100 year" type of natural disaster, but taking actions to analyze the risk in more depth and instituting programs as recommended by this working group can either mitigate the impact of the event, or can ensure a greater chance of overall system restart. Likewise, preparing for the natural disaster risk will augment resilience against the impact to the systems during a HEMP event.

As EMP threats, whether from coordinated attacks or from naturally occurring events, are not well understood by much of society, it is recommended that a specific internal and external outreach program be established as part of the risk management process. This would include a specific training and awareness program for system operators as addressed in Recommendation 2, and emergency management awareness and training as addressed in Recommendation 3. Finally, if this program is adopted, TVA is in a unique position to contribute greatly to the combined body of knowledge on the impacts of GMD

Recommended Steps

Focus on GMD

1. Provide priority risk consideration to the GMD element of EMP.
2. Apply knowledge gained from addressing GMD to future EMP threat analysis as GMD mitigation steps will concurrently help mitigate other EMP threats.
3. Identify Power System Operations (PSO) as the primary corporate sponsor for the GMD aspect of EMP risk.
4. Establish a formal TVA program to address this risk and ensure an enterprise approach that includes TVA involvement in federal and industry working groups.

Education

1. Develop a TVA-wide education and awareness program on the potential impacts of EMP to generation, transmission, and other critical infrastructure.

Outreach

1. Communicate changes to operational procedures (emergency load curtailment plans, etc.) to TVA primary customers, state, and federal emergency management authorities.

Recommendation Number 2: Perform a systems based analysis including research and development to identify and mitigate Geomagnetic Disturbance and Geomagnetically Induced Current vulnerabilities to high value assets.

Background

The consequences associated with a strong GMD event could result in damage or destruction of critical assets such as capacitor banks and EHV transformers. If the event is powerful enough, it is possible that high value assets required for generation and transmission capabilities of the bulk power system would not be adequately recovered in a timeframe acceptable to TVA operational goals.

The March 1989 geomagnetic storm caused the collapse of Hydro Quebec transmission capabilities resulting in significant damage to Generator Step-Up (GSU) transformers. Substation transformers in the PJM Regional Transmission Organization adjacent to TVA operations were also impacted. Damage occurs to transformer cores due to the flow of geomagnetically induced current (GIC) through the neutrals of wye-grounded windings of EHV (500 kV) power transformers, resulting in half-cycle saturation. Furthermore, half-cycle saturation in affected power transformers generates harmonic currents that can flow in 161 kV capacitor bank neutrals. Harmonic currents cause tripping of the 161 kV capacitor banks by neutral ground overcurrent relays with flat frequency response. Static VAR compensating devices are also susceptible to damage resulting in commutation failure and shutdown.

The risks to TVA vulnerable assets involve damage to EHV transformers from half-cycle saturation and the loss of reactive support due to tripping of capacitor banks and/or static reactive devices. TVA has 39 substation and 28 GSU EHV level transformer banks that are susceptible to GIC. Nine TVA GSU locations are base load generators that are continuously loaded close to maximum capacity. Customer and Independent Power Producer (IPP) locations also have similar transformer banks at risk on TVA's EHV system.

Analysis of transformers via DC offset instrumentation can be used to track frequency anomalies associated with GMD. DC offset instrumentation provides operators and engineers the ability to monitor and possibly mitigate GIC impacts and could help prevent damage to EHV transformers. The Electric Power Research Institute (EPRI) has an ongoing program aimed at measuring GIC events by collecting current and voltage harmonic data associated with GMD phenomena. The EPRI SUNBURST program has a mission to conduct research, study the cause, effects and mitigation of GIC impact on the bulk power system. The data collected on the SUNBURST network provides a research platform to collect data that is used in prediction models, developing mitigation techniques and advanced modeling for geomagnetic storm impact prediction. The system is used to communicate the geographic footprint, severity, intensity, and transformer saturation impact as solar storms and GMD events occur. NERC has recommended the use of SUNBURST to continue to measure GIC activities.

Currently, TVA has installed GIC monitors on nine 500 kV substation transformers, but there is presently no active monitoring program to receive data from the GIC monitoring devices. Thus, TVA is currently unable to analyze the effects of GIC on EHV transformers in its service area. TVA should reevaluate its decision to not connect this equipment to the EPRI SUNBURST network. Adding communications-enabled GIC monitoring to transformers would enable the sites to connect to the EPRI SUNBURST network assisting in data collection to provide long term probabilistic risk assessment for GMD threats.

As part of its participation in the EPRI SUNBURST project, TVA has plans to install two SUNBURST nodes as part of an initial pilot:

- Paradise Fossil Plant, GSU #3 (500/22 kV)
- Sullivan TN 500 kV Substation (either bank #1 or bank #3, 500/161 kV)

Both sites were chosen because of their location along the northern-most latitudes of the TVA service area.

While the bulk of these installation costs are covered by EPRI/TVA tailored collaboration (TC) funds, PSO will be asked to provide labor associated with oversight of these installations. TVA will record cost and lessons learned from those installations. Initial estimates are approximately $20K per site. The installations include wireless communication from the device at the transformer to the switch house (with associated cell-service charges). Present plans are to have both sites in-service/operational before third quarter FY11 (by 03/31/2011).

Of the remaining 67 EHV transformers, TVA should determine how many additional nodes will be needed. To make that determination, EPRI recommended contracting a study with the Finnish Meteorological Institute (FMI). The study will take into account such data as transformer design (shell-form or core-form, single-phase or three-phase, length of 500 kV lines, underlying geology, etc.) The cost of the study is estimated at $70K (to be covered by EPRI/TVA TC funding). The FMI study results will drive decision-making to install SUNBURST nodes at additional sites at TVA cost.

In addition to potential damage to EHV transformers, the primary system risk involves the near simultaneous, widespread loss of reactive support. Of the 71 161 kV capacitor banks within TVA, 18 installations and the 100 MVAR STATCOM at Sullivan TN are susceptible to tripping during a GMD event due to the presence of GE SFC or DSFC relays for ground overcurrent protection. On July 15, 2000 during the last solar maximum, TVA experienced 15 different trips of 161 kV capacitor banks at 6 different installations due to a Kp 9 GMD event.

The 2008 EMP Commission report provides recommendations for assessing system vulnerabilities, protecting high value assets through monitoring and hardening, separating systems into electrical islands, assuring availability of replacement equipment, and improving blackstart procedures. In addition to recommendations similar to the EMP Commission report, NERC recommends developing event monitoring for GMD.

Recommended Steps

Spare Equipment

1. Conduct an inventory of spare components for those deemed vulnerable to GMD.
2. Incorporate GMD system considerations into existing and future acquisition strategies.
3. Conduct an analysis of existing 500 kV EHV transformers and 161 kV capacitor banks to determine age of equipment and any natural resistance to electromagnetic impact based on internal shielding; determine quantity that could be retrofitted.

Blackstart Procedures

1. Analyze existing blackstart path procedures with the scenario of significantly damaged EHV transformers and capacitors.
2. Create a model to simulate load curtailment plan and blackstart procedures under severe GMD event.
3. Analyze GMD impacts to hydro blackstart equipment. Define which hydro facilities are vulnerable to GMD events.

Generation & Load

1. Have each generation business unit do an internal assessment of system vulnerabilities to GMD disturbances.
2. Assess regional load balancing against generation and load.
3. Examine ability to allow for adaptation of Reactive Reserve Regions program to analyze effects of transformer failures based on a GMD scenario (load balancing).
4. Assess the 15 Reactive Reserve Regions against the inventory of vulnerable EHV assets to determine which regions will be less impacted by an event and which regions are at greater risk.
5. Identify the business consequence of a high percentage impact on transmission assets.
6. Explore the feasibility and benefit of controlled, emergency separation of the TVA system into electrical islands within the Balancing Authority for TVA and Regional Reliability Coordinator areas of responsibility.
7. Perform further analysis on the collateral impacts to the telecommunications infrastructure.

Analysis of Transformers

1. Identify a statistically valid sampling of the transformers that appear to be more susceptible to these phenomena as candidates for a DC offset instrumentation pilot program in order to track frequency anomalies associated with geomagnetic disturbances occurring over a set period of time. The purpose would be to scientifically track and measure GMD and magnitude of DC offset with attention to the ability of the instrumentation to trigger GIC protection and counter-measures. Support and inform

industry standards associated with the installation management of the instrumentation and its performance.

2. Reestablish former EHV DC offset instrumentation program. Previous program was experimental and equipment was not field-worthy.
3. Incorporate GIC and GMD considerations into new transformer design specifications.

Table 13: Estimated Cost to Install Instrumentation Devices on GMD Vulnerable TVA Critical Assets

	500 kV Transformer GIC Monitoring	161 kV Capacitor Bank SFC/DSFC Overcurrent Protection
Total TVA Inventory	67 500 kV Transformers	71 SFC/DSFC Capacitor Bank Installations
Inventory already equipped	9 with GIC Monitoring Hardware, no active monitoring on any of the 67 EHV transformers	53 with protection not susceptible to GIC
Remaining equipment to update	To be determined based upon EPRI Study	18 SFC/DSFC Capacitor Banks
Cost to replace per installation	$25k	$135k
Total Cost to protect TVA assets	Potentially $1.7M if all transformers outfitted (likely less since it is not expected all 67 banks will require GIC monitoring)	$2.5M

Recommendation Number 3: Incorporate early warning notification and awareness of Geomagnetic Disturbances into emergency and system operational policies and procedures.

Background

The National Oceanic and Atmospheric Administration (NOAA) issues advance notification of pending solar events. These events are measured based on the Kp Index, and are distributed by NERC via the Reliability Coordinator Information System (RCIS) to the TVA Reliability Coordinator Operations Center (ROC) which in turn distributes the information to the TVA System Operations Center (SOC).

Per the July 21, 2009 testimony to the U.S. House of Representatives by Michael J. Assante, NERC Vice President and Chief Security Officer, there are some deficiencies in how these types of threats are communicated and managed:

> "NERC has in place a formal mechanism for issuing alerts to the industry about important matters that come either from NERC's own efforts, identified vulnerabilities or attacks, or from government agencies with specific information about possible threats. Alerts issued through this mechanism are not mandatory and cannot require an entity to perform tasks recommended or advised in the alert;"
>
> And
>
> "Complicating this issue, much of the information about security-related threats remains classified in the defense and intelligence communities, with restricted opportunity to share information with affected private-sector asset owners. The electric grid is placed at significant risk as a result of limited information-sharing."

While TVA receives the alerts related to potential geomagnetic disturbance, there is not a process or procedure in place to take specific actions in relationship to the magnitude of the potential risk. Actions that may be taken would include potentially taking vulnerable transmission assets out of service for a specific period of time (for example, switching out long east-west 500 kV lines such as the 123-mile Roane-Wilson 500 kV line), or at a minimum temporarily manning 500 kV switchyards to monitor EHV transformers for unusual changes in sound, bank temperature, etc. Before plans or procedures could be established or tested, more system level analysis, as outlined in Recommendation 2 of this report, would be necessary. To complicate this problem, there is risk in taking assets offline to prevent impact from GIC as well as risk of losing the assets if they are exposed. To balance this risk, modeling and simulation, participation in GIC monitoring programs, and training and outreach programs could provide the platforms to collect the type of data necessary to make these advanced trade-off analysis decisions.

These types of space weather events are rare, yet the impact to TVA operations can be catastrophic and likely requires the type of planning and analysis done for the New Madrid Fault risk; another rare but catastrophically significant event. There are many emergency plans in place at TVA but it is important to note that emergency plans such as those related to blackstart procedures cannot be executed until damaged transmission assets are repaired or replaced. Load curtailment plans will be beneficial, but likely implemented differently than normal. Fortunately, unlike a HEMP event, primary emergency operation centers and secondary systems (SCADA, ICS, some telecommunication assets, etc.) will remain functional as long as adequate supply of fuel is available for the duration of the recovery period. Adequate fuel supplies are also required for the expected multiple restart processes at generation sites. It will be important to assess recovery durations once the TVA asset vulnerability to GMD is better understood.

The loss of transmission capability, or cascading outages could directly affect the ability of other national security organizations to complete their mission. These organizations include major Department of Defense (DoD) installations and State/Local emergency response organizations. TVA also has regulatory reliability requirements it must meet in order to avoid heavy fines. These external stakeholders are an important piece in the planning efforts for a catastrophic event and should be brought into the planning process as part of an outreach strategy. Likewise, internal to TVA, a broad representation is required from major organizational elements to address this topic with myriad impacts to overall operations.

From a classified viewpoint, TVA is taking steps to obtain access to Homeland Secure Data Network (HSDN) which will provide some information and communication exchange capability with Federal and DoD organizations. This will require additional security clearance for personnel in certain roles. TVA employees who have subject matter expertise in system design and analysis of bulk power generation and transmission should also be considered for access to classified information. Finally, contracts issued for support to TVA in risk analysis may also require access to classified information as part of the contract. Classified data was available to TVA from DoD sources in support of this initial effort, but the means to exchange the information did not exist.

Emergency Operations Planning

1. Develop process to ensure formal bodies within TVA are 100% represented when planning for catastrophic EMP/GMD events.
2. Include NERC, FERC, DHS, DoD, local/state emergency response when planning for catastrophic EMP/GMD events.
3. Write a specific GMD emergency operations plan that accounts for notification of potential warning for a GMD event (NOAA), and agency-wide actions.
4. Develop a response matrix based on GMD Kp Index and aligned to SCADA controls.
5. Develop a training program for transmission system operators to train them to recognize system anomalies associated with electromagnetic disturbances.
6. Reassess the required minimum supply of backup fuel at critical facilities and operation centers and ensure they are sufficient to sustain emergency operations and restart procedures.

7. Establish procedures for improved access to classified information.
8. Incorporate this risk into established exercise and training programs.

Appendix A: Crosswalk of Federal and TVA Recommendations for EMP

Table 14: Crosswalk of Federal and TVA Recommendations

Report	Federal Recommendation	TVA Rec. #1	TVA Rec. # 2	TVA Rec. #3
2008 EMP Commission Report	Separate interconnected systems into electrical islands		•	
	Improve recovery capabilities	•	•	
	Understand system and network vulnerabilities		•	
	Evaluate and implement quick fixes		•	
	Develop national and regional restoration plans			•
	Assure availability of replacement equipment		•	
	Test and verify emergency operations			•
	Extend and expand black start capability		•	
	Prioritize and protect critical nodes		•	
	Expand and assure intelligent islanding capability		•	
	Assure protection of high value transmission assets		•	
	Assure training for recovery personnel			•
	Simulate, train, exercise, and test recovery plan	•		•
	Develop and deploy test standards and equipment		•	
	Conduct research to understand infrastructure system interdependencies and interactions		•	
2010 NERC HILF Report	Create a task force to evaluate and prioritize EMP threats		•	
	Develop and design event monitoring network for GMD		•	
	Evaluate spare equipment programs		•	
	Evaluate existing black start procedures		•	
	Develop a full defense plan		•	•
	Develop advanced methods to deliver info to system operators for GMD events		•	•
	Identify interdependencies with other infrastructures, fuel and communications		•	
	Design approach to reduce recovery and restoration times and minimize impact from an attack			•
	Government participation is important to determine level of investment for mitigation strategies		•	•
	Consider key loads		•	
	System operator plans to operate during EMP event			•
	Improve space weather forecasting and communication to system operators			•
	Continue HILF efforts	•	•	
	Continue SUNBURST network activities to measure GIC events		•	

Appendix B: The TVA EMP Working Group

TVA formed an Electromagnetic Pulse (EMP) Working Group to specifically examine the impacts of Geomagnetic Storms, Electromagnetic Pulse (EMP), High-Altitude Electromagnetic Pulse (HEMP), and intentional Electromagnetic Interference (IEMI) and the potential impacts of these events on TVA. The purpose was to understand the risk to TVA operations, determine where safeguards have been employed to help counter these risks and provide further recommendations TVA should take to reduce exposure and mitigate risk. Booz Allen Hamilton provided leadership and direction to assist the working group achieve these objectives. Table 14 provides the names of the personnel who contributed to this working group report.

Table 15: TVA EMP Working Group and Special Acknowledgements

TVA EMP Working Group and Special Acknowledgements	
TVA	Michael Tallent, Chair Gary Bullock Rick Cagle Michael Ingram Joy Irwin Gary Kobet Jeff Lawson David Pond
Booz Allen Hamilton	Julie Soutuyo, Lead William Bump Adam Gebus Mike Parvin Matthew Weiland Rick Yaw, PhD
Special Acknowledgements	Jeffrey Yauman, TVA Reliability Center Joel Wise, TVA Reliability Center Jeff Newsome, TVA Systems Operations Center Sam Austin, TVA Systems Operation Center

Glossary of Related Terms

Balancing Authority (BA): The responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports Interconnection frequency in real time. The Senior BA is the individual in charge of the SOC

Center for Network Operations (CNO): Control Center on the bottom level of the ROC which serves as an independent, unified monitor of transmission communications and control system performance and also as a 24x7 single point of contact for coordinating proper, timely response to related problems in field, SOC, and ROC operations

Coronal Mass Ejection: A massive burst of solar wind, other light isotope plasma, and magnetic fields rising above the solar corona or being released into space

Demand: The rate at which customers are using energy

Electric Power Research Institute (EPRI): Conducts research on issues of interest to the electric power industry in the USA. EPRI is an independent, nonprofit organization funded by the electric utility industry

Electromagnetic Interference (EMI): A disturbance that affects an electrical circuit due to either electromagnetic conduction or electromagnetic radiation emitted from an external source

Electromagnetic Pulse (EMP): A burst of electromagnetic energy produced by a nuclear explosion in the atmosphere, considered capable of widespread damage to power lines, telecommunications, and electronic equipment

> **E1:** A component of EMP that is a very brief but intense electromagnetic field that can quickly induce very high voltages in electrical conductors
>
> **E2:** A component of the pulse has many similarities to the electromagnetic pulses produced by lightning, although the electromagnetic pulse induced by a nearby lightning strike may be considerably larger than the E2 component of a nuclear EMP
>
> **E3:** A component of an EMP that lasts several minutes; can be caused by a solar event, or can be the final EMP component of a nuclear explosion

Federal Energy Regulatory Commission (FERC): The United States federal agency with jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, and oil pipeline rates

Gamma Radiation: High frequency electromagnetic radiation resulting from a nuclear explosion

Geomagnetic Disturbance (GMD): A temporary change in the Earth’s magnetic field, usually caused by a solar event; can cause geomagnetically induced current

Geomagnetic Storm: A temporary disturbance of the Earth's magnetosphere caused by a disturbance in space weather

Geomagnetically Induced Current (GIC): Current flow just beneath the surface of the earth caused by a slow change in the intensity of the earth's magnetic field, typically caused by a solar magnetic disturbance.

High-Altitude Electromagnetic Pulse (HEMP): The result of a nuclear detonation in the upper atmosphere

High Power Microwave (HPM): A type of directed energy weapons which use electromagnetic radiation to deliver heat, mechanical, or electrical energy to a target to cause various, sometimes very subtle, effects

Improvised Nuclear Device (IND): A device incorporating radioactive materials designed to result in the dispersal of radioactive material or in the formation of nuclear-yield reaction. Such devices may be fabricated in a completely improvised manner or may be an improvised modification to a US or foreign nuclear weapon

Independent Power Producer (IPP): An entity, which is not a public utility, but which owns facilities to generate electric power for sale to utilities and end users

Intentional Electromagnetic Interference (IEMI): A planned disturbance that affects an electrical circuit due to either electromagnetic conduction or electromagnetic radiation emitted from an external source

Kp Index: Quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval

National Oceanic and Atmospheric Administration (NOAA): A federal agency focused on conditions of the ocean and the atmosphere

North American Electric Reliability Corporation (NERC): An organization created to ensure that the bulk power system in North America is reliable

Oak Ridge National Laboratory: A multi-program science and technology national laboratory managed for the United States Department of Energy by UT-Battelle

Regional Operations Center (ROC): Houses the Reliability Center, Backup SOC, CNO, Transmission Communications (TRANSCOM) equipment and various support staff personnel

Reliability Coordinator Information System (RCIS): System used by the Reliability Coordinator System Operator (RCSO) to report incidents and notify other Balancing Areas of information pertinent to their operations

Reliability Coordinator System Operator (RCSO): Regional Operations Center (ROC) position responsible for ensuring the integrity and reliability of the TVA Balancing Area such that instability, uncontrolled events, or cascading outages will not occur as a result of the single most severe contingency

Supervisory Control and Data Acquisition (SCADA): A system of remote control and telemetry used to monitor and control the transmission system

Solar Cycle: The main source of periodic solar variation driving variations in space weather. The cycle is observed by counting the frequency and placement of sunspots visible on the sun

Sun Spot: Temporary phenomena on the photosphere of the sun that appear visibly as dark spots compared to surrounding regions caused by intense magnetic activity, which inhibits convection by an effect comparable at the eddy current brake, forming areas of reduced surface temperature

Supply: The rate at which energy is being produced to meet demand

System Operations Center (SOC): Primary PSO control center responsible for safe, reliability operation of TVA's bulk electric power system with primary focus on matching generation supply to load demand 24 hours a day, 365 days a year

System Operator: Any Transmission System Operator (TOp), Balancing Authority System Operator (BA), Reliability Coordinator System Operator (RCSO) or a Transmission Provider and Interchange System Operator (TISO)

Transmission Operator (TOp): System Operations Center (SOC) position responsible for ensuring that the bulk transmission integrity and reliability are maintained through the coordination and direction of transmission dispatch activities

Transmission Provider and Interchange System Operator (TISO): Regional Operations Center (ROC) position responsible for maintaining the integrity and reliability of the bulk TVA transmission system through coordinated efforts with the Reliability Engineering Group to determine available reservation transmission capability on the TVA system

Transmission and Reliability Organization: PSO organization whose focus is to safely manage the power grid and continually improve real time operation and control of TVA's transmission and generation resources

Ultra-Wide-Band (UWB): Electromagnetic waves emitted from a device in pulses that take up large portions of the radio spectrum; can be used for intentional electromagnetic interference

Acronyms

ACC	Agency Coordination Center
AECI	Associated Electric Cooperative, Inc.
APGI	Alcoa Power Generating, Inc.
BA	Balancing Authority
COOP	Continuity of Operations Plan
DHS	Department of Homeland Security
DoD	Department of Defense
DSFC	Digital Static Frequency Converter
EEI	Electric Energy, Inc.
EHV	Extra-high Voltage
EMP	Electromagnetic Pulse
EOC	Emergency Operations Center
EP	Emergency Plan
EKPC	East Kentucky Power Cooperative
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FMI	Finnish Meteorological Institute
GIC	Geomagnetically Induced Current
GMD	Geomagnetic Disturbance
GSU	Generator Step-up
HEMP	High-altitude Electromagnetic Pulse
HILF	High Impact, Low Frequency
HOB	Height of Burst

HPM	High Power Microwave
HSDN	Homeland Secure Data Network
HSPD	Homeland Security Presidential Directive
ICTE	Integrated Coordinator of Transmission – Entergy
IEMI	Intentional Electromagnetic Interference
IND	Improvised Nuclear Device
IPP	Independent Power Producer
ISN	Interregional Security Network
IROL	Interconnection Reliability Operating Limit
LGEE	Louisville Gas and Electric Company
NERC	North American Energy Reliability Corporation
NOAA	National Oceanic and Atmospheric Administration
OMU	Owensboro Municipal Utility
PSO	Power Systems Operations
RC	Reliability Coordinator
RCIS	Reliability Coordinator Information System
RF	Radio Frequency
ROC	Reliability Operations Center
RRR	Reactive Reserve Region
SCADA	Supervisory Control and Data Acquisition
SFC	Static Frequency Converter
SMD	Solar Magnetic Disturbance
SOC	System Operations Center
SOL	System Operating Limit
SOCO	Southeastern RC

SOP	Standard Operating Procedure
SPP	Standard Practices & Procedures; Southwest Power Pool
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
TC	Tailored Collaboration
TRO	Transmission & Reliability Organization
TVA	Tennessee Valley Authority
UWB	Ultra-wide-band
VAR	Volt- Ampere Reactive

References and Additional Sources of Information

TVA Documents

Tennessee Valley Authority. (2008). Agency Emergency Response Plan (AERP). Chattanooga, TN.

Tennessee Valley Authority. (2003). Allen Fossil Plant Emergency Response (Publication No. ALF.EP.14.001, Rev 0004). Chattanooga, TN.

Tennessee Valley Authority. (2010). Disaster Recovery, PCS Standard Processes and Procedures (Publication No. PCS-SPP-12.871, Rev 0005). Chattanooga, TN.

Tennessee Valley Authority. (2004). Emergency Response Plan, River Operations Standard Department Procedure (Publication No. RO-SDP-10.8, Rev 0001). Chattanooga, TN.

Tennessee Valley Authority. (2006). Enterprise Risk Management Policy, TVA Standard Programs and Processes (Publication No. TVA-SPP-13.17, Rev 0001). Chattanooga, TN.

Tennessee Valley Authority. (2009). Fossil Emergency Plan, Standard Processes and Procedures (Publication No. FPG.EP.14.000, Rev 0003). Chattanooga, TN.

Tennessee Valley Authority. (2010). Integrated River Operations Control System Recovery Plans, RO Standard Processes and Procedures (Publication No. RO-SPP-12.1.7 Rev 0001). Chattanooga, TN. RO Cyber Security Team

Tennessee Valley Authority. (2010). Operating Response to Solar Magnetic Disturbances, TRO Standard Processes and Procedures (Publication No. TRO-TO-SOP-30.188). Chattanooga, TN.

Tennessee Valley Authority. (2009). Power Supply & Fuels Continuity of Operations Plan, TVA PS&F. Chattanooga, TN

Tennessee Valley Authority. (2008) Power Systems Operations Continuity of Operations Plan, Power Systems Operations (PSO). Chattanooga, TN

Tennessee Valley Authority. (2010) Power System Restoration, TRO Standard Processes and Procedures (Publication No. TRO-TO-SOP-30.160, Rev 005). Chattanooga, TN

Tennessee Valley Authority. (2010). Power System Restoration (Publication No. TRO-TO-SOP-30.160). Chattanooga, TN

Tennessee Valley Authority. (2010). Sabotage and Other Security-related Threats, RO Standard Processes and Procedures (Publication No. RO-SPP-14.1, Rev 0001). Chattanooga, TN.

Tennessee Valley Authority. (2010). Reliability Plan for the TVA Reliability Coordinator Area, Tennessee Valley Authority Reliability Coordinator. Chattanooga, TN

Tennessee Valley Authority. (2009). TRO Operations Center Protocol for a Major System Emergency, TRO Standard Processes and Procedures (Publication No. TRO-VP-SPP-10.004, Rev 0001). Chattanooga, TN.

Tennessee Valley Authority. (2006) Tennessee Valley Authority Police Continuity of Operations Plan, TVA Police. Chattanooga, TN

Tennessee Valley Authority. (2010). Tennessee Valley Authority Police Emergency Response Plan. Chattanooga, TN

Commission Reports and Congressional Bills

Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. (2008). *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Critical National Infrastructures*. U.S. Congress: Title XIV of Public Law 106-398

Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. (2004). *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume 1: Executive Report*. U.S. Congress: Title XIV of Public Law 106-398

U.S. House of Representatives. (2009). Amendment to the Federal Power Act to provide additional authorities to adequately protect the critical electric infrastructure against cyber attack, and for other purposes (H.R. 2195). Washington, DC: 111th Congress, 1st Session

U.S. House of Representatives. (2009). Bulk Power System Protection Act of 2009 (H.R. 2165). Washington, DC: 111th Congress, 1st Session

U.S. House of Representitives. (2009). *Testimony of Michael J. Assante, Vice President and Chief Security Officer North American Electric Reliability Corporation*. Washington, DC: Committee on Homeland Security, Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology

Other Government Documents

Department of Defense. (2005). High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C41 Facilities Performing Critical, Time-Urgent Mission Part 1 Fixed Facilities (MIL-STD-188-125-1). Washington, DC

Department of Defense. (2005). *The Threat of Radio Frequency Weapons to Critical Infrastructure Facilities*. Washington, DC. Directed Energy Technology Office

Department of the Army. (2005). High Altitude Electro-Magnetic Pulse (HEMP) Protection Systems (Publication No. TM5-692-2). Washington, DC

Department of the Army. (2001). Maintenance of Mechanical and Electrical Equipment at Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities, Ch. 25: High Altitude Electro-Magnetic Pulse (HEMP) Protection Systems (Publication No. TM 5-692-2). Washington, DC

Federal Energy Regulatory Commission. (2009).Possible Elements of a National Action Plan on Demand Response (Publication No. AD09-10). Washington, DC

North American Electric Reliability Corporation. (2009). *Executive Brief: Electromagnetic Pulse & Geomagnetic Storm Events*. North American Electric Reliability Corporation: Critical Infrastructure Protection

North American Electric Reliability Corporation. (2010). *Technical Conference on Bulk Power System Impacts of Geomagnetic Storms, High-Altitude Electromagnetic Pulse and Intentional Electromagnetic Interference, North American Electric Reliability Corporation*. Dallas, TX

North American Electric Reliability Corporation & U.S. Department of Energy (2010) *Charter: High Impact Low Frequency Events Ad Hoc Task Force: GMD/EMP*. Washington, DC.

North American Electric Reliability Corporation & U.S. Department of Energy. (2009). *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System*. Washington, DC

Technical Reports

Argonne National Laboratory & U.S. Department of Energy. (2010). *Simulating the Impacts of a New Madrid Earthquake on the Regional Electric Infrastructure*. Argonne, IL

Barnes, P., Rizy, D., & McConnell, B. (1991) Electric Utility Industry Experience with Geomagnetic Disturbances (ORNL-6665), Oak Ridge, TN: Oak Ridge National Laboratory

Gilbert, J., Kappenman, J., Radasky, W., & Savage, E. (2010). *The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid, January 2010* (Meta-R-321). Oak Ridge, TN: Oak Ridge National Laboratory

Giri, D. & Tesche, F. (2003). *Classification of Intentional Electromagnetic Environments (IEME)*. IEEE

Kappenman, J. (nd). *Environments and Impacts due to Geomagnetic Storms*. Storm Analysis Consultants

Kappenman, J. (2010). *Geomagnetic Storms and Their Impacts on the US Power Grid* (Meta-R-319). Oak Ridge, TN: Oak Ridge National Laboratory

Kappenman, J. (2010). *Low-Frequency Protection Concepts for Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation* (Meta-R-322). Oak Ridge, TN: Oak Ridge National Laboratory

Martin, W. (nd). *Mitigation of EMP Effects*. ESCO Technologies Company: ETS Lindgren

Metatech Applied Power Soultions. (nd) *Transformer Saturation, Epidemic Failure Studies & GIC Exposure.*

Miller, C. (2005). *Electromagnetic Pulse Threats in 2010*. Montgomery, AL: Air University: Center for Strategy and Technology

National Research Council. (2008). *Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report. Washington, DC: National Academies*, The National Academies Press

Northeast Power Coordinating Council. (2007). *Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems* (C-15). New York, NY: Task Force on Coordination of Operation

Radasky, W. (2010). *Overview of EMP Threats and Hardening Options for Communications Systems, Presentation to the Continuity Communications Managers Group (CCMG)*. Metatech Corporation

Radasky, W. & Messimer, M. (nd). *Presentation and Analysis of Geomagnetic Storm Signals at High Data Rates*. IEEE

Radasky, W. & Savage, E. (2010). *High-Frequency Protection Concepts for the Electric Power Grid* (Meta-R-324). Oak Ridge, TN: Oak Ridge National Laboratory

Radasky, W. & Savage, E. (2010) *Intentional Electromagnetic Interference (IEMI) and It's Impact on the US Power Grid* (Meta-R-323). Oak Ridge, TN: Oak Ridge National Laboratory

Radasky, W.& Wik, M. (2002). *Latest Developments in SC77C Dealing with High Power EM Transient Phenomena*. IEEE EMC Society

Riswadkar, AV.& Dobbins, B. (2010). *Solar Storms: Protecting Your Operations Against the Sun's 'Dark Side,'*. Zurich Services Corporation: Risk Engineering

Savage, E., Gilbert, J., Radasky, W. (2010). *The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid* (Meta-R-320). Oak Ridge, TN: Oak Ridge National Laboratory

Savage, E., Radasky, W., Smith, K., Madrid, M. (2008) *Pulse Testing of Network Interface Cards for Upset and Damage*. Goleta, CA: Metatech Corporation

Walters, K. (2009) *STEP: Spare Transformer Equipment Program*. Edison Electric Institute

Wilson, C. (2010). *Cybercrime & Security, HPM and EMP: The Least-Discussed Cyber Threat* (Booklet IH-3). New York, NY: Oxford University Press

Woltjer, R., Trnka, J., Lundberg, J. Johansson, B. (2006). *Role-Playing Exercises to Strengthen the Resilience of Command and Control Systems*. Linkoping University: Department of Computer and Information Science