Electromagnetic Pulse: Effects on the U.S. Power Grid

Executive Summary

The nation's power grid is vulnerable to the effects of an electromagnetic pulse (EMP), a sudden burst of electromagnetic radiation resulting from a natural or man-made event. EMP events occur with little or no warning and can have catastrophic effects, including causing outages to major portions of the U.S. power grid possibly lasting for months or longer. Naturally occurring EMPs are produced as part of the normal cyclical activity of the sun while man-made EMPs, including Intentional Electromagnetic Interference (IEMI) devices and High Altitude Electromagnetic Pulse (HEMP), are produced by devices designed specifically to disrupt or destroy electronic equipment or by the detonation of a nuclear device high above the earth's atmosphere. EMP threats have the potential to cause wide scale long-term losses with economic costs to the United States that vary with the magnitude of the event. 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,[1] 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.

Naturally occurring EMP events resulting from magnetic storms that flare on the surface of the sun are inevitable. Although we do not know when the next significant solar event will occur, we do know that the geomagnetic storms they produce have occurred at varying intensities throughout history. We are currently entering an interval of increased solar activity and are likely to encounter an increasing number of geomagnetic events on earth.

In 1989, an unexpected geomagnetic storm triggered an event on the Hydro-Québec power system that resulted in its complete collapse within 92 seconds, leaving six million customers without power. This same storm triggered hundreds of incidents across the United States including destroying a major transformer at an east coast nuclear generating station. Major geomagnetic storms, such as those that occurred in 1859 and 1921, are rare and occur approximately once every one hundred years. Storms of this type are global events that can last for days and will likely have an effect on electrical networks world wide. Should a storm of this magnitude strike today, it could interrupt power to as many as 130 million people in the United States alone, requiring several years to recover. Mitigation technologies to protect the power grid against such a costly EMP event can be developed, and in some cases do exist.

This study consists of a series of comprehensive technical reports produced by Oak Ridge National Laboratory for the Federal Energy Regulatory Commission, the Department of Energy and the Department of Homeland Security and is being issued to provide the basis for a technical understanding of how EMP threats affect the power grid.

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

These reports examine the EMP threats, their potential impacts and analyze potential solutions for preventing and mitigating their effects.

In order to avoid major disruptions to the grid, it will be necessary to: (1) develop, test and deploy mitigation technologies to automatically protect the power grid from costly damage; (2) train bulk power system operators to improve their situational awareness of EMP threats; and (3) improve reporting and monitoring of geomagnetic storm and power grid events.

Background

EMP threats raise grave concerns about the ability of the modern U.S. power grid to successfully recover from the effects of a major geomagnetic event. Since the last occurrence of a major geomagnetic storm in 1921, the Nation's high voltage (HV) and extra high voltage (EHV) systems have increased in size over tenfold. Longer transmission lines that span greater surface potentials act as conductors for the geomagnetically induced current (GIC) that can devastate the electrical grid. GIC poses the risk of catastrophic damage to EHV transformers and can lead to long-term outages of large portions of the grid.

Unlike the more familiar terrestrial weather threats that the electric power grid is build to withstand, severe geomagnetic storms have a much larger geographic footprint, posing the risk of considerable equipment damage and long-term outages to major portions of the North American grid. The technical reports document a series of computer models used to estimate the impact of a major solar event by predicting the transformers that are "at-risk" from excessive GIC.

By simulating the effects of a 1 in 100 year geomagnetic storm centered over southern Canada, the computer models estimated the sections of the power grid expected to collapse during a major EMP event. This simulation predicts that over 300 EHV transformers would be at-risk for failure or permanent damage from the event. With a loss of this many transformers, the power system would not remain intact, leading to probable power system collapse in the Northeast, Mid-Atlantic and Pacific Northwest, affecting a population in excess of 130 million (Figure 1). Further simulation demonstrates that a storm centered over the northern region of the United States could result in extending the blackout through Southern California, Florida and parts of Texas.

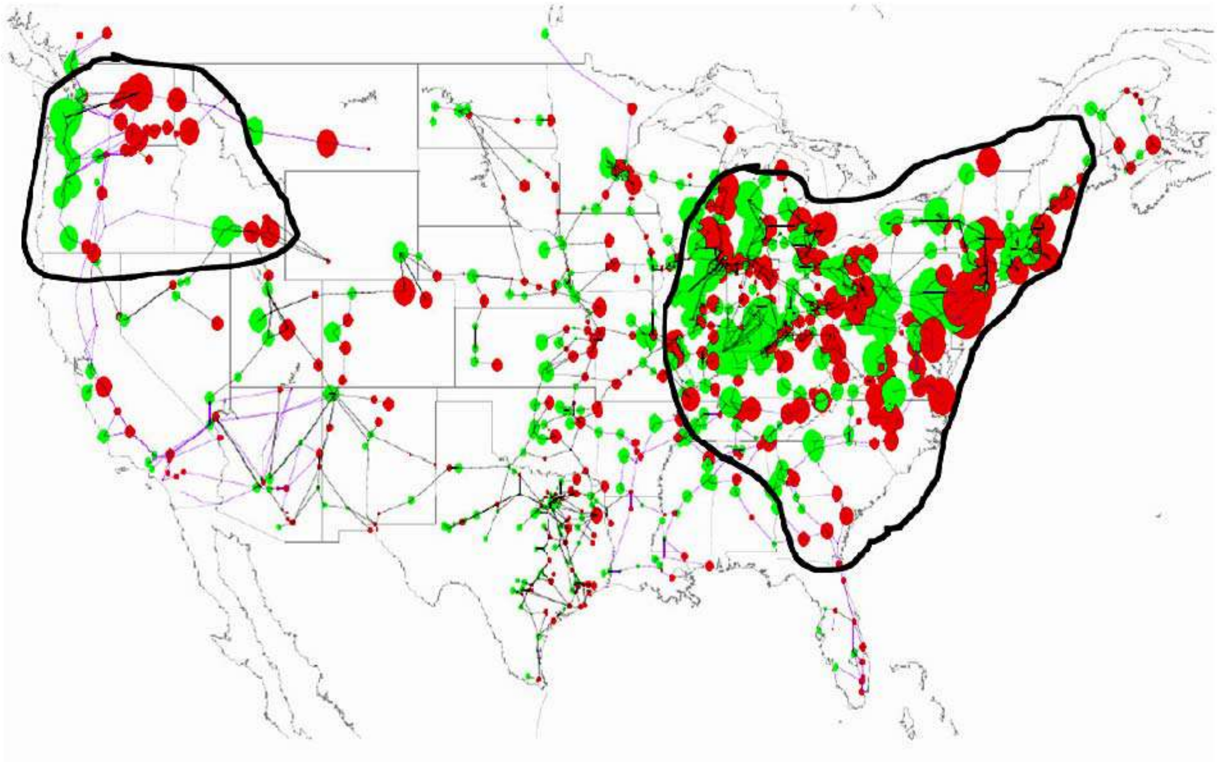

Figure 1. **Areas of Probable Power System Collapse**

In addition to causing the immediate damage and failure of transformers, there is also evidence that GIC may be responsible for the onset of long-term damage to transformers and other key power grid assets. Damaged transformers require repair or replacement with new units. Currently most large transformers are manufactured in foreign countries and replacements would likely involve long production lead times in excess of a year. The long-term power outages associated with such a delay would pose unacceptable societal burdens.

The two other types of electromagnetic threats to the power grid examined in this study are high altitude electromagnetic pulse (HEMP) and intentional electromagnetic interference (IEMI). While man-made, such threats can prove similarly devastating to the electrical infrastructure and produce similar harm to the power grid.

HEMP is produced by a nuclear weapon detonated above the atmosphere. No blast, shock or radiation is felt at the Earth's surface; however, electromagnetic fields do reach the surface. The technical reports that comprise this study summarize the early-time and late-time HEMP environments that can threaten the U.S. power grid. These reports consider a number of areas to be particularly vulnerable to HEMP: substation communications and control systems, power generation facilities, power control centers and certain distribution power equipment.

IEMI is a term that is applied to the non-explosive, non-nuclear intentional generation of intense electromagnetic fields that are used to introduce signals into electronic equipment for the specific purpose of disrupting, confusing or damaging these electronics. IEMI devices are malicious in nature and are used for terrorist or criminal purposes. Many types of IEMI are commercially available and can be as compact as a briefcase in size. In many ways, the IEMI threat is similar to that of the early-time threat of high-altitude EMP and can be addressed in a similar fashion.

Findings and Recommendations for Action

The technical reports that comprise this study analyze potential solutions for preventing and mitigating EMP threats and the impacts on the power grid. The reports make a series of findings demonstrating the need to proactively address electromagnetic threats with mitigation technologies to protect the power grid. The U.S. power industry must implement mitigation technologies to prevent catastrophic impacts to the grid resulting from EMP threats.

The findings from the technical reports are as follows:

- Development and testing of geomagnetically induced current blocking or reduction devices is necessary to prevent or mitigate electromagnetic threats to the power grid.

- Bulk power system operators must be trained to improve their situational awareness about geomagnetic threats.

- Reporting, monitoring, and prediction and forecasting methods of geomagnetic storm and power grid events must be improved.

- Development, testing and deployment of a means for protecting substation communication and control systems, power generation facilities and power control centers is necessary. It is also necessary to protect distribution line insulators and distribution transformers against early-time high-altitude EMP.

Guide to This Study

The technical reports that comprise this study and the major issues covered are as follows:

Geomagnetic Storms and Their Impacts on the U.S. Power Grid (Meta-R-319), John Kappenman, Metatech Corporation, January 2010.

- Overview of geomagnetic storms and past effects on the power grid
- March 13, 1989 geomagnetic storm and its impact
- Geomagnetic storm scenarios and effects on the U.S. power grid
- At-risk EHV transformers

The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid (Meta-R-320), Edward Savage, James Gilbert and William Radasky, Metatech Corporation, January 2010.

- Overview of the E1 early time HEMP wave
- History of E1 HEMP experience
- How the E1 wave is generated
- Coupling of E1 to lines
- Electronic device vulnerability to the E1
- Main concerns of the E1 on the power grid
- Recommendations for protection approaches

The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid (Meta-R-321), James Gilbert, John Kappenman, William Radasky and Edward Savage, Metatech Corporation, January 2010.

- The E3 late time HEMP and effects on the power grid
- Mechanism of E3 creation and coupling to the power grid
- HEMP burst impact scenarios over the United States
- Potential impact on grid equipment
- Potential impact on transformers

Low-Frequency Protection Concepts for the Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation (Meta-R-322), John Kappenman, Metatech Corporation, January 2010.

- GIC and E3 protection techniques for the high voltage portion of the Grid, including: series capacitors, neutral blocking capacitors and neutral blocking resistors

Intentional Electromagnetic Interference (IEMI) and Its Impact on the U.S. Power Grid (Meta-R-323), William Radasky and Edward Savage, Metatech Corporation, January 2010.

- IEMI background information
- Types of electromagnetic (EM) weapons
- EM coupling to systems
- Susceptibility of equipment to IEMI
- Specific aspects of IEMI threats to the power grid

High-Frequency Protection Concepts for the Electric Power Grid (Meta-R-324), William Radasky and Edward Savage, Metatech Corporation, January 2010.

- High frequency protection methods
- E1 and IEMI impacts on power delivery systems
- Identification of protection steps