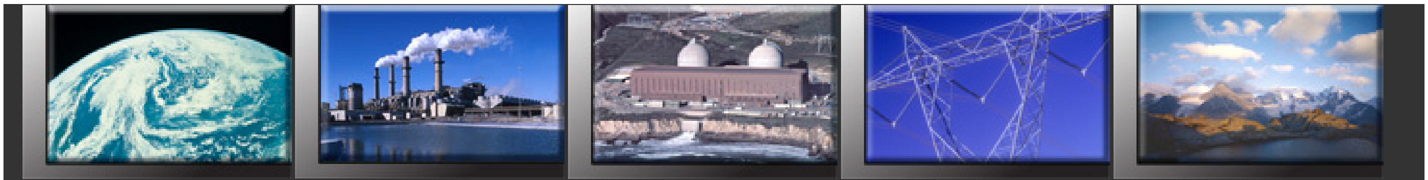
ELECTRIC POWER RESEARCH INSTITUTE

GMD News and Observer

Your View into EPRI Research on Geomagnetic Disturbance Vulnerabilities, Impacts, and Mitigation



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EXECUTIVE UPDATE

The highly complex, interconnected North American power grid has demonstrated a long track record of reliable, secure delivery of electric power for over a century. However, solar storms or "geo-magnetic disturbances" (GMDs) have demonstrated their ability to disrupt the power grid. A GMD in March 1989, for example, led to the collapse of the Hydro-Québec TransÉnergie Interconnection, leaving over six million people without power for over nine hours.

To address power system reliability, EPRI is working closely with industry across North America to launch a three-year, comprehensive, multi-deliverable GMD project that aims to:

- Develop tools and methods necessary to determine the likely impact of an extreme event on the North American bulk power system.
- Identify technologies available today or in the near term (especially in operations) to mitigate the effects of an extreme event on the bulk power system, reduce the extent of the interruption, and speed recovery.
- Identify technologies that can be developed to reduce the impact of GMDs as well as lower the cost of protection.

The knowledge developed in this project will help utilities and other stakeholders prepare for large solar storms and to reliably operate the grid through such events. This will also identify the risks of equipment damage and improve bulk power system reliability by shortening customer interruptions. In addition, the project may identify gaps in analysis, forecasting and mitigation solutions. The project will attempt to provide guidance on the economic feasibility of available mitigation technologies. EPRI plans to accomplish the project goals in three tasks: 1) development of planning tools and methods, 2) education and vulnerability assessment, and 3) mitigation.

This newsletter, to be published quarterly, will provide progress reports and insights for the industry on this important topic. In this issue, we summarize what we know about GMDs, and how transformers and the power system as a whole can be affected GMDs. In subsequent issues, we will discuss emerging research on GMDs and proposed mitigation plans by various industry leaders. We welcome your feedback.

Best regards,

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GMD Primer: How GMDs Occur

GMDs result from a distinct process that begins with the sun (see Figure 1). According to space scientists, coronal mass ejections (CMEs) are the primary solar activity that drives solar magnetic disturbances on the Earth. CMEs involve the ejection of a large mass of charged solar energetic particles that escape from the sun's halo (corona), traveling to the Earth in a time span of 15 hours to 4 days. The charged particles from the CME interact with the Earth's magnetosphere-ionosphere system in a complex manner that produces high-altitude ionospheric currents called electrojets. Typically millions of amperes in magnitude and several hundred km about the earth's surface, an electrojet is characterized by a slowly varying magnetic field which induces a geoelectric field at the earth's surface which drive geomagnetic-induced currents (GICs) wherever there is a path for them to flow. These quasi-dc currents flow in the Earth and on long man-made conducting paths, such as transmission lines, metallic pipelines, telecommunication cables, and railways. GICs can enter and exit the power system at transformer grounds, disrupt the normal operation of power systems, and can potentially damage operating equipment.

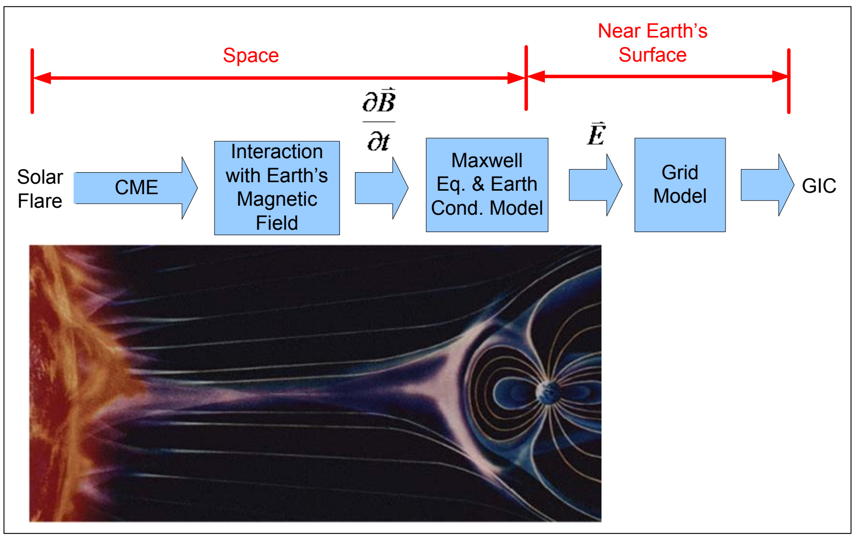

Figure 1. Storm Interaction with the Earth and Transmission Lines

How GMDs Can Impact Transformers

The impacts of GICs on the transmission system include half-cycle saturation in high-voltage transformers (see Figure 2). When GICs flow through the transformer windings, they set up a flux offset in the core. With sufficient offset, the crests of the flux waveform can exceed the saturation level of the ferromagnetic core material. This half-cycle saturation can cause:

- Harmonics: Even-numbered and odd-numbered harmonics occur, possibly causing mis-operation of relays (capacitor bank unbalance schemes are particularly vulnerable to mis-operation), overloading in capacitor banks, and heating in generators.
- Fringing fields: During saturation, magnetic flux extends beyond the core into the transformer's parts. Fringing fields can produce eddy current heating and magnetization losses, causing increased heating in transformers.

- Reactive power absorption: A large increase in reactive power is required to sustain the operating level of flux, and the transformer's exciting current becomes very large. This reactive loading increase can lead to voltage depression, transmission line disconnection, and even system voltage collapse.

Transformer saturation depends the B-H characteristic of the core material and, more importantly, the transformer core-winding construction. Single-phase transformers are the most vulnerable to saturation because the dc flux has a low reluctance path through the core. Thus, saturation in transformers can occur for relatively low levels of GIC. While high-voltage transformers are more susceptible to GICs, single-phase high-voltage transformers are particularly vulnerable due design and operating characteristics. An estimated 66 percent of all 500-kV transformers are single-phase, and an estimated 97 percent of 765-kV transformers are single-phase.

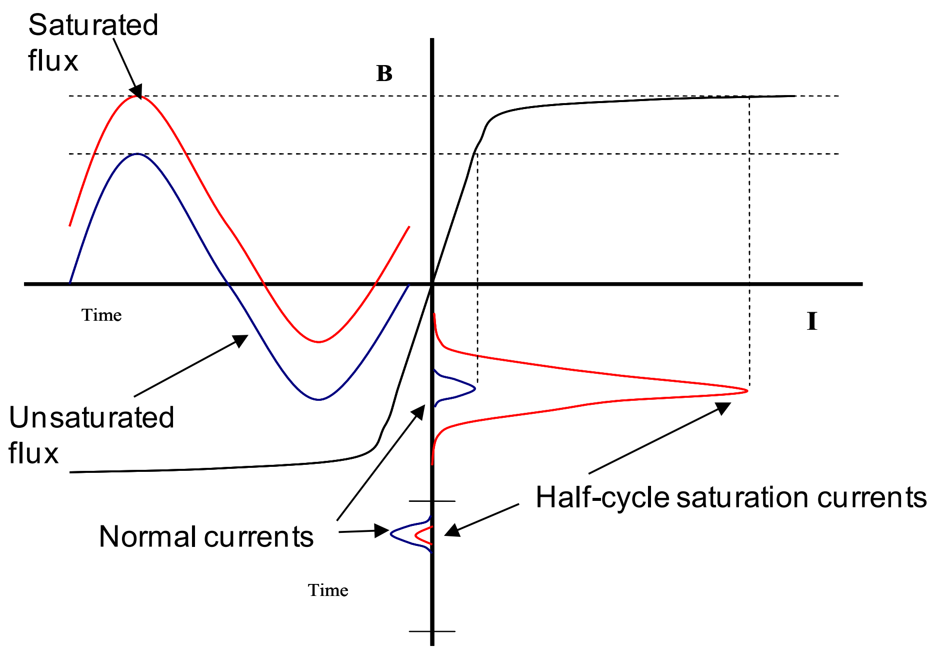

Figure 2. GICs can saturate transformers, causing them to demand high levels of reactive support, produce large amounts of harmonic current, and generate heat that can impact the operation of high-voltage transformers.

For a given geo-electric field (magnitude and direction), the combination of longer transmission line lengths and lower average resistances can result in higher GICs. This combination of attributes occurs primarily in high-voltage transmission lines, which play a critical role in bulk power transfer across North America. The lower resistance associated with high-voltage lines makes them more conducive to the flow of GIC than the lower voltage transmission and distribution system.

POWER SYSTEM

Potential GMD Impacts on the Power System

In addition to impacting the operation of power transformers, GMDs can affect grid stability through changes in reactive power profiles and extensive distortions of the alternating current. Potential effects include improper operation of relays; heating of generator stators; as well as possible damage to shunt capacitors, static var compensators, and harmonic filters. Solar storm effects on GPS systems and communications may also impact grid operations.

Opportunities for Participation

To find out about opportunities to participate in EPRI's research on GMDs, please contact EPRI Senior Technical Executive Rich Lordan, rilordan@epri.com, (650) 855-2435.

RESOURCES

Upcoming Events

Next Meeting April 18-20, 2012

- ***GIC and System Analysis Workshop*** **(Contact Randy Horton 205-424-3927 rhorton@epri.com)**
- **NERC Headquarters, Atlanta GA**

Next Call April 25, 2012

- ***Deep Dive: 100-year GIC event scenarios***

News

On February 29, 2012, NERC released a report entitled "2012 Special Reliability Assessment: Effects of Geomagnetic Disturbances on the Bulk Power System." For more information, visit http://www.nerc.com/fileUploads/File/News/MR_GMD29FEB12.pdf

NERC, EPRI, and participating utilities are developing the research plan going forward. The US Department of Energy (DOE) has recently reached out to help support this EPRI/NERC project as well. DOE is especially interested in developing wide area GIC monitoring across North America and enhancing data sharing protocols to bring existing sensors into the SUNBURST network. One of the defined outcomes of DOE's participation will be to identify new GIC monitoring locations in the United States.

For More Information

The following resources provide additional information about GMDs and their potential impact on transmission system equipment:

EPRI, "Geomagnetic Disturbances (GMD): Monitoring, Mitigation, and Next Steps; A Literature Review and Summary of the 2011 NERC GMD Workshop," EPRI Final Report, 1024629, November 2011

NERC, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," A Jointly-Commissioned Summary Report of the North American Electric Reliability Corporation and the U.S. Department of Energy's November 2009 Workshop. http://www.nerc.com/files/HILF.pdf

Gerry Cauley, Electric Infrastructure Security Summit, Panel Session on Industry Perspectives, NERC, 2011, http://www.nerc.com/fileUploads/File/News/EISS_Cauley_12APR11.pdf

Centra Technology, Inc., "Geomagnetic Storms," produced for the OECD/IFP Futures Project on "Future Global Shocks," January 14, 2011, http://www.oecd.org/dataoecd/57/25/46891645.pdf

NOAA SWPC, "A Profile of Space Weather," http://www.swpc.noaa.gov/primer/primer_2010.pdf

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