Insight: Geomagnetic Storms

Recognizing the Risk

Geomagnetic storms have the potential to impact utility operations in the generation, transmission and distribution of electrical energy. Industry groups and literature appear to be at odds over the damage severity concerns. There are some industry articles that imply that this event will happen inevitably with major consequences, whilst other articles indicate that a geomagnetic event is very manageable based upon today's technology and early warning for proactive measures. This dichotomy is likely due to the unknown risk owing to the limited experience with these events with today's infrastructure.

The general focus of this article is the impact to the energy industry. Other impacts outside the purview of this article include potential satellite loss or damage, spatial positioning error (GPS), communications industry losses, and pipeline damage.

Geomagnetic storms are caused by large coronal mass ejections of charged particles from the sun's surface which impact and distort the earth's magnetic field. Changes in the earth's magnetic field impact long high voltage transmission lines, creating low frequency (quasi-DC) geomagnetic induced currents (GIC) and variations in ground voltages. The GICs circulate through transmission lines and various high voltage connected transformer windings.

Due to the low frequency content of the GIC, transformers operate outside their normal design parameters as the core iron saturates resulting in distorted voltage waveforms and abnormal heating due to stay magnetic flux. Transformers operating in this manner can result in equipment failure. In addition to equipment damage, geomagnetic storms challenge grid stability due to inadequate reactive power support, and unplanned relay trips of transmission lines, Static VAR (Volt Amperes Reactive) Compensators (SVC's), and generation facilities from distorted voltage waveforms. The upset in the generation/load balance and loss of reactive power resources can result in large scale system blackouts. Restoration of the system may be challenged if critical equipment with long lead times is damaged. In addition to potential damage to high voltage transformers, other equipment such as long high voltage cables, pipe type cables, SVC's and High Voltage AC-DC-AC Converters can be damaged.

Previous geomagnetic storms have been documented where impact to infrastructure and power supply loss has occurred. These include the "Halloween" storms of 2003, the Quebec power outage of 1989, and the largest known storm of record, the Carrington event in 1859.

The so-called "Halloween" storm is the most recent event and occurred from late October to early November, 2003. Its geomagnetic storm strength measured ~ 410 nano-teslas and affected the power system, aviation industry, and satellite communications in Europe and North America. In Sweden, a large power utility lost some transformers which resulted in loss of the power supply along with degraded satellite and airline communication. On March 13, 1989, a geomagnetic storm of ~ 640 nano-teslas affected Canadian and Northeast US Power systems. Geomagnetic induced currents severely damaged / tripped seven SVC's owned by Hydro-Quebec along with failure of a Generating Step-Up (GSU) transformer at a New Jersey nuclear plant. The Hydro-Quebec transmission system failed and it took approximately 9 hours to restore power to ~ 83% of their customers as a result of damaged equipment. The most significant geomagnetic storm on record is the Carrington event of 1859. This ~ 850 nano-tesla event severely disrupted the telegraph systems (which were the only long overhead lines at the time). Research indicated that this event was the result of two different geomagnetic storms that spanned several continents and resulted in auroras around the world for several days. It is estimated that with today's infrastructure, economic costs associated with this type of event could be several trillion US dollars.

Although a Geomagnetic storm can occur at any time, the sun's solar activity level peaks in approximately 11 year cycles. Research has shown that countries located in the more northern latitudes such as Canada, US and Scandinavia are more vulnerable to geomagnetic storms based upon their proximity to the North Pole, the nature of their high resistivity soil/ground conditions and the fact that much of their infrastructure is composed of long transmission lines.

Controlling the Hazard

One way industry is protecting against the potential effects of a geomagnetic storm, including large area power losses and equipment damage, is the mitigation approach across two strategies.

1) Hardening of the critical transmission infrastructure to prevent GIC from flowing through critical infrastructure is costly, requires detailed engineering studies and most utilities use their limited catastrophe planning budget to address the more frequent natural catastrophes.
2) Operational notification of impending storms can allow grid system operators to remove critical equipment from service, unload critical transformers and provide additional reactive (VAR) resources to support system voltage.

The remainder of this paper addresses the operational mitigation approach to dealing with a geomagnetic storm.

Various governments and agencies around the world are concerned with the potential impact posed by a geomagnetic storm, particularly loss of the grid and the economic consequences of a long term loss. As part of the mitigation approach, governments have funded various projects and agencies to provide early warning of impending geomagnetic storms. The US, Canada, and Europe are actively involved in early detection of geomagnetic storms and information is shared between organizations. The current process for detection of a geomagnetic storm relies on the US National Oceanic and Atmospheric Administration (NOAA) and Canada's Space Weather Forecast Center (CSWFC) to monitor all solar geomagnetic disturbances. Upon determination of an event, NOAA grades the event severity and notifies all US and Canada transmission system operators. The transmission system operators notify transmission system owners to allow them to take actions such as reduction of key transformer loading and removal of at risk transformers and transmission lines from service. NOAA is also responsible to notify the International Space Environment Service (ISES). The CSWFC notifies the ISES as well. Generally, notification occurs between 1 and 4 days prior to the storm reaching earth although in some cases there may only be hours of notification warning.

Another area of concern to insurers relative to risk is the consequences of improper facility shutdowns as a result of loss of power supply events. A loss of power supply requires facilities such as power plants, oil/petrochemical facilities, process industries, etc. to shut down on their emergency power supplies, such as emergency generators, DC batteries, UPSs etc. Many major losses occur during these events so exposure across various occupancies provides additional risk and concern. Business interruption and contingent business interruption are significant concerns, particularly if the outage length is aggravated by long term equipment replacement/repair.

In addition to critical transformer failures, other utility equipment of concern to us are the large converter stations (AC to DC or DC to AC), long underground cables, high voltage capacitors and Static VAR Compensators. In addition, long length gas lines could suffer damage. Mitigating actions may assist but may not prevent all failures, similar to the large transformers discussed above.

Historically, in the US and Canada, few utilities, generators and grid operators considered geomagnetic storms in detail. However, after North American Electric Reliability Council (NERC) became responsible for the reliability of the transmission system, NERC was tasked by Federal Energy Reliability Council (FERC) to formally address geomagnetic storms. A reliability assessment committee was convened by NERC to review this issue. Committee members consisted of personnel from academia, utility, Grid operators, and various government agencies (e.g. Nuclear Regulatory Commission). The February, 2012 report [1] resulted in the following conclusions:

- The most likely worst-case impact from a severe geomagnetic event is voltage instability leading to voltage collapse.
- There may be some equipment damage, but not as significant as previous reports had indicated.
- There are other studies that provide a different assessment of equipment damage.
- Measures could be taken to mitigate this type of event. However, this would require adequate notification, utilities and grid operators identify critical equipment likely to be affected, and that emergency operating procedures be established and followed in the event of a solar storm.

FERC reviewed the 137-page report and was concerned that the system could be at risk of failure due to voltage collapse even if there was not significant equipment damage. Consequently, FERC issued a proposed rule mandating that NERC require action to manage geomagnetic storm scenarios.

Initial efforts would address operational actions whereas longer term, efforts would eliminate vulnerabilities though improved design. In the future, it is likely that plans to address geomagnetic storms in the US and Canada will be required as part of the regulatory process.

Conclusion

There are numerous articles addressing geomagnetic storms with various opinions as to the level of possible equipment damage. However most studies agree that loss of power supply is likely and that operational mitigation action can be effective in minimizing damage to critical facilities provided that facilities are identified, early warning systems are in place and emergency operating procedures identify actions to be taken.

Recommendations

- An operational mitigation plan should be prepared in conjunction with the grid operating staff which documents critical facilities, the process, of storm identification, organizational communication, and required actions. Emergency Operating procedures should be in place to document mitigation actions to protect critical equipment.
- A longer-term mitigating strategy of hardening critical facilities to prevent GICs from impacting critical equipment should be established.
- Mitigation plans may become mandatory for US/Canada as part of NERC regulation so proactive measures may be appropriate.
- Emergency shutdown systems should be inspected and tested in a complete, holistic manner. Batteries, emergency generators, Uninterruptable Power Supplies (UPS), emergency oil pumps, etc. should be verified and tested per OEM/industry standards. This should be completed across all occupancies/industries. Surveys should verify adequacy of safe shutdown on loss of power events.
- Engineers at the Broker/Client/Insurer should be aware of the issue for preparedness and survey review.
- Insurers and insured’s should consider augmenting their natural catastrophe warning systems to include identification of geomagnetic storms.

References & Resources

NERC Special Reliability Assessment Interim Report, titled “Effects of Geomagnetic Disturbances on the Bulk Power System” dated February, 2012

Risk Management Issue Brief, titled “Geomagnetic Storms: An Evaluation of risk and risk Assessments”, by the Office of Risk Management and Analysis, dated May 2011

IEEE Boston joint PES/Communications Society chapter meeting lecture addressing “Space Weather in Solar Cycle 24: Is the Power Grid at Risk”, April 16, 2013

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