

## Background for Alert: Preparing for Geo-Magnetic Disturbances

### Introduction

The potential impact of geo-magnetic disturbance events have gained renewed attention as recent studies<sup>1</sup> have suggested the severity of solar storms may be higher and reach lower geographic latitudes than formerly expected. NERC and the U.S. Department of Energy identified this as a High Impact, Low Frequency event risk to bulk power system reliability in a joint report issued in April 2010.<sup>2</sup> Geo-Magnetic disturbances (GMD) can impact bulk power system reliability. The most well-known recent experience in North America was the March 13-14, 1989 geo-magnetic disturbance, which led to the collapse of the Hydro Québec system in the early morning hours of March 13, 1989, lasting approximately nine hours.

Severe GMD events present risks and vulnerabilities that may not be fully addressed in conventional bulk power system planning, design, and operating processes. Solar storms emanating from the sun can produce an impulsive disturbance to earth's geo-magnetic field over wide geographic regions. This field disturbance can induce quasi-DC ground currents (geomagnetically-induced currents or GIC). As GMD storm intensity increases, both the geographic footprint and resulting levels of geomagnetically-induced current flows also increase, simultaneously damaging many transformers across the bulk power system. At each vulnerable transformer, the level of saturation of its core and reactive power consumption is amplified with increasing GIC levels. Because geomagnetically induced current flows occur simultaneously in many transformers, the bulk power system could encounter voltage regulation problems throughout portions of the affected network.

The facilities operated at 345-765 kV typically experience the highest GIC flow levels, in part because these lines and connected transformers have lower resistance per mile, than the underlying systems (less than 230 kV) and, therefore, will cause proportionately larger geomagnetically induced current flows. More importantly, the higher voltage lines and transformers are key network elements, whose upset or loss can widen into geographically widespread disturbances on the power grid. The 765 kV, 500 kV, and 345 kV single

<sup>1</sup> The U.S. Federal Energy Regulation Commission and Oak Ridge National Labs issued a number of reports on Geo-Magnetic Storms and their impact on the bulk power system in November 2010:

[http://www.ornl.gov/sci/ees/etsd/pes/ferc\\_emp\\_gic.shtml](http://www.ornl.gov/sci/ees/etsd/pes/ferc_emp_gic.shtml)

<sup>2</sup> The High-Impact, Low -Frequency Report can be found here: <http://www.nerc.com/files/hilf.pdf>

phase units, whether they are either core form or shell form, are highly susceptible to saturation from geomagnetically-induced currents, depending on the severity, geography, and solar storm orientation. Identifying the type of transformer that may be more susceptible to damage can be challenging due to specific design parameters and construction.

Depending on the location and concentration of stray flux internal to the transformer, heating of the oil, and relative equipment health, hot spots can emerge on tank or core locations, internal windings, and other structures within the transformer and can damage the transformer insulation systems. Further, during saturation, the reactive demands increase proportional to the transformer operating voltage (i.e. a 765 kV transformer will produce twice as much MVAR demand as a 345 kV transformer with the same level of geomagnetically-induced currents), and it emits substantial amounts of both even and odd harmonics making traditional relaying challenging.

Many organizations have long recognized these potential impacts of geomagnetically induced currents from geo-magnetic disturbances based on experience in North America, and have adopted long-standing operating procedures to address their potential impacts. However, the extent of protection from these actions to survive severe geo-magnetic disturbances is not well understood. At the same time, as the network topology of the bulk power system continues to evolve, continued attention to the potential impacts and the benefits from design changes is warranted.

### **Understand the event risk from Geo-Magnetic Disturbances**

Geo-Magnetic disturbances are caused by Coronal Mass Ejections (CME) directly toward the earth from the sun. Very large CME are uncommon, but can occur anytime, including during lower sunspot activity periods. The following is a typical sequence of events that aid in the forecasting of relative solar storm severity:

- Coronal Mass Ejections can be spotted eight minutes after they occur on the sun by the STEREO (Solar TERrestrial RELations Observatory) satellite.<sup>3</sup> Solar flare radio blackout alerts will be issued by U.S. National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC) as soon as a large solar flare is observed on the sun.<sup>4</sup>
- Within minutes, radiation storm warnings will be issued by NOAA if forecasters conclude that the eruption on the sun accelerated solar protons toward Earth. Radiation storm alerts will be issued by NOAA SWPC when the solar protons measured on NOAA's Geostationary Satellite exceed alert thresholds.

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<sup>3</sup>Background on the STEREO satellite can be found here: <http://science.nasa.gov/missions/stereo/>

<sup>4</sup>This is a summary page of all alerts that NOAA issues on Geo-Magnetic Disturbances:  
<http://www.swpc.noaa.gov/alerts/AlertsTable.html>

- Forecasters then begin the process of assessing whether a geo-magnetic storm is likely and must answer five specific questions prior to releasing an alert:
  1. Did a CME occur?
  2. Is it Earth-directed?
  3. How fast is it moving towards Earth?
  4. When it impacts Earth, how strong will the impact be?
  5. How long will the storm last?
- About 40-60 minutes before reaching the earth, the CME reaches the L1 satellite, which has a vantage point 1 million miles from Earth, along the Earth-Sun line. Solar wind speed, temperature, density, and magnetic field are all measured at L1. If forecasters conclude that the CME is Earth-directed, and a significant geo-magnetic storm is possible, a **Geo-Magnetic Storm Watch** is issued by NOAA SWPC.<sup>5</sup>
- NOAA's SWPC forecasters, at this point can then provide reliable warnings that will be up to 30 to 60 minutes in advance of the onset of a geo-magnetic storm.<sup>6</sup> Forecasters will issue a **Sudden Impulse Warning**, indicating earth's magnetic field will soon be impacted.
- NOAA's SWPC Forecasters may also issue **Geo-Magnetic K index Warnings** (for storms that are strength of K-index strength of 4, 5, 6, 7, or greater), depending the expected geo-magnetic storm strength.
- This alert will be followed immediately by the appropriate **Geo-Magnetic K-index Alert** (K4-K9) as thresholds are crossed. Alerts and warning will be issued by NOAA SWPC as warranted for the duration of the storm. These are integrated into the existing NERC situational awareness functions through the Reliability Coordinator Information System to all potentially affected Reliability Coordinators/Transmission Operators, etc.
- The NOAA's G-scale was designed to correspond to the significance of effects of geo-magnetic storms; however, this scale does not provide electric and magnetic field intensity (nanotesla/minute) or orientation (directionality) information. NOAA's SWPC estimates the following potential impacts on the bulk power system:

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<sup>6</sup> Sudden Impulse Warning Background: <http://www.swpc.noaa.gov/alerts/description.html#SI>

Kp - Index	Nanotesla (nT)	Severity	Power System Impacts	Advisory Actions
Kp= 5	70-120	G1 (Minor)	Weak power grid fluctuations can occur	<ul style="list-style-type: none"> <li>Ensure communications with Reliability Coordinators is maintained</li> <li>Increase attention to situation awareness</li> </ul>
Kp= 6	120-200	G2 (Moderate)	High-latitude power systems may experience voltage alarms; long-duration storms may cause transformer damage	<ul style="list-style-type: none"> <li>Increase reactive reserves and decrease loading on susceptible equipment</li> <li>Consider increases in import capability</li> </ul>
Kp= 7	200-330	G3 (Strong)	Voltage corrections may be required; false alarms triggered on some protection devices	<ul style="list-style-type: none"> <li>Ensure that all operating entities are aware of the potential for a geo-magnetic disturbance and its potential impacts</li> <li>Reduce power output at susceptible generator stations if erratic reactive power output from generators or excess reactive power consumption by generator step-up transformers is detected</li> </ul>
Kp= 8	330-500	G4 (Severe)	Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid	<ul style="list-style-type: none"> <li>Adjust voltage schedules, where possible, to increase dynamic reactive reserves</li> <li>Consider bringing synchronous condenser equipment online to provide additional reactive power reserves</li> </ul>
Kp= 9	>500	G5 (Extreme)	Widespread voltage control problems and protective system problems can occur; some grid systems could experience complete collapse or blackouts. Transformers could experience damage	<ul style="list-style-type: none"> <li>Remove transmission equipment from service if excessive GIC is measured or unusual equipment behavior is experienced</li> <li>Decrease loading on susceptible equipment through reconfiguration of transmission and redispatching of generation</li> </ul>