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Good morning FERC staff and fellow panelists.

My name is Mark Lauby, Vice President and Director of Reliability Assessment and Performance Analysis of the North American Electric Reliability Corporation (NERC). I have a Master of Science of Electrical Engineering and more than thirty years experience in the bulk power system industry, and was recently elevated by the Institute of Electrical and Electronic Engineers to Fellow status.

Background – NERC/DOE HILF Report and Formation of NERC HILF Task Forces

In November 2009, NERC and the U.S. Department of Energy (DOE) held a two-day workshop on high-impact, low-frequency (HILF) event risk to the North American Bulk Power System which focused on a class of rare risks to bulk power system reliability. The proceedings of this workshop and recommendations were documented in a jointly released report in 2010, which outlined a plan to address these risks to the bulk power system, including geomagnetic disturbances. The report, released in June 2010, summarized the proceedings and discussions, including proposals for action and mitigating options.

Following the release of the NERC and DOE June 2010 assessment, the Electricity Sub-Sector Coordinating Council (ESCC) developed the Strategic Roadmap that provided an approach to address high-impact, low-frequency events through an organized combination of industry-led task forces and initiatives. Further, NERC's technical committees developed an action plan to address the ESCC's roadmap strategy. NERC's Board of Trustees endorsed this joint approach in November 2010.

As part of these joint activities, NERC, working with its stakeholders, created four task forces, including two that are relevant to this technical conference, with participation from industry, equipment manufacturers and risk experts to address key HILF risks. Two task forces, whose results address the topic of this technical conference, were formed: spare equipment database and geomagnetic disturbances or GMD. Both groups have completed their interim reports which were accepted by NERC's Board of Trustees. They are now working on the detailed work plans endorsed by the board.

The Spare Equipment Database (SED TF) Task Force recommended the creation of a spare equipment database for long-lead time equipment, with emphasis on high voltage transformers. The goal is to provide information needed to support industry if and when the loss of long lead-time equipment, such as bulk power system transformers, occurs. The work is now ongoing to finalize the data collection software and begin the collection of this information by the third quarter of 2012.

Geomagnetic Disturbance Task Force

The remainder of my remarks will now focus on the geomagnetic disturbance task force or GMDTF, which, in a unique way, brought together experts from each of the fields of space weather

characteristics, earth sciences, space weather forecasting, bulk power system transients/dynamics, transformer manufacture and design, equipment design, as well as protection and control. Participants included members representing the users, owners and operators of the North American bulk power system, along with observers from manufacturers, government, academia, and vendors. For example observers included: U.S. Department of Energy, Department of Homeland Security, Department of State, National Oceanic and Atmospheric Administration Space Weather Prediction Center, National Aeronautics Space Administration, United States Geological Survey, Natural Resources Canada, all major transformer and blocking device manufacturers.

Throughout this assessment, NERC had access to the preeminent Canadian industry engineers and scientists, who were not invited to participate on either of today's technical conference panels. Due to its higher geomagnetic latitudes, Canada experiences more severe geomagnetic disturbances than in the United States, and this experience has translated into a deeper understanding of bulk power system impacts. Therefore, NERC was able to leverage the expertise of Canadian scientists and engineers who made significant contributions to the interim report. Sharing Canada's expertise today at this technical conference would have increased the value to all participants.

Overview – Geomagnetic Disturbances

Solar magnetic disturbances emanate from the sun, causing geomagnetic disturbances on Earth. According to space scientists, solar coronal holes and coronal mass ejections are the two main categories of solar activity that drive solar magnetic disturbances on Earth. Coronal mass ejections create a large mass of charged solar energetic particles that escape from the sun's halo (corona), traveling to Earth in 14 to 96 hours. These high-energy particles consist of charged electrons, along with coronal and solar wind ions. Geomagnetic disturbances, which can affect the power system, are produced when a large coronal mass ejection occurs and is directed at Earth. The interaction between the particle cloud and the earth's magnetic field can cause geomagnetically induced currents into the power system. The intensity of the effects on the power system depends on a number of factors such as the polarity of the magnetic structures created by charged particle cloud, geomagnetic latitude, directionality, and geology (electrical conductivity of the ground).

Geomagnetically induced currents can be measured directly using monitors of geomagnetically induced current typically attached to the neutral connections of power transformers. These monitors, along with alerts and warnings issued by the NOAA Space Weather Prediction Center or the Canadian Space Weather Forecast Centre, can provide the key information that a geomagnetic disturbance event is imminent or in progress and can support or trigger pre-planned operational decisions and actions.

GMD TF Mission

The Task Force set out to:

- Validate existing studies
- Identify the vulnerability of the bulk power system to geomagnetically induced currents
- Set an industry path forward towards addressing identified vulnerabilities

After review, it became evident that previously-released studies were based on a single data set that relied on closed-source methods and assumptions which could not be fully verified or validated by

industry experts, researchers or scientists. Further, the reports that had been released had not been fully vetted by industry, nor were the results independently validated in an open forum such as the Institute of Electrical and Electronic Engineers. Therefore, NERC deemed it necessary to develop an open and transparent assessment of these reports, develop open-source simulation tools to support industry study, and provide recommendations applicable to the North American bulk power system.

Identified Risks and Effects

Based on the task force's work, two risks where identified from the introduction of geomagnetically induced currents to the bulk power system:

- Damage to bulk power system assets, typically associated with transformers
- Loss of reactive power support, which could lead to voltage instability and system collapse

The NERC Special Assessment interim report also explores the maximum "1-in-100 year" geomagnetic disturbance scenario. Study has shown that the effects of the "1-in-100 year" storm vary across North America. In addition, though the change in magnetic field over time has been used as a way to measure intensity, the study work found that this measure is not a complete way to characterize the effects of magnetic fields on the bulk power system. Rather, both the magnitude and rate of change are needed to characterize the geoelectric fields. Therefore, the electric or magnetic field waveform characteristics over time are an important way to study impacts on the North American bulk power system as well as equipment.

The task force found that, ultimately, the effects on the power system are defined by the magnitude, wave-shape and duration of geomagnetically induced currents. These dc-like currents cause half-cycle saturation in transformers, the effects of which are:

- *Harmonic currents* can cause some types of relays to operate incorrectly by either operating when they should not or by not operating when they should.
- *Fringing fields* can create hot spot heating (not to be confused with top oil heating) in transformers which, if sufficiently high and sustained for a relatively long duration, can affect the mechanical properties of oil impregnated paper insulation and reduce its expected life. The effect of this heating on the condition, performance, and insulation life of the transformer is also a function of a transformer's design and both the operational loading during the life of the transformer and during a geomagnetic disturbance event.
- *Excessive transformer reactive var consumption* can cause the system to collapse due to voltage instability. These effects depend on the extent of half-cycle saturation, which in-turn depends on transformer construction type and characteristics (for example, single-phase or three-phase, number of transformer legs, and shell or core-type).

Based on analysis of task force members, the effects on power system voltage stability from the excessive reactive consumption from transformers can become severe in a matter of tens of seconds, while transformer hot-spot heating effects can become an issue in tens of minutes or hours. Studies of the impact of geomagnetic disturbances should examine two particular problem areas: 1) studies to assess voltage stability for the short time frame, and 2) studies that look at the longer term thermal response of transformers.

Based on the work of the GMDTF, the effects on transformers and the power system as a whole, must consider geomagnetically induced currents and geoelectric field waveforms in terms of magnitude, frequency and duration. Induced geoelectric field waveforms were developed by NASA based on historical data which can be scaled for local earth resistivity conditions, which are now under development by the USGS. These waveforms are available for system engineers to use for their voltage stability and equipment thermal analysis.

The task force participants reviewed commonly identified transformer failures to understand the failure mechanisms. The available evidence regarding the failure of transformers during GMD events does not reveal a common mechanism of failure that could apply to a large number of transformers of different ages and makes, simultaneously. Objectively, the evidence to date shows that geomagnetically induced currents act as a stressor in vulnerable transformers. This suggests that one of the best ways to protect vulnerable transformers is to ensure proper maintenance and condition assessment, especially where it applies to oil moisture content and dissolved gasses, which have a direct proven impact on the withstand capabilities of a transformer under any type of electrical stresses such as lightning and short circuits.

The task force participants also reviewed the effects of GIC on system equipment such as static var compensators and capacitor banks, which provide reactive support critical to maintaining system stability during geomagnetic disturbances, when var demand is high. One of the important conclusions of the task force is that unless the effects of geomagnetic disturbances are considered in the design phase, improper operation of protection and control systems could remove them from service at a time where they effectively support reactive requirements of the system.

Projected System Impacts from Severe Geomagnetic Disturbances

Based on the overall work of the task force, the most likely system impact from a severe geomagnetic disturbance is voltage instability caused by a significant loss of reactive power support simultaneous to a dramatic increase in reactive power demand. Loss of reactive power support can be caused by the unavailability of shunt compensation devices (*e.g.,* shunt capacitor banks, static var compensators) due to harmonic distortions generated by transformer half-cycle saturation. This is exactly what caused the 1989 Hydro-Québec blackout.

The impact of reactive power loss on the reliability of the bulk power system must be taken in context of its impact on local and interconnection reliability. Notably, fast voltage collapse happens in a timescale of tens of seconds, while thermal impacts take much longer. Restoration times from system collapse due to voltage instability may be a matter of hours to days, perhaps similar to that following the August 2003 blackout affecting the northeast United States and parts of Canada.

NERC recognizes that other studies have indicated a severe geomagnetic disturbance event would result in the failure of a large number of extra-high voltage transformers. The work of the GMD Task Force documented in the report does not support this result. Instead, voltage instability is the far more likely result of a severe geomagnetic disturbance storm, although older transformers of a certain design and transformers near the end of operational life could experience damage. We came to this conclusion based on review of reports, results of ongoing studies and tests, and discussions with manufacturers of transformer equipment.

Implementing the Task Force's Recommendations and Next Steps

The potential for voltage collapse and the loss of a limited number of transformers is a serious issue, and NERC is working with industry to address the potential concern and mitigate any impacts to the reliable operation of the bulk power system. Though our results differ from previous studies regarding the magnitude of impacts, the uncontrolled collapse of the bulk power system is not an acceptable result from a severe geomagnetic disturbance. NERC, through industry groups and the GMD Task Force, will continue to amplify its work to provide power system planners and operators information to develop design criteria and the tools needed to identify problems; operating procedures; and, mitigating approaches to address impacts of geomagnetic disturbances. The approaches and need for action may differ depending on the geomagnetic latitude, geology, as well as transformer design and health.

To supplement the work of the GMD Task Force, NERC, the Electric Power Research Institute (EPRI), DOE, and 12 industry organizations have funded a collaborative research and development project focused on developing and enhancing tools to better prepare and manage effects from strong geomagnetic disturbances. In fact, open-source software to calculate geomagnetically induced current has been developed and already incorporated into a commercial power flow package. Additionally, the recent release of publically available "1-in-100 year" wave-forms by NASA will facilitate industry benchmarking and establish common frames of reference for comparative analysis.

Conclusion

There is much work yet to be done by industry through the GMDTF and other groups. A comprehensive plan has been developed, and documented in the interim report. NERC is now beginning towards completion of this plan including a system and equipment vulnerability assessment, industry training, and improved equipment specifications to name a few areas of focus.

Thank you for the opportunity to speak to the Commission today.