UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

TECHNICAL CONFERENCE ON	**)**	**Docket No. AD12-13-000**
GEOMAGNETIC DISTURBANCES	**)**	
TO THE BULK-POWER SYSTEM	**)**	

COMMENTS OF THE NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

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I. <u>INTRODUCTION</u>

Pursuant to the Federal Energy Regulatory Commission's ("FERC" or "Commission") "Technical Conference Agenda" issued in the above-referenced docket on April 20, 2012, the North American Electric Reliability Corporation ("NERC") submits these comments following the April 30, 2012 Technical Conference on Geomagnetic Disturbances to the Bulk-Power System. Attached hereto are copies of the prepared statements that Gerry Cauley and Mark Lauby delivered at the technical conference on NERC's behalf.

NERC is grateful for the opportunity to participate in the technical conference. As explained by Messrs. Cauley and Lauby (see **Attachment A**), NERC's Geomagnetic Disturbance Task Force ("GMDTF") *2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System* highlights the potential for voltage collapse and the damage or loss of a limited number of vulnerable transformers across the bulk power system of North America.

By this filing, NERC submits supplemental comments in response to the technical conference. As explained below, NERC proposes to work with the Commission to develop guidelines, objectives, and specific goals for enhancing the capability of the bulk power system to withstand severe geomagnetic disturbances, which, as described in the NERC report, can present a serious threat to reliability. Through this joint effort, NERC and the Commission will collaborate to implement detailed action plans, which include gathering information vital to space weather mitigation proposals, conducting a rigorous risk assessment, and filing periodic informational reports.

II. NOTICES AND COMMUNICATIONS

Notices and communications with respect to this filing may be addressed to the following:[1]

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III. COMMENTS

A. Background

The Electricity Subsector Coordinating Council ("ESCC"), in response to the action items identified in the NERC-DOE Report,[2] developed an industry roadmap approved by NERC's Board of Trustees, to address specific High-Impact, Low-Frequency ("HILF") events. Further, NERC's technical committees, in response to this roadmap, developed a detailed plan to address HILF events identified by the ESCC, including Geomagnetic Disturbances ("GMD").

The joint NERC-DOE Report found that the best approach to study HILF events was to organize industry-led task forces, including the formation of a GMD Task Force. The scope of

[1] Persons to be included on FERC's service list are indicated with an asterisk. NERC requests waiver of FERC's rules and regulations to permit the inclusion of more than two people on the service list.

[2] *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 ("NERC-DOE Report"), available at: http://www.nerc.com/files/HILF.pdf.

the GMD Task Force was approved by the NERC Planning Committee at its September 14-25, 2010, meeting.

As reflected in the statements of Gerry Cauley and Mark Lauby at FERC's April 30, 2012 technical conference (see **Attachment A**), the GMD Task Force *2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System*[3] ("Interim Report") highlights the potential for voltage collapse and the damage or loss of limited number of vulnerable transformers across the North American bulk power system. Specifically, the Interim Report identifies four industry recommendations:

- Improve tools for industry planners to develop geomagnetic mitigation strategies;
- Improve tools for system operators to manage geomagnetic impacts;
- Develop education and information exchanges between researchers and industry; and
- Review the need for enhanced NERC Reliability Standards.

The Interim Report provided a detailed plan of action for industry to address geomagnetic disturbance events. Based upon the findings and recommendations of the Interim Report, electric industry preparations for geomagnetic disturbance events should be a part of industry planning efforts, similar to preparations for earthquakes, hurricanes and snowstorms.

While the Interim Report provides a plan of action and several recommendations to address geomagnetic disturbances, there is still a great amount of uncertainty, and in some cases disagreement, around the specific technical issues that must be addressed before industry- and continent-wide corrective actions can be proposed. To ensure that "no regrets" actions are taken to address geomagnetic disturbances, NERC will apply the principles of reliability risk control.

B. Reliability Risk Control Based Approach

[3] Available at: http://www.nerc.com/files/2012GMD.pdf.

NERC works closely with industry members to take a practical approach to reliability risk control, and NERC is focusing on this process as a way to address emerging reliability issues. Through the process of risk control, NERC understands that all reliability hazards need to be qualified, that risks must be clearly defined as well as prioritized according to metrics of success, and that the most severe risks must be avoided. Furthermore, a rigorous risk assessment for GMD has not been done, and it is vital to avoid errors that may unintentionally make a complex issue worse.

In consideration of the reliability risk control process and the substantial costs often associated with incremental reliability improvements incurred by industry, NERC has determined that it is critical to correctly characterize the risk of geomagnetic disturbances to the reliable operations of the bulk power system prior to determining potential solutions. For example, the Interim Report identifies the potential for transformer failures to occur depending on the relative transformer health, design, geology and geomagnetic latitude. While all transformer designs and construction types have not been tested at varying levels of geomagnetic induced current, proponents of devices to mitigate geomagnetic induced currents have proposed that these devices should be installed on every transformer in service. However, without careful analysis, wide-scale deployment of the proposed mitigation methods would add an additional layer of complexity as well as costs into the power system. As noted in the technical conference, unintended consequences could occur. This added layer of complexity may present new and unknown reliability risks, whether in terms of device reliability and failure modes or in terms of human error in system planning and device maintenance.

The acceptance of a mitigation method requires accurate, peer-reviewed, and validated models. Further, the at-risk transformer population must be properly identified, and system studies must be completed to ensure that mitigating geomagnetic induced current at one location does not adversely affect another. The additional risks of introducing new devices into the power system must be characterized before large-scale deployment takes place.

C. NERC's Findings and Clarifications

The Interim Report concluded that the most likely system impact to the bulk power system resulting from a high-impact, low-frequency strong geomagnetic disturbance is voltage instability, caused by a significant loss of reactive power support and a simultaneous dramatic increase in transformer reactive power absorption. Though the most likely result is voltage collapse, the GMD Task Force members agreed that, depending on the transformer health, design, geology and geomagnetic latitude, geomagnetic induced current flows can result in transformer loss-of-life, and may ultimately result in the failure of some transformers. The industry is well-equipped to face a small number of transformer failures; however, it is important to carefully quantify the nature of the reliability risk.

A number of previously completed government-sponsored studies have reached a conclusion that an extreme geomagnetic disturbance would result in irrecoverable damage to large amounts of bulk power system equipment. However, these prior studies did not engage the industry subject matter experts in long-term planning, equipment design and manufacture, solar storm characteristics, or real-time operations. Furthermore, the results documented in these prior studies, which predicted wide-spread equipment failures, were the product of the same principal authors. (See **Attachment B**).

NERC believes that further steps are needed to completely understand the appropriate ways to control the risks to reliability. NERC's position on the impact of geomagnetic disturbances to both bulk power system assets (including transformers) and power system operations are supported by a number of peer-reviewed journal articles and industry studies. These reports reach similar conclusions to the Interim Report with regard to the likelihood of voltage collapse and that the impacts will not be as severe in length or duration as suggested by previously released governmental reports. (See **Attachment C**).

An oft-repeated error is made in equating the threat from geomagnetic disturbances to the threat from electromagnetic pulse ("EMP") and high-altitude EMP ("HEMP") events. While, at some level, the physical mechanisms of geomagnetic disturbances and electromagnetic pulses may be similar, it is an oversimplification of the science and statistics involved to equate random emanations from the sun interacting with the outer atmosphere with a direct attack of a nuclear weapon – the electro-magnetic characteristics, impacts and preventive system solutions to address these risks are very different.

The potential threats posed by EMP and HEMP events from direct and deliberate attacks on the bulk power system raise important and complex questions – particularly in relation to the assessment of costs to either users or the general population. Yet damage from EMP and HEMP attacks represent a reliability concern, given that such attacks could inflict economy-wide damage well beyond the scope of the electric power and transmission industry.

Accordingly, NERC and the ESCC have determined that the threat of EMP and HEMP attacks is beyond the scope of civilian power industry to address. Rather, the threat from such attacks is a matter for national defense policy and law enforcement agencies to address. Consensus needs to be reached on the tradeoffs between making massive investments for full protection against an EMP attack and addressing other pressing reliability priorities.

Finally, from a technical perspective, NERC notes the inappropriateness of using the incremental excitation current necessary for transformer core saturation as a way to suggest vulnerability of transformers to geomagnetic induced currents. (See **Attachment D**).

D. Action Plans

To address the two key risks of system collapse and transformer failures, NERC intends to coordinate its activities with FERC, the U.S. Department of Energy ("DOE"), the National Oceanic and Atmospheric Administration ("NOAA"), the U.S. Geological Survey ("USGS"), Natural Resources Canada ("NRCan"), The National Aeronautics and Space Administration ("NASA"), the Canadian Space Agency ("CSA"), the Electric Power Research Institute ("EPRI"), the Institute of Electrical and Electronics Engineers ("IEEE"), the International Electrotechnical Commission ("IEC"), the North American Transmission Forum ("NATF"), and other industry members, manufacturers and scientific organizations in two key areas: (1) assessing the vulnerability of the North American transformer fleet, incorporating power system modeling with space weather simulation and transformer thermal characteristics, and (2) surveying the industry for best practices in operations to respond to geomagnetic disturbances and updating the May 2011 NERC Industry Advisory "Preparing for Geomagnetic Disturbances."[4]

NERC will work closely with FERC to develop and file a responsive work plan and timetable, and will keep FERC apprised to progress through periodic informational reports. As part of this process, NERC requests that FERC identify the guidelines, objectives and specific goals that should be accomplished through these efforts, including a reasonable schedule for completion, given the: 1) the complexity of the problem at hand, 2) volume and sensitivity of

[4] Available at: http://www.nerc.com/fileUploads/File/Events%20Analysis/A-2011-05-10-01_GMD_FINAL.pdf, with background at: http://www.nerc.com/fileUploads/File/Events%20Analysis/A-2011-05-10-01_GMD_Background_FINAL.pdf.

data that must be gathered from industry, and 3) the cost and burden to the industry to support these efforts.

Given the uncertainty involved and the work required, immediate changes to the NERC Reliability Standards to address geomagnetic disturbances would be premature, although changes and additions will be considered in parallel as the proposed high-level actions are executed. Further, though the actions below provide an approximate schedule, NERC will continuously review to identify opportunities to accelerate the schedule when possible, without sacrificing reliability gains.

1. Initial Actions

While some of the most complex tasks will not likely be complete before the end of 2013, due to the scale and scope of scientific challenges, NERC has prioritized its geomagnetic disturbance efforts to support a "no regrets" strategy. Although NERC is examining ways to compress this schedule, some activities will take the scheduled time to support industry analysis and complete appropriate tests. As a starting point for discussion with FERC and industry, NERC proposes the following initial actions, which should take 18-24 months:

Identify facilities most at-risk from severe geomagnetic disturbance

As the first step in identifying the risk of geomagnetic disturbance to the bulk power system, NERC intends to complete a system-wide vulnerability assessment. To facilitate this vulnerability assessment in the near-term, NERC will request specific and detailed information from all North American asset owners (transmission and generator) on installed high voltage transformer construction (*e.g.,* shell or core type design, number of core legs, age, in-service time, winding configuration). Furthermore, special attention will be given to the evaluation of critical transformers, such as generator step-up units at large generating facilities.

Conduct wide-area geomagnetic disturbance vulnerability assessment

With the transformer data collected by NERC, a high level review will be conducted to identify and classify the at-risk population based on existing peer-reviewed research. This assessment will be based on a high level screening approach that will include transformer design, condition, geology and geomagnetic location.

To complete a comprehensive, wide-area vulnerability assessment NERC proposes that two models be implemented: 1) thermal response models of transformers to geomagnetic induced current must be developed for different construction types, and in parallel 2) a power system model that incorporates the effects of space weather and ground conductivity will need to be developed to simulate expected geomagnetic induced current flows. These two models will be combined for a complete picture that demonstrates the risk of both voltage collapse and transformer damage and failure as a result of geomagnetic disturbances. Once the models are publically available, NERC will then work with Planning Coordinators[5] to perform a detailed analysis of system and transformer impacts, and mitigation approaches.

Identify spare equipment availability

NERC's Spare Equipment Database, in coordination with other mutual assistance programs such as EEI's spare transformer equipment program (STEP), has been developed to facilitate the sharing of equipment amongst entities in the face of extreme conditions, such as geomagnetic disturbances or other catastrophic events. Location and transformer details gathered in the Spare Equipment Database may help organizations identify suitable replacements

[5] The NERC Functional Model defines Planning Coordinators as the functional entity that coordinates, facilitates, integrates and evaluates (generally one year and beyond) transmission facility and service plans, and resource plans within a Planning Coordinator area and coordinates those plans with adjoining Planning Coordinator areas. http://www.nerc.com/files/Functional_Model_V5_Final_2009Dec1.pdf.

during a time of need. An assessment of transformer spares and transformer vulnerability will be completed by NERC in conjunction with industry members.

Enhance equipment specifications to be geomagnetic disturbance capable

In addition to assessing the vulnerability of the bulk power system, NERC proposes to work with industry and standards organizations such as the IEEE Transformers and Standards Committees, along with the IEEE Power and Energy Society, to enhance equipment specifications to withstand geomagnetic disturbances. As noted in the technical conference, initial discussions have already occurred with the responsible IEEE committees.

Enhance training for system operators and planners

NERC will concurrently work with industry experts to collect best practices and share information for system operations. This information will be used along with results from power system simulations to support the development and enhancement of training for system operators and planners.

2. Mid-Term Actions

Following the initial tasks of vulnerability assessment and industry outreach, NERC will continue work with EPRI, industry, manufacturers and the scientific community to develop models and tools to improve bulk power system reliability. The following mid-term actions, requiring 12-36 months, are proposed:

Refine probabilistic geomagnetic disturbance storm scenarios

NERC will continue working with NASA and the offices of SpaceWeather Canada, a division of NRCan, to expand the development of a family of geomagnetic disturbance event scenarios and to develop extreme event scenarios. This will include 1-in-100 year scenarios and a worst case scenario when they can be derived. Further, NERC will continue working with the

USGS and NRCan to develop detailed ground resistivity models vital to determining the ground potential that drives geomagnetic induced current levels in transformers.

Perform comprehensive tests of transformers to geomagnetic induced current

NERC will work with EPRI, DOE, industry participants, and equipment manufacturers to identify appropriate transformer test candidates and support testing efforts at a laboratory facility to be determined. Testing transformer thermal and operating response to geomagnetic induced current is an activity with a significant cost burden, but such testing is necessary to validate finite-element thermal models and corroborate operational responses to geomagnetic induced current. Testing would also enable improved performance monitoring and post-mortem analysis of transformer failures.

Increase geomagnetic induced current monitoring locations across North America

NERC will also promote the deployment of geomagnetic induced current monitors throughout North America, using the results of the vulnerability analyses to identify the most useful locations. NERC also supports the development of a data warehouse that would provide both neighboring organizations and the academic community access to non-confidential geomagnetic induced current data for further analysis. Data collected by a larger number of geomagnetic induced current monitors would be used to enhance system awareness and operational practices, and feed into improved analytical tools.

Develop analytical tools for system planners and operators to reliably manage geomagnetic disturbance impacts

NERC will continue work with EPRI and the academic community to develop tools for use by the industry. These tools should allow power system planners to analyze the effect of geomagnetic disturbances as the bulk power system evolves, and so that utility operators can be aware of impending geomagnetic disturbances and their effects and respond adequately. Models will continue to be enhanced through collaboration with agencies such as NASA, CSA, USGS and NRCan, and with equipment manufacturers.

3. Long-Term Actions

NERC understands that geomagnetic disturbances will pose a risk beyond the solar maximum, which is expected to occur in May 2013. As such, NERC proposes the following continuing actions to address bulk power system reliability over the long term:

Improve space weather forecasting

NERC will work with the scientific community to support space weather forecasting improvements, so that forecasts provide adequate warning time frames to system operators. NERC will incorporate these enhancements into improved operational alerts and communications among bulk power system entities.

Ensure analysis of geomagnetic disturbances becomes part of the conventional planning and operation analyses

Geomagnetic disturbances are expected to become normal planning and operations scenarios for industry to analyze and for which they will prepare. Beyond the continued support of analytical and planning tool development, NERC will evaluate the Reliability Standards for changes and additions required to incorporate the planning and operations aspects that arise as result of geomagnetic disturbance data, assessment and studies.

Develop a spare equipment strategy for industry hazards

To address geomagnetic disturbances along with other HILF risks, NERC intends to facilitate the development of an industry-wide spare equipment strategy that addresses assessed hazards.

Develop equipment standards

NERC will continue working with organizations such as the IEEE and IEC to improve equipment standards and specifications where the results of assessments and analysis signify requirements.

Expand reactive resources and modify or replace equipment

The results of the assessments and analysis may indicate that additional reactive resources are needed to avoid system collapse, or where modifications to equipment such as protection and control, static var compensators and high voltage transformers may need to be modified or replaced to support correct operation or avoid equipment damage. NERC will work with the industry to address the need for such changes, support risk control, and consider necessary changes to the Reliability Standards that may be identified in the process.

E. Summary

NERC recognizes that there is a need for action on the impacts from geomagnetic disturbances. NERC also wants to ensure that a "no regrets" approach is taken and that mistakes that might adversely impact reliability are avoided. The complex technical issues involved in determining the risk associated with geomagnetic disturbances and deploying appropriate mitigating solutions must be planned carefully to ensure that no harm is done to bulk power system reliability in the process of addressing this low-probability, high-impact event.

NERC intends to develop a comprehensive plan, coordinated with FERC and subject matter experts from industry, manufacturers and scientific community, with milestones for oversight and progress reporting. Global expertise in the fields of science and engineering will be engaged to expand the collective understanding of the complex nature of geomagnetic disturbances and their effects on the bulk power system. Solutions will continue to be monitored, analyzed and refined as the knowledge base grows. NERC will also work with industry throughout the course of these efforts to introduce and adjust risk controls that are well-suited to the complexity of the problem, and work will commence on interim mitigation steps where possible and appropriate.

IV. CONCLUSION

NERC is pleased to provide these comments in response to the Commission's Technical Conference.

Respectfully submitted,

<u>/s/ Willie L. Phillips</u>

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CERTIFICATE OF SERVICE

I hereby certify that I have served a copy of the foregoing document upon all parties listed on the official service list compiled by the Secretary in this proceeding.

Dated at Washington, D.C., this 21st day of May 2012.

/s/ Willie L. Phillips
Willie L. Phillips
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ATTACHMENT A

The following attachment is a reproduction of the written testimony submitted by Mark Lauby and Gerry Cauley to FERC at the April 30, 2012 technical conference.

Comments of Mark Lauby
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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.

Gerry Cauley, P.E.
President and Chief Executive Officer (CEO)
North American Electric Reliability Corporation
Atlanta, Georgia, USA

Good afternoon FERC staff and fellow panelists.

My name is Gerry Cauley and I am the President and Chief Executive Officer (CEO) of the North American Electric Reliability Corporation (NERC). I am a graduate of the U.S. Military Academy, a former officer in the U.S. Army Corps of Engineers, and have more than 30 years experience in the bulk power system industry, including service as a lead investigator of the August 2003 Northeast blackout and coordinator of the NERC Y2K program.

NERC's mission is to ensure the reliability of the bulk power system of North America and promote reliability excellence and accountability. To ensure the reliability of the bulk power system, NERC relies on the combined expertise of the electric industry to draw realistic and credible conclusions to past and future events based on facts, not speculation or opinion. NERC works collaboratively with industry experts to address issues from standards development to responding to high impact, low frequency threats.

The NERC 2012 Special Assessment interim report on geomagnetic disturbances highlights the potential for voltage collapse and the damage or loss of a limited number of vulnerable transformers across the bulk power system of North America. Previous examples, such as the 1989 event in Hydro Québec demonstrate that severe solar storms represent a serious risk that can challenge the reliability of the bulk power system. NERC is working with industry to develop strategies and plans to control this risk.

NERC's interim report identifies four recommendations for industry:

- Improved tools for industry planners to develop geomagnetic mitigation strategies
- Improved tools for system operators to mange geomagnetic impacts
- Develop education and information exchanges between researchers and industry
- Review the need for enhanced NERC Reliability Standards

From a high level perspective regarding next steps, I see three key activities:

1. Vulnerability assessment through system analysis, and enhancing system design, operating procedures, and, if required, addition of neutral current blocking
2. Training of planners and operators
3. Spare equipment inventory management

I will cover each of thee with more specificity:

1. Vulnerability assessment through system analysis, and enhancing system design, operating procedures, and, if required, retrofitting of existing transformers

The conclusions of the 2012 Special Assessment interim report will be validated with the completion of a vulnerability assessment that NERC, along with industry in 2012, with final results being published in 2013. This joint effort will examine transformer vulnerability and will take into consideration the two primary risks to reliability from geomagnetic disturbances: reactive power loss and transformer hot spot heating. These two phenomena involve two very different time constants, seconds for reactive power loss and potential voltage collapse compared to tens of minutes for transformer heating.

NERC has supported the development of publically available simulation software to support the overall vulnerability assessment. We are now validating reactive power and thermal models to focus attention on the appropriate characteristics of the system. This information will be used to complete the high level vulnerability assessment which can be used to further industry discussion on mitigation strategies. To complete the vulnerability assessment, NERC is working with a number of private and governmental agencies. For example:

- Transformer vendors to determine the thermal characteristics of hot spot heating due to geomagnetic induced currents to identify the risk associated with specific transformer types
- U.S. Geological Survey and Natural Resources Canada to improve the ground impedance maps of North America
- Interconnection modeling groups (Eastern Reliability Assessment Group or ERAG, WECC, ERCOT, and Québec) to improve system models so the effects of geomagnetic disturbances on and across grids can be simulated
- U.S. National Aeronautics and Space Administration and Canadian Space Agency to develop a credible study design basis for systems, which can differ based on geology and geomagnetic latitude, as well as develop the theoretical maximum geomagnetic disturbance
- North American Transmission Forum to support review of confidential information on bulk power system and equipment performance, as well as to support the vulnerability assessment

To support these activities, NERC will pursue an industry voluntary data request on the existing transformer fleet to gather the important transformer characteristics and appreciate the risks to reliability. The data collected through this request would remain confidential and would be subject to NERC's Rules of Procedures regarding data confidentiality. If there is low industry participation and the data cannot be obtained through other avenues, NERC can make a mandatory request for information under Section 1600 of its Rules of Procedure.

Further, we are reviewing the existing NERC Alert on geomagnetic disturbances, to determine if it requires updating with recommendations outlined in the NERC report to ensure that the guidance given reflects the most recent information.

2. Training of planners and operators

NERC will continue to educate industry on the topic of geomagnetic disturbances, work with industry to refine operator tools and procedures, and to consider actions such as preemptively increasing reserves, enabling forced cooling or taking equipment out of service in advance of storm. As part of this transfer of knowledge, it will be vital that open-source models are developed to facilitate industry learning, study and action. Further, NERC will also add training as part of its Operator Certification program.

3. Spare equipment inventory management

The industry continues to work hard to demonstrate its commitment to reliability in the response to high impact, low frequency events. One way is to develop programs to share spare equipment in the event of a severe event. NERC's Spare Equipment Database has been now fully vetted by industry and will be re-launched with specific focus on spare transformer equipment. The Spare Equipment Database is a voluntary program whereby owners of long lead-time transformers would share information about their spares in a database for potential equipment sharing.

In addition, the IEEE Transformers committee has begun development on a guide on transformer and step response **specifications** to meet the service conditions related to a geomagnetic disturbance as well as the magnitude and stress cycle due to geomagnetically induced current transformers should be designed to withstand. This project was initiated at the spring 2012 meeting of the IEEE Transformers Committee in Nashville, Tennessee. We will monitor the progress of this effort, and provide technical expertise as warranted to its conclusion.

From an operational perspective, more useful forecasting is needed to support operator action. The U.S. National Oceanic and Atmospheric Administration (NOAA) and SpaceWeather Canada need to enhance warning time frames and granularity of forecasts so industry can take the right action, in the most affected parts of North America.

The GMD task force interim report provided a roadmap for action for industry to address GMD. For industry to recognize that, just as they prepare for earthquakes, hurricanes and snowstorms, preparations for GMD should be a part of their planning efforts. It is important for us to learn from those who have had experiences with GMD, to get the source code information out to industry and train the planners and system operators to deal with these events.

Thank you for the opportunity to speak to the Commission today and I welcome your questions.

ATTACHMENT B

This attachment provides references to frequently-cited studies that conclude that a strong, extreme geomagnetic disturbance would result in irrecoverable damage to large amounts of bulk power system equipment. Note these studies are the product of the same principal authors.

High-Impact, Low-Frequency Event Risk to the North American Bulk Power System
Published by NERC, U.S. Department of Energy, 2010
http://www.nerc.com/files/hilf.pdf

Geomagnetic Storms and Their Impact on the U.S. Power Grid Meta R-319
John Kappenman
Published by Oak Ridge National Laboratory, January 2010
http://www.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-319.pdf

Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack
Published by the EMP Commission, 2008
http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf

Executive Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack
Published by the EMP Commission, 2004
http://www.empcommission.org/docs/empc_exec_rpt.pdf

Low-Frequency Protection Concepts for the Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation – Meta R-322
John Kappenman
Published by Oak Ridge National Laboratory, January 2010
http://www.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-322.pdf

Management of the Geomagnetically Induced Current Risks on the National Grid Company's Electric Power Transmission System
A. Erinmez, J. Kappenman, W. Radasky
Journal of Atmospheric and Solar-Terrestrial Physics, Volume 64, Issues 5–6, March–April 2002, Pages 743-756
http://www.sciencedirect.com/science/article/pii/S1364682602000366

Severe Space Weather Events-Understanding Societal and Economic Impacts Workshop Report
Published by the National Research Council of the National Academies of Science, Engineering, and Medicine, 2008

http://www.nap.edu/catalog/12507.html

ATTACHMENT C

This attachment provides references to independent technical reports and studies that support the NERC technical findings and conclusions on geomagnetic disturbances

Developing Threats: Electro-Magnetic Pulses (EMP)
United Kingdom House of Commons - Defence Committee, February 2012
http://www.publications.parliament.uk/pa/cm201012/cmselect/cmdfence/1925/192504.htm

Impacts of Severe Space Weather on the Electric Grid
JASONS Summer Study – Department of Homeland Security, November 2011
http://www.fas.org/irp/agency/dod/jason/spaceweather.pdf

Protection against geomagnetic storms
Published by Svenska Kraftnät, 2011
http://www.svk.se/Global/02_Press_Info/Pdf/120330-Skydd-mot-geomagnetiska-stormar.pdf

Hydro One GMD Preparedness Plan for Cycle 24
L. Marti, Filed with FERC in Docket No. AD12-13-000, May 8, 2012
http://elibrary.FERC.gov/idmws/file_list.asp?accession_num=20120508-5018

Simulation of Transformer Hot-Spot Heating due to Geomagnetically Induced Currents
Marti L.; Rezaei-Zare, A.; Narang, A.
Submitted for publication to *IEEE Transactions on Power Delivery*

Effects of GIC on Power Transformers and Power Systems
Girgis, R.; Vedante, K.
Presented at the IEEE T&D Conference & Exposition held in Orlando, FL, May 7 – 10, 2012

GIC occurrences and GIC test for 400 kV system transformer
Lahtinen, M.; Elovaara, J.
IEEE Transactions on Power Delivery, vol.17, no.2, Apr 2002

Characteristics of transformer exciting-current during geomagnetic disturbances
Walling, R.A.; Khan, A.N.;
IEEE Transactions on Power Delivery, vol.6, no.4, pp.1707-1714, Oct 1991

Calculation techniques and results of effects of GIC currents as applied to large power transformers
Girgis, R.S.; Ko, C.-D.
IEEE Transactions on Power Delivery, vol.7, no.2, pp.699-705, Apr 1992

ATTACHMENT D

Transformer Excitation and Geomagnetic Induced Currents

The facts about transformer overexcitation, and its differences from the half-cycle saturation that might be cause by GIC, are discussed in detail below. The key points are: 1) GIC can result in saturation of the transformer core, but it is a different phenomenon than overexcitation and does not result in elevated operating voltage or stress the dielectric strength of the insulation, and 2) while the level of GIC necessary to drive the transformer into half-cycle saturation is of some interest, the more important concern is the extent to which the GIC results in an offset of the transformer flux which defines the extent to which the transformer is saturated.

Overexcitation limits for transformers are based on the applied voltage and frequency. Transformer overexcitation can result in higher than normal operating voltage that stresses the dielectric strength of the insulation as well as saturation of the transformer core. Overexcitation limits are on the order of 10 seconds for 40 percent overexcitation and up to minutes for 10 percent overexcitation. Assuming rated frequency, 40 percent overexcitation would require applying 1.4 pu voltage to the transformer and 10 percent overexcitation would require applying 1.1 pu voltage. The resulting insulation stress accounts for the relatively low overexcitation limits. The amount of overexcitation that will saturate the transformer core varies, but typically is on the order 10 percent to 20 percent depending on the design specification. Overexcitation above the specified value results in non-sinusoidal and non-symmetric excitation current rich in harmonics, including even harmonics. The harmonics present and the level of each are dependent on whether the transformer is single-phase or three-phase, shell-form or core-form, and the number of “legs” in the core. Since the excitation current magnetizes the core, it can be viewed as a shunt reactance similar to the charging current for a transmission line which is modeled as a shunt capacitance. A full model for the transformer includes shunt branches for magnetizing and core losses, but these branches are ignored in models for short circuit and powerflow programs because they are high impedances at nominal frequency and voltage. The phenomenon that the excitation current is a shunt current explains why transformer differential relays have harmonic restraint to prevent operation during magnetizing inrush or overexcitation.

Statements such as “[d]riving a transformer to 10% overexcitation requires only a very small GIC” are imprecise in that, while both overexcitation and GIC may result in transformer saturation, GIC does not result in overexcitation of the transformer in the same context as this term is typically used. GIC can result in saturation of the transformer core; however, it is a different phenomenon than overexcitation and does not result in elevated operating voltage or stress the dielectric strength of the insulation. When overexcitation occurs due to high voltage and/or low frequency, the level of saturation is essentially the same on the positive half-cycle as it is on the negative half-cycle. In contrast the GIC flowing through a transformer requires a proportional flux, and because GIC is a quasi-direct current it results in a corresponding dc offset in both the excitation current and the flux resulting in saturation of the core every half cycle. It is clear is that GIC cannot replicate the overexcitation achieved when applying high voltage/low frequency to the transformer, but the end effects related to transformer heating and harmonics are a concern regardless of whether their origin is overexcitation in a classical sense or due to GIC.

The level of GIC necessary to drive a transformer into half-cycle saturation is a function of the transformer design and the operating point on the transformer saturation curve (which defines the relationship between flux and exciting current). While the level of GIC necessary to drive the transformer into half-cycle saturation is of some interest, the more important concern is the extent to which the GIC results in an offset of the transformer flux which defines the extent to which the transformer is saturated. To understand the distinction, it is important to consider the two regions on the transformer saturation curve. The transformer saturation curve has two regions: (i) the steep slope below the knee of the curve where the slope is defined by the magnetizing inductance and (ii) the flatter portion above the knee of the curve where the slope is defined by the air-core inductance. Once the transformer saturates a significant portion of the flux is forced outside the transformer core resulting in heating of transformer components that are not part of the normal flux path.

Transformer designs have evolved in response to purchasers placing a higher valuation on losses, resulting in a reduction in excitation current from values on the order of 0.01 pu down to values on the order of 0.001 pu. This means that the current required to achieve rated flux in the transformer core has been reduced by a factor of approximately 10. This results in a steeper slope below the knee of the saturation curve because the magnetizing inductance is increased by a factor of approximately 10. For a transformer operating just below the knee of the transformer saturation curve the amount of current necessary to increase the flux to the point of saturation is therefore less for a modern transformer design with lower exciting current. However, it is important to note that the incremental current necessary to increase the flux to the point of saturation is relatively small in either case (*i.e.*, for either a newer transformer with lower exciting current or an older transformer with higher exciting current) when compared to the incremental current necessary to increase the flux once the transformer is saturated. This is because the incremental current necessary to increase the flux once the transformer is saturated is dominated by the air-core inductance which is much lower (by 2 to 3 orders of magnitude) than the magnetizing inductance. As a result, when GIC circulates through a transformer the resulting level of half-cycle saturation is relatively insensitive to the rated magnetizing current as demonstrated by Walling and Khan in their October 1991 paper in the IEEE Transactions on Power Delivery. The end result is that the level of saturation caused by GIC does not vary significantly as a function of the transformer rated magnetizing current or the lower losses of modern transformer core designs. Rather, the design of the transformer as it relates to the air-core inductance (*e.g.*, core-form versus shell-form) is the dominant design factor that influences the level of saturation resulting from a given level of GIC.