Technical Conference on Proposed Reliability Standard TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance (GMD) Events

Remarks of Mark Lauby, Senior Vice President and Chief Reliability Officer
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Chairman Bay, Commissioners, FERC staff, and fellow panelists:

My name is Mark Lauby and I am the Senior Vice President and Chief Reliability Officer of the North American Electric Reliability Corporation (NERC). I earned a Master of Science of Electrical Engineering and have more than thirty years of experience in the bulk power system industry. In 1992, I was selected as the Institute of Electrical and Electronic Engineers (IEEE) Power Engineering Society (PES) Young Engineer of the Year. In 2012, I was awarded Fellow status with IEEE, and in 2014, I was honored with the IEEE-PES Roy Billinton Power System Reliability Award. I sincerely appreciate the opportunity to participate in today's technical conference on NERC's proposed Reliability Standard TPL-007-1, Transmission System Planned Performance for Geomagnetic Disturbance (GMD) Events.

Introduction

Over the past several years, NERC and the North American electric power industry have made significant progress in understanding and addressing the risks posed by geomagnetic disturbances, or GMDs, to the reliability of the North American Bulk Power System. In Order No. 779, the Commission directed NERC to address the impacts of GMDs on the reliable operation of the Bulk Power System through the development of Reliability Standards in two stages. The Commission approved the first stage Reliability Standard EOP-010-1 in Order No. 797. NERC is encouraged by the Commission's proposal to approve the second stage GMD Reliability Standard, TPL-007-1, as outlined in the Notice of Proposed Rulemaking (NOPR) issued in May 2015. NERC has appreciated its opportunities to inform the Commission of its progress on GMD efforts. I look forward to discussing the proposed standard with the Commission staff and panelists during today's technical conference.

An important part of NERC's role as the Commission-certified Electric Reliability Organization is to address vital concerns that may impact reliability. In early 2011, NERC kicked off a multi-year, cross-disciplinary effort to improve the understanding of GMD events and the risks these events may pose to the reliability of the Bulk Power System. Over the next several years, NERC brought together representatives from industry, academia, governmental agencies, and equipment and software vendors to advance understanding of these risks. Through its work with entities such as the Electric Power Research Institute (EPRI), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), the Department of Energy (DOE), and others, NERC has supported the development of publicly-available models and tools to help industry address the impacts of GMDs and geomagnetically-induced currents (GICs) on their systems. In just a few years, NERC and the North American electric power industry made significant progress in understanding and addressing the risks posed by GMDs to the reliability of the North American Bulk Power System.

Proposed Reliability Standard TPL-007-1 is an important addition to the body of Reliability Standards for the North American electric grid because it will contribute to a high level of resiliency to a severe GMD event. The proposed standard requires entities to perform engineering assessments using state-of-the-art techniques, referred to as GMD Vulnerability Assessments, to determine the potential impact of severe GMD conditions on their systems and equipment. Entities would use a technically justified benchmark 1-in-100 year GMD scenario, referred to as the Benchmark GMD Event, to assess their systems for vulnerabilities to known GMD impacts such as system voltage collapse issues and potential transformer heating concerns. The proposed standard would require entities to develop and implement plans to address issues identified in the GMD Vulnerability Assessments that could lead to voltage collapse, cascading, or uncontrolled islanding, thereby protecting reliability.

As I will explain today, the proposed standard is based on the most advanced space weather and geomagnetism information available and is supported by rigorous scientific and technical analysis. It employs a highly-advanced approach for identifying the most likely impacts of a severe GMD event, given what is now known about severe GMD events and the characteristics of their impacts to power systems. Most notably, the Benchmark GMD Event relies on sound scientific and engineering principles to convert individual station measurement data into actionable information that can be used to evaluate the wide scale impacts of GMD events. These techniques, which are sometimes called "spatial averaging," reflect what is known about GIC and how it is developed in power systems and help improve the accuracy of GIC modeling by reducing biases caused by peak measurements from individual locations.

In short, the rigorous approach prescribed by the proposed standard elevates resilience across the North American Bulk Power System to the potentially serious consequences of GMD events and ensures that mitigation is planned and coordinated effectively. In developing this standard, NERC has benefited from the substantial scientific, engineering, planning, and operational expertise of the standard drafting team. This team consisted of engineers, planners, and operators that are at the forefront of the industry's GMD activities, including an experienced representative from Canada, as well as a leading space researcher from NASA. NERC has also benefited from the work of the GMD Task Force, which includes leading experts from the scientific community and industry. This Task Force has been advancing the industry's understanding of GMD risks through cross-disciplinary collaboration since its formation in 2011 and has developed the state-of-the-art guidelines, modeling approaches, and technical research that underpin the proposed standard.

Much progress has been made on GMD issues over the last several years, and proposed Reliability Standard TPL-007-1 represents an important step in protecting the reliability of the Bulk Power System during severe GMD events. Nevertheless, NERC recognizes that its understanding of this high-impact, low-frequency risk is evolving. Future research and understanding may bring refinements or different approaches to best protect reliability. Therefore, NERC supports the Commission's objectives for continued research and is committed to supporting ongoing efforts to improve the understanding of GMD impacts on reliability.

The Benchmark GMD Event

In keeping with the Commission's directives in Order No. 779, NERC has proposed a technically-justified Benchmark GMD Event to serve as the basis for the GMD Vulnerability Assessments required by proposed Reliability Standard TPL-007-1. This benchmark represents the most severe GMD conditions that the Bulk Power System is expected to encounter in a 100-year period. Selection of this 1-in-100 year threshold takes into account the potential widespread effects that GMD events can have on the Bulk Power System. As was observed during the March 1989 storm affecting Québec, Canada, GMD events have the potential to cause significant Bulk Power System impacts. By adopting the 1-in-100 year storm severity scenario, the Commission would assure reliable operations during storms similar to the March 1989 storm while at the same time reasonably protecting the grid from substantially stronger GMD events.

NERC's estimate of the magnitude of a 1-in-100 year GMD event for GMD Vulnerability Assessments is based on widely-used scientific data, rigorous statistical methods, and an understanding of the physical processes involved in the production of GIC in the power system. The Benchmark GMD Event makes use of a well-known source of dense, high-resolution geomagnetic data commonly used in space weather research. This data was also used in earlier research into GMD scenarios conducted by the NERC GMD Task Force, which are described in NERC's 2012 report titled *Effects of Geomagnetic Disturbances on the Bulk Power System*. As scientific work with this data set has evolved, researchers have developed techniques to better characterize field strengths over distances that are relevant to analyzing GIC in power systems. This work is based on observed patterns in magnetic field measurements from a dense magnetometer network. As NERC described in its NOPR comments and again in its October 2015 comments, these advanced techniques avoid local spatial bias and provide a robust averaging approach. These techniques largely account for the differences in the 1-in-100 year GMD event estimate in the Benchmark GMD Event, compared to estimates that do not use this technique, such as those in the 2012 NERC GMD report and the September 2015 Los Alamos National Laboratory review.

These techniques are necessary and appropriate for the purposes of developing a Reliability Standard that is designed to address the potential wide scale impacts from severe GMD events. GIC is developed in the Bulk Power System over long transmission line-length distances between grounded elements in the Bulk Power System. Typically, these distances are on the order of 100 kilometers.

The advanced techniques for averaging field strength data over similar areas improve the accuracy of GIC modeling by reducing biases caused by discrete localized peak geomagnetic observations found in the magnetic field data. The NERC standard drafting team analyzed the potential impact of localized peak fields on a sample section of the North American Bulk Power System and described the results in the Benchmark GMD Event Description white paper. The results show that these local peaks do not appreciably affect GIC in a power system and would not produce a system-wide impact. Therefore, the Benchmark GMD Event's reliance on techniques that avoid local spatial bias is scientifically sound and represents a sound engineering approach to evaluating wide scale impacts, given what is known about GIC and how it is developed in power systems.

Further, NERC has high confidence, supported by statistical analysis, that the Benchmark GMD Event accurately characterizes and defines a 1-in-100 year GMD event. In determining the Benchmark GMD Event, NERC employed extreme value analysis, a well-established statistical method for hazard assessment. Using this method, members of the NERC standard drafting team and their research partners rigorously determined, from the data set, that the magnitude of the Benchmark GMD Event exceeds the 95% confidence interval of a 1-in-100 year event. In other words, although the available data set of modern magnetometer observations covers just 21 years, we have high confidence that the proposed Benchmark GMD Event represents to the power grid the most severe GMD event expected in a 100-year period. This method can also be used going forward, to review the confidence interval as the set of geomagnetic data grows over time and ensure the Benchmark GMD Event remains correctly characterized and defined.

The Benchmark GMD Event also incorporates what is known about the different effects GMD events may have on different locations in North America. A severe GMD event like the Benchmark GMD Event has the potential to cause wide scale consequences on the interconnected transmission system. Because of these potential wide scale impacts, a continent-wide Reliability Standard is needed. However, GMD events do not affect all locations in North America the same way. Location and geographic differences result in variations in geomagnetic conditions throughout North America. For a continent-wide standard to be viable, it must be able to take into consideration the variations in GMD conditions over all areas of the North American electric grid. The proposed standard and Benchmark GMD Event account for these variations and enable entities to tailor the standard to their specific location. Specifically, the proposed standard includes latitude scaling factors and scaling factors to account for differences in deep earth conductivity. I will now discuss both of these factors and how they were derived.

First, the proposed standard includes latitude scaling factors to address the variations in geomagnetic conditions. Documented research of severe GMD events describes the change in field strength that occurs from the northern latitudes toward the equator. The scaling factors developed for proposed Reliability Standard TPL-007-1 model this change so that an entity can tailor the Benchmark GMD Event to the location of its system. To determine these factors, the standard drafting team analyzed documented research and public geomagnetic data from the strongest GMD events since the late 1980s, including the March 1989 GMD event. This represents a more rigorous approach to describing the relationship between latitude and field strength than that employed by previous analyses, such as the 2010 Oak Ridge National Laboratory report cited in the NOPR.

Second, to address variations in deep earth conductivity across North America, the proposed standard includes default scaling factors which provide an important baseline for entities to use for tailoring the Benchmark GMD Event by geographic region. Variations in deep earth conductivity found throughout North America influence the strength of the current-inducing electric fields produced in a geographic area during a GMD event. Although the geology of North America is extremely complex and the resulting deep earth conductivity may have local variations, accurate GIC modeling may be obtained by using earth models that approximate the effective deep earth conductivity over the geographic area of interest. Proposed Reliability Standard TPL-007-1 includes default scaling factors based on documented studies of geological structure for each of 28 geographic regions spanning the North American electric grid. In some cases, entities may have specific geologic information for their system area that may improve the accuracy of their GMD Vulnerability Assessments. For this reason, the proposed standard provides flexibility for entities to use area-specific earth conductivity models in place of the provided default scaling factors when tailoring the Benchmark GMD Event.

In its NOPR comments, NERC has described in detail how the currently-available information provides a strong technical basis for the proposed scaling factors and why the Commission should approve the proposed standard as written. Nevertheless, NERC agrees with the Commission that more research is needed. NERC recognizes that the earth conductivity models used to develop default scaling factors are first-generation products based on currently-available information. NERC is committed to further advancing the earth conductivity models that are available for GMD Vulnerability Assessments through its collaborative efforts with industry and research partners. NERC plans to work with entities and its research partners to use data, such as ground magnetotelluric measurements or GIC and magnetometer data, to further refine and advance the maturity of these models. Furthermore, NERC envisions a role for the GMD Task Force to continue its engagement with researchers and vendors in the evolution of tools for calculating GICs. For example, research efforts that are underway to incorporate granular models developed from new 3D surveys may provide more accurate GIC calculations, particularly in areas that are difficult to represent with uniform earth conductivity models such as coastal regions.

NERC is committed to working with the Commission staff and stakeholders to address these and the other research areas described in the NOPR and to continue to advance industry understanding of GMD-related issues.

GMD Vulnerability Assessments and Mitigation

The GMD Vulnerability Assessments required by proposed Reliability Standard TPL-007-1 provide the framework for owners and operators of the Bulk Power System to evaluate the potential impacts of the Benchmark GMD Event on Bulk Power System equipment and the Bulk Power System as a whole. The process outlined in the standard coordinates the planning, modeling, and analysis activities of various entities into an integrated assessment of the risk to the reliable operation of the Bulk Power System. Recognizing that industry's understanding of GMD impacts will continue to evolve, the proposed standard would provide entities with needed flexibility to incorporate new models, tools, and other capabilities into their periodic GMD Vulnerability Assessments as they become available.

In its 2012 report, the NERC GMD Task Force identified the following as the two primary risks of GMD events on the Bulk Power System: first, the potential damage to power system transformers from GIC-related heating; and second, the loss of reactive power support which could lead to voltage collapse. The proposed standard requires entities to assess their systems for these risks against the 1-in-100 year Benchmark GMD Event and to take steps to mitigate any issues that impact reliability.

The GMD Vulnerability Assessment process would work to identify an entity's susceptibility to these two primary risks through a multi-step process taking into account all relevant factors. Applicable transmission planners and planning coordinators calculate transmission system GIC flows for the Benchmark GMD Event using GIC system models. These models represent the direct current characteristics of the transmission system, including applicable power transformers, transmission lines, and GIC reduction or blocking devices. In order to realistically assess the voltage impacts of a severe GMD event, the models must consider the potential equipment impact that GIC-related harmonics could have on transmission system elements, including protection systems and reactive power compensation devices. The GIC flow information at each applicable power transformer is used with electrical models to determine the maximum reactive power losses; these reactive power losses are then applied to the power flow analysis required by the GMD Vulnerability Assessment to determine if the system is at risk for voltage collapse, which occurs in a matter of seconds, rather than minutes.

The approach used in the proposed standard represents a fundamental improvement over earlier studies where the effect on the Bulk Power System from loss of reactive power was not taken into consideration. If a transformer is no longer connected to the network due to system voltage collapse, it will not experience loss-of-life due to heating.

To determine the additional transformer heating that could be caused by the Benchmark GMD Event, applicable transmission owners and generator owners would use transformer thermal models and GIC flow information for the Benchmark GMD Event to conduct transformer thermal impact assessments. The thermal assessments that would be required by the proposed standard simulate stressful GMD conditions on the transformer using a 30-hour representation of time-varying waveforms representing severe GIC flows derived from the Benchmark GMD Event parameters and transmission system information. Using these waveforms is another significant improvement over earlier studies, which assumed GIC pulses of long, somewhat arbitrary duration. The proposed standard would not require performance of detailed thermal simulations for transformers that would experience GIC levels with an instantaneous peak value (up to 10 seconds) of less than 75 Amps per phase for the Benchmark GMD Event. This is because NERC’s analysis, which used available data-supported transformer models and which is described in the supporting white papers, indicated that worst-case heating of an otherwise healthy transformer would not exceed the IEEE industry equipment standard C57.91 with this instantaneous peak.

In the next step of the GMD Vulnerability Assessment process, entities would evaluate the results of the power flow analysis and transformer thermal impact according to the standard’s assessment criteria. If an entity determines that mitigation measures are necessary, the entity repeats steps in the process to recalculate GIC flows and reevaluate transmission system performance to ensure that these measures would be effective. Where mitigation is needed to meet the standard’s performance requirements, the entity would be required to develop a Corrective Action Plan. This plan must: (i) address how the performance requirements of the standard will be met; (ii) list specific deficiencies and associated actions that are necessary to achieve performance; and (iii) set forth a timetable for completion. Throughout the GMD Vulnerability Assessment process, planning coordinators, transmission planners, transformer owners, and reliability coordinators would share analysis information to ensure the reliability of the wide area.

The modeling and analysis techniques forming the technical basis for proposed TPL-007-1 are leading-edge capabilities that have evolved through collaborative partnerships among industry experts, researchers, software application vendors, and equipment manufacturers. In recent years, a number of vendors have introduced software tools that enable entities to gain experience in analyzing GMD impacts. These tools, along with the development of the GMD Task Force technical guidelines and the GMD Reliability Standards, establish a consistent engineering-based approach for addressing the risk that severe GMD events could pose to the Bulk Power System.

As mentioned before, NERC recognizes that there is an ongoing need for further advancement of the tools and techniques for assessing and mitigating GMD impacts. NERC maintains an active research effort with EPRI, DOE, and other collaborators through the NERC GMD Task Force. Recently, EPRI completed a technical report containing considerations for specifying and evaluating GIC reduction devices to be used in mitigating GMD impacts. Future EPRI research in the GMD project is aimed at improving capabilities and methods for assessing harmonic impacts on Bulk Power System equipment.

Additionally, the industry continues to need additional transformer simulation models validated by measured field data to support the thermal impact assessments required by the proposed standard. Throughout the standard development process, industry stakeholders expressed concern with transformer thermal model availability. This concern is reflected in the proposed implementation plan for TPL-007-1, which would provide a 48-month implementation period for the transformer thermal assessment requirement. NERC is committed to working with industry and other partners to improve model availability during this period.

Monitoring and Future Work

To date, a number of entities have installed GIC monitors, either through the EPRI's collaborative SUNBURST program or independently. For example, the EPRI SUNBURST network currently operates over 40 GIC monitoring nodes, providing near real-time GIC data to participating members. There are also a number of entities that have installed GIC monitors independently to address their needs for GIC data. One example is PJM's use of GIC monitoring to trigger operating procedures, which was noted by the Commission in the NOPR. Another example is the advanced monitoring network and operational procedures in place at Hydro One in Ontario. Entities have initiated these GIC monitoring activities to address their operational and planning needs. Through collaborative forums such as the NERC GMD Task Force and the EPRI SUNBURST program, these networks can also be an important resource for broader validation and situational awareness. It is important to note that these GIC monitoring networks must be periodically calibrated by the operating entity to ensure that they provide consistency and accuracy in the measurement of GICs.

NERC views GMD monitoring activities as divided into two categories, with different objectives, responsibilities, and information elements in each. The first category concerns monitoring activities that support the basic understanding of space weather, the geomagnetic environment, and the geoelectric fields that can influence the North American Bulk Power System and other infrastructures. In this research-focused area, NERC believes it is important to continue to collaborate with research partners to increase the density of the magnetometer network in North America, use monitoring or other means such as magnetotelluric measurements to refine earth conductivity models, and undertake other activities that will improve understanding of the geomagnetic environment during GMD events. NERC intends to continue its collaborative efforts with NASA, USGS, Natural Resources Canada, and others that oversee these research functions and possess the necessary expertise, and to leverage NERC's position as a learning organization within the industry to engage electric utilities in these efforts. This monitoring should add to the understanding of geoelectric fields throughout North America that may be produced during GMD events. Ongoing, collaborative research such as this is important to maintaining NERC's GMD standards and the Benchmark GMD Event, through NERC's standards development process, with up-to-date information.

The second category of monitoring activity is focused on an entity's information needs for the reliable operation and planning of their system and equipment for GMD resilience. The monitoring activities undertaken by Hydro One, PJM, and participants in the EPRI SUNBURST network are examples of entities installing monitors to meet their operational or planning needs. An entity's operating plans may call for operator awareness of near real-time GIC levels so that pre-determined steps may be taken to maintain reliable operations. An entity may also need additional collected GIC data, along with system information and data of the geomagnetic environment, to improve its system models by comparing actual GIC levels with predicted levels.

These and other GMD monitoring activities are complex and relatively new to many in the industry. Entities are gaining and sharing valuable experience related to the siting, installation, and use of GIC monitors and magnetometers. As NERC has emphasized in its comments on the NOPR, an entity's GMD Vulnerability Assessment is a foundational element for these reliability-related applications of GIC monitoring. In addition, the best placement and number of GIC monitors depends on both the underlying geology and specific network configuration. Until all of the relevant needs and factors are better understood, NERC believes that a mandatory Reliability Standard requiring entities to install GIC monitors would be premature.

NERC notes that many entities are installing GIC monitors absent a mandatory requirement to do so. NERC anticipates that the continent-wide implementation of proposed Reliability Standard TPL-007-1 would further promote entity-initiated GIC monitor installations and data acquisition as applicable entities address system and equipment impacts identified through the GMD Vulnerability Assessment process. The growth trend in GIC monitors that results from implementation of proposed TPL-007-1 would support the timely and effective development of expanded GIC information for planning and operational needs. However, much remains to be learned before an effective mandatory Reliability Standard could be developed.

Thank you for the opportunity to present on these issues today. I look forward to answering any questions.