UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

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Reliability Standards for Geomagnetic	)	**Docket No. RM12-22-000**
Disturbances	)	

COMMENTS OF
THE AMERICAN PUBLIC POWER ASSOCIATION, THE EDISON ELECTRIC INSTITUTE, THE LARGE PUBLIC POWER COUNCIL AND THE NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

The American Public Power Association ("APPA"), the Edison Electric Institute ("EEI"), the Large Public Power Council ("LPPC") and the National Rural Electric Cooperative Association ("NRECA"), jointly on behalf of their respective member companies (collectively the "Trade Associations") hereby respectfully submits these Comments in response to the Notice of Proposed Rulemaking ("NOPR") issued by the Federal Energy Regulatory Commission ("Commission" or "FERC") on October 18, 2012, in the above-referenced docket. The NOPR proposes to direct the North American Electric Reliability Corporation ("NERC") to create and submit Reliability Standards that address and mitigate the effects of geomagnetic disturbances[1] ("GMDs") on the Bulk-Power System ("BPS") caused by solar events.[2]

[1] The Trade Associations' Comments focus exclusively on GMDs as specified in this docket and are not intended to address other phenomena, which are not naturally generated by the effects of the sun.

[2] *See Reliability Standards for Geomagnetic Disturbance*s, Notice of Proposed Rulemaking, 141 FERC ¶ 61,045 (2012).

EXECUTIVE SUMMARY

The Trade Associations appreciate the Commission's effort to gather information on this issue, and understand the sentiment favoring action in order to guard the nation's grid from failure. The electric industry takes the risk associated with GMDs very seriously and has worked diligently to better understand GMD effects and to minimize their impacts. GMDs are not a new phenomenon; hence, the industry has learned from various events and believes it has taken effective actions based on current consensus-based knowledge and available tools to address the issues that could challenge reliability. For example, industry has been involved in significant work through NERC's GMD Task Force ("GMDTF"), the Electric Power Research Institute ("EPRI") SUNBURST Project, the National Oceanic and Atmospheric Administration ("NOAA"), and the Goddard Community Coordinated Modeling Center ("CCMC"), which are described in detail in Attachment A of these Comments.[3]

While the Trade Associations share the Commission's goals to protect the BPS against the impacts of GMDs, the NOPR nonetheless raises but does not resolve the many concerns that must be addressed prior to issuance of any final order that would direct NERC to adopt Reliability Standards imposing mandatory changes to the design, operation and control of the BPS. Many aspects of the science surrounding GMDs are still immature, the methods of grid impact analysis remain crude and unrefined, and necessary assessments of the impact of methods of remediation are unproven. In addition, the Trade Associations strongly support the work activities of the NERC

[3] Additionally, the Institute of Electrical and Electronics Engineers ("IEEE") and the International Council on Large Electric Systems ("CIGRE") have commissioned working groups to address GMD impacts on the grid.

GMDTF, an open and inclusive technical group with broad and diverse expertise, and that work requires completion. The Trade Associations strongly recommend that the Commission also support these efforts, as well as other industry activities aimed at addressing GMD issues. Trade Associations also read the NOPR as giving too little weight to contrasting viewpoints, including groups such as the GMDTF and other national laboratory reports[4] that were developed by much broader groups of technical experts, and subject to greater transparency and peer review. The contrasting studies suggest far different opinions of the risks and urgency related to GMDs with respect to the BPS.[5] The Trade Associations also believe that the NOPR inappropriately relies on certain studies characterizing the nature of a possible "100-year" threat scenario to infer that GMD events could place a significant number of transformers at risk for failure or permanent damage. The Trade Associations do not believe that these studies have undergone the rigorous peer review necessary to be relied upon to support the Commission's findings and proposals. These supporting studies are also problematic because they rest upon equations and data that are not transparent and the software used to support such analyses remains largely unavailable.[6]

In the absence of a strong consensus on the technical specification of a severe GMD event that would induce realistic geomagnetic induced current ("GIC") levels that need to be protected against, as well as the immaturity of tools necessary to accurately

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[4] *See* PNNL-21033, Geomagnetic Storms and Long-Term Impacts on Power Systems and Special Reliability Assessment Interim Report: *Effects of Geomagnetic Disturbances on the Bulk Power System* (2011) ("PNNL-21033").

[5] Accordingly, the Trade Associations describe below specific concerns with the ORNL/Metatech Report.

[6] Software to assess GIC withstand capability of transformers may be available to equipment manufacturers, but is not directly available to the member companies of the Trade Associations.

determine where and to what level GIC might have detrimental effects, the Trade Associations believe the Commission would be asking the industry to make assessments of risk and apply solutions at a point when these tools are simply incapable of doing so without creating significant unknown risks to reliability that could be of a greater degree than any known risk resulting from a severe GMD event. Moreover, without such a consensus, it is extremely challenging for industry to identify and assess reasonable, cost-effective and widely available solutions that could meet the standard set forth in the NOPR, in as much as the Commission is proposing to require owners and operators to develop and implement plans so that instability, uncontrolled separation, or cascading failures of the BPS, will not occur as a result of a GMD event, no matter how extraordinary. *See* NOPR at 23. Understanding the nature of the GMD threat and modeling of the potential impacts of GMDs caused by such a threat is by necessity the cornerstone of any effective mitigation strategy. Unfortunately these tools are still immature and not yet validated (*e.g.*, power flow models that incorporate the behavior of half-cycle saturated power transformers have not been validated with measurement data) and therefore are not ready for broad application by the industry. Hence, the Trade Associations are concerned that the NOPR appears to wrongly reflect the belief that GMD modeling tools are sufficiently refined and readily available to effectively mitigate the impacts of a severe GMD event.

In sum, the Trade Associations believe that without a strong consensus on the technical specification of a GMD event and confidence in the tools currently available for modeling the effects of GICs, the NOPR presents insufficient basis to conclude that there is an adequate technical foundation for a new or modified NERC Reliability Standard on

GMDs as proposed in the NOPR. For these reasons, a directive to NERC to develop mandatory standards under Section 215(d)(5) of the Federal Power Act ("FPA") is premature. NERC's GMDTF Phase 2, Recommendation 4 seeks to review the need to enhance NERC Reliability Standards.[7] The NERC GMDTF Phase 2 should be completed prior to any new or amended Reliability Standards being promulgated on this issue. To do otherwise would not serve the industry or the electric customers they serve well and could result in Commission mandates that may do more harm than good, because they would direct Registered Entities to take actions that could have unintended adverse impacts on reliable operation of the BPS.

The Trade Associations do support the Commission encouraging NERC to expedite completion of the work of the GMDTF and to submit NERC's recommendations for concrete GMD mitigation activities as soon as possible. The Commission should require NERC to make an informational filing within six months of an order in this proceeding, providing a status report on its work plans and activities. The Trade Associations stand ready as well to assist their members and other industry participants in efforts to catalogue and share current industry knowledge of GMD phenomena and best practices for the mitigation of GMD through operating procedures, GIC monitoring equipment, situational awareness and the design, testing and coordination of specific devices to mitigate GICs.

If the Commission finds it must direct NERC to develop a standard or standards to address the impact of GMDs on the BPS, the Trade Associations support the

[7] NERC GMD Task Force Phase 2.

Commission's stage one proposal to require NERC to file one or more standards which would require grid owners and operators to develop and implement operations procedures that would mitigate GMD effects.[8] The Trade Associations agree that the Commission should avoid directing prescriptive standards. At this stage, it would be inappropriate to require owners and operators of the BPS to engage in determining and implementing mitigation measures until greater consensus on GMDs can be achieved. The Trade Associations support the NOPR's proposal for stage one to include identification of facilities most at-risk from severe GMD events since this exercise is required to conduct meaningful ongoing assessments of the potential impact of GMDs on BPS equipment and on the BPS as a whole. However, as discussed below, NERC should not be performing these assessments and it should be recognized that such an effort is highly dependent on improved modeling of GICs, improvements to area and regional power flow modeling of GIC propagation, and benchmarking of such models against actual GICs.

In view of the unsettled state of the science analyzing the GMD phenomena, and uncertainty regarding the best methods for addressing it, as well as the lack of mature modeling tools, the Trade Associations urge the Commission to refrain from implementing its stage two proposal at this time. Ongoing studies of GMD phenomena and appropriate responses reveal a good deal of disagreement regarding the nature of the threat and the efficacy of various strategies for addressing it. Given this uncertainty, stakeholders cannot develop requirements to reasonably address a GMD disturbance. Thus, it will be difficult to arrive at a uniform procedure without a better understanding

[8] In this regard, the Commission should recognize that areas most likely to be affected by a GMD event already have such procedures in place.

of the nature of the risk and vulnerabilities presented by GMDs, particularly in areas otherwise believed to have little risk from such phenomena.[9] Nor is there any assurance that the strategies that have been studied to date will in fact guarantee there will be no system disruptions, as the proposed phase two rule appears to contemplate. For these reasons, the Trade Associations urge the Commission to coordinate closely with NERC and the industry as additional work on this issue is undertaken, and remain ready to take further affirmative steps when the nature of the threat and the efficacy of proposed solutions are better understood.[10] The Trade Associations in turn pledge that they will work with their members, subject matter experts and NERC to address these technical uncertainties on an expeditious basis.

Above all, the Trade Associations urge the Commission to exercise significant caution in this docket and guard against the possibility that directives to NERC could inadvertently create a cure that is worse than the potential GMD disease. In particular, "GIC blocking devices" have not yet been adequately studied or tested to determine their local area system impacts or failure modes, and therefore should not be relied upon at this time. Furthermore, any application of such devices without understanding their broader impact as part of the coordination of protection systems could potentially introduce new everyday reliability problems well beyond any benefit achieved through the mitigation of a severe GMD event with a very low likelihood of ever happening. Since the system-

[9] In turn, without a consensus on the nature of GMD events, the Commission would be unable to have a reasoned basis for approving requirements that would purport to avoid causing widespread cascading outages, uncontrolled separation, or system instability.

[10] GMDTF work is vital to informing the technical assessments of potential GMD events and addresses four important issues: (1) Improvement of tools for industry planners to develop GMD mitigation strategies; (2) Improvement of tools for system operators to manage GMD impacts; (3) Education and information exchanges between researchers and industry; and (4) review the need to enhance NERC Reliability Standards.

wide modeling tools are not ready and such modeling is critical to inform mitigation decisions, including the design scheme for the placement of equipment such as blocking devices, again, the Trade Associations strongly believe that a Commission directive for equipment assessments is premature.

Finally, the Trade Associations ask the Commission to consider the cost of mitigating the potential effects of GMDs and to allow for ISOs/RTOs to make tariff filings to provide for recovery of out-of-market costs incurred to comply with GMD Reliability Standards and GMD mitigation costs.[11] The NOPR's cost/benefit justification is questionable and the fact is that many generation facilities lack a mechanism for recovery of such extraordinary investments deemed to be in the national interest and would not be compensated by other market means.

IDENTITIES OF THE TRADE ASSOCIATIONS

APPA is the national service organization representing the interests of not-for-profit, publicly owned electric utilities throughout the United States. More than 2,000 public power utilities provide over 15 percent of all kilowatt-hour sales of electricity to ultimate customers, and do business in every state except Hawaii. Collectively, public power systems serve over 46 million customers. Three hundred twenty-eight public power utilities are now included on the NERC compliance registry and are thus directly subject to NERC Reliability Standards, pursuant to FPA Section 215. One hundred and twelve public power utilities are designated as Transmission Owners.

[11] Note that APPA and NRECA do not join in the section of these comments addressing recovery of out-of-market costs.

EEI is the association of United States investor-owned electric utilities and industry associates worldwide. Its U.S. members serve almost 95 percent of all customers served by the shareholder-owned segment of the U.S. industry, about 70 percent of all electricity customers, and generate about 70 percent of the electricity delivered in the U.S. EEI frequently represents its U.S. members before Federal agencies, courts and Congress in matters of common concern, and has filed comments before the Commission in various proceedings affecting the interests of its members. EEI's members have a strong interest in efficient grid operations, which will go far to ensure reliability and efficiency of BPS equipment.

LPPC represents 25 of the largest state and municipal-owned utilities in the nation. Together, LPPC's members represent 90% of the transmission investment owned by non-federal public power entities.

NRECA is the not-for-profit national service organization representing approximately 930 not-for-profit, member-owned rural electric cooperatives, including 66 generation and transmission cooperatives that supply wholesale power to their distribution cooperative-owner members.

BACKGROUND

Given the concern that a solar storms and other high-impact, low frequency (HILF") events may have the ability to disrupt the normal operations of the power grid, in July of 2009, NERC and the U.S. Department of Energy ("DOE") partnered on an effort to address HILF risks to the electric grid. In June 2010, this effort resulted in the issuance of a joint NERC/DOE report titled: High Impact, Low Frequency Event Risk to the Bulk Power System of North America[12] ("NERC/DOE HILF Report") that included GMD risks.[13] The NERC/DOE HILF Report recommended, among other things, that NERC, working with its stakeholders, the DOE and appropriate government authorities in Canada create a task force of industry, equipment manufacturers, and risk experts to evaluate and prioritize mitigation and restoration options for GMD events. The NERC/DOE HILF Report provided the basis for NERC to form the GMDTF to study GMDs and produce an assessment that focused on the effects of GMDs on the BPS.

Since the formation of the GMDTF, a number of studies that have concluded that GMD events can have an adverse impact on the reliable operation of the BPS. However, these studies differ significantly on the nature of the risks that result from the introduction of GICs. For example, the ORNL/Metatech Report stated that GMD events can develop quickly over large geographic footprints, having the capability to produce geographically large outages and significant damage to BPS equipment.[14] The ORNL/Metatech Report assessed the effects of a "1-in-100 year" geomagnetic storm on the modern BPS and concluded that such an event could put hundreds of BPS transformers at risk for failure or permanent damage. Estimates prepared by the National Research Council of the National Academies concluded that these events have the potential to cause wide-spread, long-term losses with economic costs to the United States estimated at $1-2 trillion and a recovery time of four to ten years.[15]

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[12] *See* NERC/DOE Report: *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System* (June 2010). Available at: http://www.nerc.com/files/HILF.pdf.

[13] *See id*.

[14] *See* Meta-R-319, at 1-31.

[15] *See* NAS Workshop Report: *National Research Council of the National Academies Severe Space Weather Events,*

In contrast, the NERC Interim GMD Report that was issued in February 2012 concluded, that the worst-case scenario for an extreme GMD event is "voltage instability and subsequent voltage collapse." [16] In addition, the Pacific Northwest National Laboratory ("PNNL") report on ("PNNL Report") the impact of a severe GIC event on the Western Interconnection said that the impact of such a storm on the electric power deliver system could be significant, but based on the results of the study, PNNL found no reason to think it would be catastrophic in the Western region.[17]

The seriousness of the risk posed by GMDs to the reliable operation of the BPS was debated at a Technical Conference held by the Commission on April 30, 2012. At the Technical Conference, several panelists indicated that severe GMD events could potentially compromise the reliable operation of the BPS, with some noting as an example the GMD-induced disruption of the Hydro-Québec grid in 1989 (other panelists, however, disagreed with his conclusion). At the Technical Conference, panelists stated that the current 11-year solar activity cycle is expected to hit its maximum activity in 2013 and large solar events often occur within four years of such a cycle maximum.

On October 18, 2012, in the above-referenced docket, the Commission issued its NOPR. The Commission proposes to direct NERC to create and submit Reliability Standards that address and mitigate the effects of GMDs on the BPS. While strong

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Understanding Societal and Economic Impacts at pp. 4 and 79 (2008). Available at: http://www.nap.edu/catalog/12507.html. Note, this paper indicates that these estimates were derived by Metatech Corporation, presented by J. Kappenman at the space weather workshop, May 22, 2008.

[16] *See* NERC Special Reliability Assessment Interim Report: *Effects of Geomagnetic Disturbances on the Bulk Power System* at 69 (Feb. 2012) ("GMDTF Interim Report").

[17] *See* PNNL-21033. The Trade Associations believe that the widely varying conclusions in the body of science demonstrate that much more work is necessary to better assess the risks of GMD

GMDs are extremely rare events, the NOPR takes the view that their potential impact on the reliable operation of the BPS (*e.g.*, widespread blackouts) requires Commission action under section 215(d)(5) of the FPA. Additionally, the NOPR asserts that currently GMD vulnerabilities are not adequately addressed in the Reliability Standards and this constitutes a reliability gap because GMD events can cause the BPS to collapse suddenly and can potentially damage the BPS.

Specifically, the NOPR proposes to direct NERC to act in two stages: (a) in stage one, the Commission would direct NERC to file, within 90 days of the effective date of a final rule in this proceeding, one or more Reliability Standards that require owners and operators of the BPS to develop and implement operational procedures to mitigate the effects of GMDs consistent with the reliable operations of the BPS; and (b) in stage two, the Commission would direct NERC to file, within six months of the effective date of a final rule in this proceeding, one or more Reliability Standards that require owners and operators of the BPS to conduct initial and on-going assessments of the potential impacts of GMDs on BPS equipment and the BPS as a whole.[18] Based on those assessments, the Reliability Standards would further require owners and operators of the BPS to develop and implement a plan, subject to certain requirements, so that instability, uncontrolled separation, or cascading failure of the BPS, caused by damage to critical or vulnerable BPS equipment or otherwise, will not occur as a result of a GMD.

[18] The NOPR states that this second stage would be implemented in phases, focusing first on the most critical BPS assets.

COMMENTS

I. The Trade Associations take the risk of GMDs seriously and the electric industry has worked diligently to better understand their effects and minimize their impacts, but the tools necessary to assess the risks of GMDs have not yet been fully developed.

The Trade Associations take very seriously all potential threats and vulnerabilities that could affect the reliability of the electric system, including GMDs. The electric industry has recognized that understanding the effects of GMDs on the BPS and the ability of the industry to mitigate their effects are important to managing system reliability. As a consequence, there has been a broad array of activities underway for several years to better understand and address this issue at EPRI, NASA, NOAA, and the CCMC Industry Collaboration. *See* Appendix A. Additionally, IEEE and the CIGRE have commissioned working groups to address GMD impacts on the grid. Although progress has been made, the industry is not yet ready to say with certainty where reasonable methods of mitigation are necessary or in what manner they should be applied because many industry initiatives have not been fully refined. Hence, the Trade Associations are concerned that the Commission may believe that necessary tools and refined solutions are readily available to effectively assess and mitigate the impacts of GMD events, when this is not the case.

The Commission should understand that the modeling tools necessary to assess GMD and GIC impacts are highly immature. Only recently have some commercial products become available, but even these are not yet adequately developed for broad application. Moreover, EPRI, through the GMD Project, has developed an open source tool that is now available for general use but it also needs substantial work before it can be relied upon to produce reliable results that have been verified through field measurements. Furthermore, the open source tool lacks some of the desirable features now being provided by the commercial solutions.

Similarly, while utilities are expanding their GIC monitoring capabilities, this is often being done without the necessary predictive modeling and as a result this data does not fully inform the risks of elevated GICs to a level of accuracy that is desired or achievable in the future. Therefore, given the complexities of how GICs are manifested, the Trade Associations does not believe that these efforts can be fully depended upon to predict the overall impacts of postulated GMD events until the necessary modeling tools have been completely developed and validated.[19] Once all of the necessary tools have been developed and validated and company networks have been modeled, GIC monitoring may prove to be an extremely useful tool in validating the planning models, in addition to its operational benefits.

The Commission should also understand that companies are taking all reasonable actions to protect their assets, including GIC impact assessments of power transformers.[20] However, this data can only provide marginal usefulness until there is a better understanding of projected GIC levels through system modeling. Although this information provides an incomplete picture of transformer risk and cannot be fully useful

[19] The Trade Associations understand that these modeling tools have not yet been validated against values obtained from field measurements.

[20] Transformer assessments data provided by ABB; GIC Studies performed by ABB on Power Transformers for Utilities worldwide; PowerPoint slide presentation dated June 9, 2011. These assessments are conducted by industry experts in the design of power transformers in order to evaluate GIC susceptibility. For each category of transformer, assessments are made to determine the potential for core saturation and winding damage due to component overheating. More detailed assessments are conducted on transformer categories classified as susceptible to core saturation as well as those susceptible to overheating caused by GICs. Asset owners receive these analyses when they take receipt of new equipment.

without necessary GIC system planning results, it does provide some information as to which assets may be at risk and may help to educate and inform system operations personnel of prudent steps they can take to better protect system assets during a severe GMD event. Nevertheless, the full impact and value of this knowledge is tied to effective GIC modeling through effective system planning tools. More specifically, GIC transformer withstand capability can only be effectively assessed though an understanding of GIC levels at specific geographical locations given their position in the network, system operating conditions and the magnitude of a given GMD.

Situational awareness, (*i.e.*, the methods and processes for alerting the industry to a pending GMD event) is improving but considerable R&D work remains before it can deliver the advanced notifications needed by the electric industry. The scientific understanding of extreme space weather events and the physics of solar-terrestrial phenomena has experienced a measured improvement over the past decade, but much work remains before satellite data received from NASA and NOAA can be effectively integrated into industry systems that adequately inform system operators in ways that effectively guide industry operational procedures. Until these solutions are fully developed, the industry will continue to refine and collaborate with groups such as the CCMC.[21] The Trade Associations note that improvements are now less reaction-based and beginning to enter a new era of proactive situational information through both *in situ* and remote observations and physics-based large-scale simulations of the space environment.

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[21] The CCMC is a multi-agency (governmental) partnership. The CCMC provides, to the international research community, access to modern space science simulations. In addition, the CCMC supports the transition to space weather operations of modern space research models. http://ccmc.gsfc.nasa.gov/about.php.

At the present time, the industry is capable of effectively managing risk through operations procedures due to the currently available space weather forecasts and warning systems which allow for event lead-time of 1-2 days and more refined short lead-time notices of 30-60 minutes bases on current satellite data from the Advanced Composition Explorer ("ACE") spacecraft.[22] Operational Procedures continue to be the only effective solution even though they remain imperfect due to the state-of-the-art of supporting technologies. It is also important to note that PJM, ISO-NE, NYISO, and MISO all have developed communications and mitigation procedures for this type of vulnerability.

II. The Trade Associations support the efforts and findings of the NERC GMD Task Force and believe its work presents a foundation for effective mitigation of GMD risks.

In 2010, NERC established the GMDTF to address the implication of severe GMD events. This included assessment of GMD studies developed after the 1989 GMD storm, performing analysis of GMD scenarios as set forth in the NERC/DOE HILF report, and reporting on the impacts that a GMD event would have on the BPS. GMDTF was also charged with focusing on enhancing and improving existing prevention, mitigation and system restoration approaches.

The Trade Associations cannot emphasize enough that the GMDTF represents an open and inclusive process, leveraging a large body of technical expertise with decades of experience. For example, the GMDTF is a joint task force reporting to the NERC Planning Committee and Operating Committee, with participation by the Critical Infrastructure Protection Committee. The GMDTF includes NERC member entities,

[22] The ACE is an Explorer mission that was managed by the Office of Space Science Mission and Payload Development Division of the National Aeronautics and Space Administration. The ACE satellite data is used to by the Solar Shield project to generate Alert for the electric utility industry. *See* http://www.swpc.noaa.gov/ace/ACE.

equipment suppliers and manufacturers, GMD experts, government agencies (Federal, Provincial, and State), and NERC staff. Moreover, it is also significant that the GMDTF work is peer reviewed and collaboratively developed including input from non-NERC members. Specifically, the results of the GMDTF efforts are reviewed periodically by the leadership of the technical committees, in coordination with the Electricity Sub-Sector Coordinating Council. The Trade Associations underscore the importance of an organized effort that includes a broad range of experienced technical experts who are dedicated to identifying technical challenges, conducting thorough analyses, and seeking to address those challenges with reasonable and integrated solutions.

A. The Trade Associations strongly agree with the GMD Task Force Interim Report Recommendations

The GMDTF Interim Report[23] was issued in February 2012 and made the following high level recommendations:

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

For the purposes of considering the proposals made by the Commission in this NOPR, the Trade Associations believe that the GMDTF Interim Report contains several critical conclusions to which the Commission has not given due weight. First, the lack of sufficient reactive power support was a primary contributor of the 1989 Hydro-Quebec

[23] *See* NERC GMD Taskforce Interim Report at 85.

GMD induced blackout.[24] This finding is consistent with the findings of the PNNL Report.[25] Second, a severe GMD would not result in the failure of large numbers of EHV transformers.[26] Again, the PNNL Report arrived at similar conclusions.[27] Third, the GMDTF Interim Report also concluded that "the most significant issue for system operators to overcome from a strong GMD event would be to maintain voltage stability, as transformers absorb high levels of reactive power while protection and control systems may trip supportive reactive equipment due to harmonic distortion from signals."[28] Additionally, the GMDTF Interim Report concluded that transformers of certain older designs along with those in poor condition are most vulnerable to the effects of GMD.[29] Finally, the industry needs "technical tools to model GIC flows and subsequent reactive power losses to develop mitigating solutions."[30]

The Trade Associations strongly agree with the GMDTF Interim Report and believes that the report's recommendations align well with the current state of the art relative to the GMD phenomenon. Any effective response to a GMD event must ultimately rest on the industry's ability to effectively model GIC flows and reactive power losses.

The GMDTF has now begun the second phase of its work. Since the work plan intends to address several issues that directly relate to GMD modeling and mitigation

[24] *See id*. at 85.

[25] *See* PNNL-21033, at 15-17.

[26] *See* GMDTF Interim Report, at 85.

[27] *See* PNNL-21033, at 17.

[28] *See* GMDTF Interim Report, at 85.

[29] *Id.* at 85-86. Such technical tools need to be validated with measurement data.

[30] *Id*. at 86.

issues, the Trade Associations recommend that the Commission direct NERC to make an informational filing within six months of the final rule in this docket, seeking a status report on GMDTF work plans and activities. The informational filing could identify priority activities and timelines, and tasks that might be accelerated as well as activities that can be deferred or eliminated.

III. The Trade Associations cannot support the analyses and findings of the ORNL/Metatech Report (Meta-R-319, etc.) because they are based on proprietary tools and methodologies, lack peer review, and contain numerous technical flaws and omissions that color the credibility of the report.

Although the NOPR states the Commission proposes to take action on the basis of certain government-sponsored studies and NERC studies that are characterized as establishing that GMD events can have adverse, wide-area impact on the reliable operation of the BPS, [31] the Commission's primary foundation for its proposal appears to be the ORNL/Metatech Report. The Trade Associations have multiple concerns with this report.

In contrast to the GMDTF and its open and transparent process, the ORNL/Metatech Report was developed without the benefit of a rigorous peer review, a basic requirement for scientific inquiry involving complex technical subject matters. Subject matter experts cannot verify the methods, processes, equations, or data, making the report a "black box." Moreover, software used to support analyses in the ORNL/Metatech Report remains largely unavailable for technical review, making it nearly impossible to verify or refute the findings.[32]

[31] NOPR at P 2.

[32] Again, this software may be available to equipment manufacturers, but is not available directly to the member

The Trade Associations believe that relationships between numerous technical conclusions that are revealed in the ORNL/Metatech Report need far more testing and validation before the Commission can reliably use such analyses as the basis for action under Section 215(d)(5). As previously stated, the Trade Associations understands that the PNNL study of the Western Interconnection arrived at very different conclusions than the ORNL/Metatech Report.[33] Of those conclusions found in the PNNL Report that are most significant include the following:

> Without doubt, a major geomagnetic storm will again hit earth. It is not a matter of *if*, but *when*. The impact of such a storm on the electric power delivery system may be significant, but based on the results of our study, we found no reason to think it would be catastrophic.[34]
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> GIC currents are blocked by series capacitors, and the transformers on lines that do not have series capacitors can be well protected by relaying schemes using technologies that already exist.[35]

B. The ORNL/Metatech Report contains numerous basic technical flaws that diminish the credibility of its findings.

The Trade Associations identified three key technical flaws when evaluating the ORNL/Metatech Report that are key in both the understanding of the level of risk and the urgency with which the industry should respond to the effects of a severe GMD event. Specifically, these flaws call into question the credibility of the severe geomagnetic storm scenario, the voltage collapse scenario due to increased reactive power demand, and transformer damage due to increased hot-spot heating. These flaws are basic analytical problems that cause the Trade Associations to conclude that the Commission has wrongly

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companies of the Trade Associations.

[33] *See* PNNL-21033.

[34] *See* PNNL-21033, at P 21.

[35] *See Id*.

placed its confidence in this work as a basis for the NOPR's proposals.

First, without a firm scientific basis for the representation of what constitutes a "severe geomagnetic storm," credible studies cannot be performed, let alone effective engineering responses. The ORNL/Metatech Report contains a depiction of such a scenario that the Trade Associations believe lacks scientific credibility. Specifically, the Trade Associations respectfully submit that one cannot define the broad impacts of a storm scenario utilizing peak historic measures with any degree of accuracy. To do so seriously exaggerates what is known in the current body of science. The Trade Associations also find a number of inaccuracies and inappropriate technical leaps relative to storm event frequency that suggest levels of accuracy but contain no information that could reasonably suggest that the necessary rigorous statistical analysis needed to support the claims had been performed. The Trade Associations are also concerned that separate and isolated events have been linked together in order to provide justification for extreme GMD storm levels (*i.e.*, "disturbance intensity approached a level of ~5000 nT/min"), while providing no rigorous statistical analysis to justify such claims. *See* Appendix B.

Second, the Trade Associations believe that the basis for the voltage collapse scenario as contained in the ORNL/Metatech Report lacks credibility because the Trade Associations can find no indication that power flow simulations were conducted to support its conclusions. Without such studies, at best, any conclusions can only be speculation. The Trade Associations also believe some of the methods used to calculate reactive power, although based on earlier work, are now considered obsolete because they yield erroneous results that overestimate reactive losses by 60% or more. The Trade Associations also note that the ORNL/Metatech Report assumes nominal system voltage in its calculations while during an actual GMD event, system voltage will be depressed, which also reduces reactive power losses, rendering the use of nominal system voltage a basic analytical error that significantly affects the conclusions of the planning study. Finally, the report assumes a linear relationship between GIC and reactive power demand (Q) for all transformer types, which the Trade Associations believe is an overgeneralization that further diminishes the paper's conclusions. See Appendix B.

Third, the Trade Associations believe the methods used to assess transformer damage for a GMD event to have been arbitrarily selected and devoid of any theoretical foundation or basis. Specifically, the assumption of 90 Amps per phase GIC loading was used to determine transformer failure. This makes for dramatic and potentially frightening predictions, however, the Trade Associations can find no credible engineering basis in the ORNL/Metatech Report for this extreme assumption.

The Trade Associations also understand that the deficiencies in the methods and assumptions used to estimate the risks associated with transformer heating in the ORNL/Metatech Report are inconsistent with actual heating time constants used throughout the industry for power transformer windings and metallic parts of on the order of 3-5 minutes, which further translates to a 15-25 minute lag time before winding and metallic hotspots can reach their steady-state values. The Trade Associations provide greater detail on these deficiencies in Appendix B of these Comments.

C. The ORNL/Metatech Report does not fully disclose information on key GIC events, which serve to inflate the perception of wide spread equipment damage due to GICs based on historical events.

The Trade Associations find some aspects of the ORNL/Metatech Report are missing key facts that provide a more unbiased view of those events. For example, with respect to the Hydro Quebec Blackout, Section 2 of the ORNL/Metatech Report appropriately describes the events leading to the two transformer failures that were due to overvoltage resulting from the network collapse and not a direct result of GICs. However, in Section 4, the event is again referenced, however, this section of the report seeks to make the case that power transformers are at risk of damage due to the heating effects of resulting in GICs heating, which was not the root cause of these failures. Similarly, the PSEG/Salem generator step up transformer failure was used to point to the potential risks to industry transformers. While this transformer failed as a result of GIC heating, its design and location made it particularly vulnerable to these effects. The Trade Associations do not believe this transformer accurately represents the broad risks for the industry. Finally, the Trade Associations believe that descriptions of the transformer failures in the Eskom, South Africa event have lacked some pertinent information which may further inform the nature of those failures and the impacts of low level GICs.

A more detailed description of these events can be found in Appendix B.

IV. Although the Commission has authority pursuant to Section 215(d)(5) of the FPA to direct NERC to develop a mandatory reliability standard, it should not adopt the NOPR's proposals.

Section 215 of the Federal Power Act sets out the Commission's authority with regard to Reliability Standards, and defines a "reliability standard" as a requirement approved by the Commission "to provide for reliable operation of the bulk-power system." 16 U.S.C. §§ 824o(b) and (a)(3). The statute defines "reliable operation" to mean "operating the elements of the bulk-power system within equipment and electric system thermal, voltage, and stability limits so that instability, uncontrolled separation, or cascading failures of such system will not occur as a result of a sudden disturbance, including a cybersecurity incident, or unanticipated failure of system elements." 16 U.S.C. § 824o(a)(4).

The NOPR asserts that the Commission exercised its authority to order the actions proposed in the NOPR under Section 215 is justified on the basis of certain government-sponsored studies and NERC studies that establish GMD events can have adverse, wide-area impacts on the reliable operation of the BPS. *See* NOPR at P 2. For example, the NOPR states that although strong GMDs are infrequent events, their potential impact requires Commission action. *See* NOPR at P 3. The NOPR does acknowledges that there is not unanimity among experts with respect to BPS risk as a result of a GMD event, but it asserts that Commission action is also warranted "by the lesser consequence of a projected widespread blackout without long-term, significant damage" to the BPS. *See* NOPR at 5. Moreover, with regard to NERC Reliability Standard IRO-005-3a (Reliability Coordination – Current Day Operations), Requirement R3, which discusses GMDs and requires Reliability Coordinators to make Transmission Operators and Balancing Authorities aware of GMD forecast information and assist as needed in the development of response plans, the Commission's view is that "GMD vulnerabilities are not adequately addressed in the Reliability Standards" ostensibly because NERC Reliability Standards do not require steps for mitigating the effects of GMD events. Accordingly, the NOPR concludes that there is a gap in the NERC Reliability Standards that justifies use of its authority pursuant to Section 215(d)(5).[36]

The Trade Associations understand the Commission is afforded considerable discretion to interpret this provision of the FPA as a matter of first impression, but as set forth in these Comments the NOPR does not adequately explain the Commission's reasoning in light of the issues attendant to the studies it relies upon for support.

Holding aside the substantial questions about the underlying studies that the NOPR asserts justify Commission action with respect to the nature of GMD events and the potential impacts of such events, the Trade Associations acknowledge that NERC Reliability Standards do not expressly require steps for mitigating the effects of GMD events. Nevertheless, this does not suggest that the Commission should exercise its authority under the statute by adopting the NOPR's proposal without modification. While FERC has authority under Section 215(d)(5) to direct the ERO to develop a mandatory standard on a specific matter, the specific matter that is the subject of this NOPR, GIC levels caused by strong GMD events, does not have a strong scientific or technical consensus upon which to develop standards. Especially with regard to the proposal to develop a mandatory standard for the assessment of 'critical' transformers and other equipment, and to conduct system-wide assessments on the impacts of a historic GMD event, defining a technically sound specification for 'critical' would rest on guesswork. In addition, the models for assessing system-wide impacts do not even exist. Accordingly, the Trade Associations believe it would be premature for the Commission to adopt the specific proposal presented in the NOPR without modification, as discussed

[36] *See* NOPR at P 4.

below.

A. If the Commission finds that a Reliability Standard or standards are necessary, the Trade Associations support the NOPR's proposal to direct the development of Reliability Standard requiring operational procedures to mitigate the effects of potential GMD events.

The NOPR proposes that during the first stage NERC would develop standards requiring electric companies to develop and implement procedures to mitigate the effects of GMD events. *See* NOPR at PP 18-19. These standards should be coordinated among all entities across the grid. These standards would be filed with the Commission within 90 days of the effective date of a final rule in this proceeding. In addition to developing Reliability Standards that require operational procedures during the first stage, the Commission also proposes for NERC to identify facilities most at risk from severe GMD events. *See* NOPR at P 22.

With respect to the proposal for NERC to file one or more Reliability Standards requiring owners and operators to develop and implement operational procedures, the Trade Associations note that the NOPR recognizes that areas most likely to be affected by a GMD event already have sufficient procedures in place. However, these procedures are based on each system's specific experiences with and assessment of future risks of GMD impacts on system operations. It will be a much greater challenge to define operational procedures to mitigate a GMD threat, as proposed in the NOPR, when there is no consensus on the nature of this risk, as discussed above. Similarly, it is very important for the Commission to appreciate that it will be unrealistic to meet the expectation of a uniform procedure because the magnitude of the GIC impacts and the specific vulnerabilities faced by each system differ so widely across North America.

Even with a limited requirement, the Trade Associations do not believe that the NOPR's proposed deadline for NERC to file this standard or standards within 90 days of the effective date of the final rule is realistic. *See* NOPR at P 19. In a similar vein, the Commission should not propose to direct a specific implementation schedule for the proposed Reliability Standards, such as the 90-day target that the Commission encourages. *See* NOPR at P 21.

Such deadlines are not consistent with the Commission-approved NERC Rules of Procedure, in particular Appendix 3A and the Expedited Reliability Standards Development Process. The Commission's time periods contravene Section 215 of the FPA when it denies the industry and the ERO the opportunity to develop the proposed Reliability Standards and thereby not give due weight to the technical expertise of the industry. The Commission's proposed deadlines also violate the due process rights of the industry. Under the Commission's proposal, those who would become subject to penalty for failure to comply are denied the opportunity to develop any standards in a manner that is consistent with the Commission-approved requirements set forth in the NERC Rules of Procedure. Moreover, the NOPR fails to justify departure from the approved and established standards development process. To the extent that it is necessary to develop the standards proposed by the Commission, the Trade Association's preliminary view is that it may be realistic to expect owners and operators to implement the required operational procedures six months after final Commission approval of the stage one Reliability Standards, provided that the Commission establishes a realistic target date for NERC development and approval of the stage one operational procedure standards.

The Trade Associations support the Commission's proposal that NERC provide periodic reports assessing the effectiveness of operational procedures in mitigating the effects of GMD events and make recommendation to owners and operators that they incorporate lessons-learned and research findings. *See* NOPR P 21. In this regard, the Trade Associations suggest that NERC should make such reports based on the timing of the solar cycle. The Trade Associations caution that depending on the levels of GIC experienced, there may be minimal data to assess the effectiveness of these operational procedures.

With respect to the proposal for NERC to identify facilities most at-risk from severe GMD events and to conduct wide-area GMD vulnerability assessments simultaneously with the development and implementation of the first stage GMD Reliability Standards, the Trade Associations believe that this assessment of the potential impact of GMDs on BPS equipment and on the BPS as whole is necessary. *See* NOPR at P 22. However, the Trade Associations do not agree that NERC should be directed to actually perform these assessments and they should be performed after the necessary tools and methodologies have been developed and validated. This type of activity is not within NERC's role or expertise. The Trade Associations believe that system wide assessments are appropriately conducted by Planning Authorities, and that equipment assessments should be done by owners and operators of the BPS.[37] More fundamentally, the Commission must understand that there is limited benefit from such assessments when there is no consensus on the nature and risks of GMDs. Thus, it will be very difficult to develop an assessment lacking such critical criteria. Moreover, without

[37] If FERC does determine that NERC should conduct these assessments, then it should specify that the NERC Planning Committee is tasked with this work in order to ensure that stakeholder expertise is leveraged.

criteria and mature modeling tools, it will be difficult to determine what constitutes "critical transformers."[38] Furthermore, preparing an assessment in advance of stage two will limit utilities to characterizing their existing asset inventory as opposed to performing vulnerability assessments.

Thus, the Trade Associations recommend that the Commission task NERC, working with the industry through the GMDTF and other committees and vendors, with developing agreed-upon baseline criteria and modeling tools that can be applied by Planning Authorities and asset owners that are at risk of significant GICs within their respective BES areas. This effort should take place after the development of any stage one standards for operating procedures.

B. If the Commission finds that a Reliability Standard or standards are necessary, it should modify the NOPR's proposal to direct the development of Reliability Standards to require the assessment of the impact of GMDs on BPS equipment.

In the NOPR, the Commission proposes that NERC conduct an "initial action" systemwide assessment, as well as an assessment of "critical" or "vulnerable" transformers and other equipment. *See* NOPR at P. 22. The NOPR also proposes that the Commission direct NERC to develop a mandatory standard which would require owners and operators to conduct periodic assessments of equipment, and for mitigation plans that describe actions to resolve problems identified in these assessments.[39] Based on those assessments, the Reliability Standards would then require owners and operators to develop and implement a plan "so that instability, uncontrolled separation, or cascading

[38] *See* NOPR at 22. Furthermore, the need to develop a vulnerability assessment tool was identified in the NERC Interim GMD Report as an industry recommendation. *See* GMDTF Interim Report at p. 89.

[39] *See* NOPR at PP 24-25. The NOPR cites the ORNL/Metatech Report and NERC/DOE HILF Report as the basis for the proposal.

failure of the BPS, caused by damage to critical or vulnerable BPS equipment, or otherwise, will not occur as a result of a GMD." *Id.* at P 23. Finally, the Commission proposes a set of criteria that might inform the content of this standard. *Id.* at PP 27-32.

The Trade Associations do not support this proposed directive for several reasons. As previously stated in these Comments, the reliability basis for conducting these assessments is not strongly rooted in a robust body of scientific work, the ORNL/Metatech Report in particular is flawed, and the various modeling tools that would support the effort are not yet in place.

If the Commission moves ahead with the NOPR's stage two proposal, the Trade Associations request that the Commission should not direct NERC to create a mandatory standard that contains uniform evaluation criteria.[40] A uniform set of GIC values would not be realistic for all owners and operators, due to the widely varying geology and geomagnetic latitudes within which the BPS is planned and operated. BPS topology, power flows, geology, the orientation of transmission lines, and the design characteristics and ratings of transformers all vary widely. Moreover, the proposed uniform criteria could conflict with the proposal that owners and operators conduct studies under varying intensities of GICs. Instead, the Commission should allow NERC to develop a standard that recognizes the broad diversity of the industry. Hence, as an alternative to directing NERC to develop such a Reliability Standard within six months of the effective date of

[40] *See* NOPR at P 28. The Trade Associations are not clear on whether the Commission means a uniform GMD event scenario, or that all owners and operators must assess their equipment on the basis of identical assumptions. The former is problematic because there is no consensus storm scenario and GMDTF is working on this in phase two. The latter is problematic because of wide differences in geology and latitude, two basic ingredients for GIC current expectations.

Final Rule in this proceeding,[41] the Commission should have the NERC GMDTF accelerate its activities for this work as suggested above.

The Trade Associations similarly suggest that if the Commission requires stage two assessments that the Final Rule should avoid raising a debate on how to define the term "critical." The NOPR proposes that the Reliability Standards would require plans so that instability, uncontrolled separation, or cascading failures of the BPS "caused by damage to critical" BPS equipment or otherwise.[42] Again, the Commission should avoid prescription in light of the widely varying geology and latitudes within which the BPS is planned and operated. Accordingly, the Trade Associations agree with the NOPR's statement that the owners and operators of the BPS "are the most familiar with the equipment and system configuration,"[43] and suggest that avoiding the use of the term "critical" may reduce delays, and disputes.

The Commission should recognize that the potential array of mitigation activities can introduce new reliability problems. The NOPR states that the Commission does not propose a particular solution in the second stage Reliability Standards, but also states that the Commission expects that some assessments will demonstrate that automatic blocking is necessary in some instances. *See* NOPR at P 34. In the NOPR, the Commission seeks comment on "GIC blocking devices," saying that they can prevent GIC from flowing into transformers and causing damage. *See* NOPR at PP 34-36.

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[41] *See* NOPR at P 25.

[42] *See* NOPR at P 26 (offering guidance on assessments of BPS vulnerability to GMDs and potential measures for automatically protecting "critical" or vulnerable components). *See* NOPR at P 22. The NOPR also uses the term "critical" with respect to evaluating "critical transformers" pursuant to initial actions in stage one.

[43] *See* NOPR at P 18.

The Trade Associations are not aware that the industry has adequately studied and tested devices that are intended solely to block GICs. Transmission Owners have installed a variety of devices such as series capacitors and static var compensators to support BPS voltage, increase transfer capabilities and ensure reliable operations under normal and abnormal system conditions. These devices may have the corollary benefit of reducing vulnerability to GICs. These devices have also been extensively tested and modeled for their specific impacts and facility limits before they are installed and placed into operation. Transmission Owners are extremely wary of installing any device that has not been fully studied, because the consequences can be severe: cascading, instability and uncontrolled separation and damage to other equipment. For example, it is possible that a GIC blocking device could cause inadvertent relay operations. Any directive to develop a standard to require equipment assessments must not be developed until the industry has verified that such devices are proven to be reliable. While Trade Associations understand that the NOPR states that the Commission does not propose to require any given solution, it is important to realize that these devices are being evaluated by the GMDTF (Team 3) that includes manufactures of such devices and the EPRI GMD Project. Allowing for this body of expertise to carefully study and discuss, and reach an informed consensus opinion on the application of neutral blocking devices is paramount to maintaining the reliability of the BPS.

More importantly, any determination of need for mitigating a problem must be based on a realistic characterization of the GIC levels likely to be experienced at any site. As addressed throughout these Comments, the body of science simply does not support a strong consensus on the nature of the threat. The studies cited by the Commission in the

NOPR are not reliable. Again, the NERC GMDTF in its phase two work plans to address these important threshold issues.

In sum, the Commission should not require the NERC to identify in the proposed Reliability Standards what would constitute appropriate automatic blocking measures, rather, it should require companies to develop effective methods of mitigation based on their knowledge and expertise of their own individual systems.

C. The Commission needs to consider the costs of mitigating potential effects of GMD events.

As a matter of good public policy, there needs to be some reasonable limits with respect to the costs involved in mitigating the effects of GMD events pursuant to a NERC Reliability Standard. The Trade Associations appreciate that the NOPR recognizes that there "could be substantial costs associated with some measures to protect against damage to the BPS,"[44] but the NOPR presents no reliable cost benchmarks to guide these investment decisions. *See* NOPR at P 7. Instead, the NOPR's cost-benefit analysis solely rests upon "[e]stimates prepared by the National Research Council of the National Academies [that] concluded … economic costs to the United States estimated at $1-2 trillion and a recovery time of four to ten years."[45]

The Trade Associations believe this report does not provide any support for the NOPR's conclusion of a favorable cost/benefit ratio for its proposal. The NOPR does not acknowledge that the National Research Council report is not an actual report, but is

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[44] *See* NOPR at P 7.

[45] *See* NOPR at P 5 citing to the NAS Workshop Report: *National Research Council of the National Academies Severe Space Weather Events, Understanding Societal and Economic Impacts* at pp. 4 and 79 (2008). Available at: http://www.nap.edu/catalog/12507.html. Note, this paper indicates that these estimates were derived by Metatech Corporation, presented by J. Kappenman at the space weather workshop, May 22, 2008.

instead only a summary of a workshop held in 2008. Importantly, the National Research Council did not prepare the cited estimate and conducted no analytical research whatsoever. This cost estimate is based on the comments from a single speaker at the workshop for which there is no support in the National Research Council summary report. The Trade Associations do not believe this "report" provides the Commission with any useful information or realistic substantiation of its cost claims. Coupling the weaknesses embedded in the ORNL/Metatech Report with this NRC report leaves the Commission with a speculative case for its proposal, at best.

The Trade Associations are unable to locate the analysis underlying this estimate, however for the purposes of comparison observe that the entire shareholder-owned segment of the electric industry owns or operates approximately $700 billion in net plant, property, and equipment.[46] To provide some further context for this estimate, the most expensive natural disaster to occur in the last hundred years was the earthquake and tsunami that hit Japan on March 11, 2011. Estimates of the cost of this natural disaster range from $200 to $300 billion dollars.[47] Thus, it appears that the estimate cited by the Commission would be a scenario that would be six to ten times worse than the worst event to occur in the last hundred years. Furthermore, importantly, utilities plan for natural disasters and are able to rebuild the electric grid in the aftermath (*e.g.*, Hurricane Katrina). For example, nearly two thirds of the transmission and distribution system of

[46] *See* Edison Electric 2011 Financial Review at 16.
http://www.eei.org/whatwedo/DataAnalysis/IndusFinanAnalysis/finreview/Documents/FinancialReview.pdf

[47] *See* Japan Damage Cost: $300 Billion; A. Greil, S. Oster, S. Ng, Wall Street Journal, March 22, 2011 http://online.wsj.com/article/SB10001424052748703858404576214271676234818.html

Mississippi Power was damaged or destroyed in the Hurricane Katrina.[48] Despite this extensive destruction, service was restored to every customer within twelve days. Thus this estimate also does not appear to adequately consider the ability of the industry to work together to plan and quickly rebuild the electrical grid. Accordingly, this estimate of trillions of dollars of damage appears extremely aggressive.

The Trade Associations believe it would be prudent for active cost-benefit studies to be performed in order to determine whether particular mitigation measures present costs that are commensurate with expected benefits. However, the Trade Associations do not agree that the Commission may properly rely upon such rough estimates of societal costs such as those referred to in the NOPR to justify issuing its proposed rule. *See* NOPR at P 7. The Trade Associations do believe that any Reliability Standard developed in this proceeding should include a requirement to demonstrate that mitigation measures are cost-effective.

All outages cannot be eliminated. Cost-effectiveness must consider the point at which the investment of additional resources reaches the point of diminishing returns in terms of achieving additional reliability. If a historically severe GMD event is viewed in ways similar to other severe natural events that can affect the electric system, then it may be most rational for some facilities to be shut down, or bypassed, causing some amounts of load shedding. In unusual circumstances, it is far more cost effective to interrupt service for a few hours or a few days in order to avoid prolonged outages caused by irreparable equipment damage, or destruction. The Commission has recognized that load

[48] *See* Rebuilding Electrical Infrastructure Along the Gulf Coast: A Case Study, Billy Ball, The Bridge: Linking Engineering and Society, Spring 2006.

shedding is an important operational tool. GMD Reliability Standards should allow for this practice as part of the operational procedures that may be adopted under both stage one or stage two standards, consistent with the Commission's rules and policies.

D. The Final Rule should allow for ISOs/RTOs to make tariff filings to provide for recovery of out-of-market costs incurred to comply with GMD Reliability Standards and GMD mitigation costs.[49]

The NOPR acknowledges that the proposed second stage Reliability Standards "will likely require an extended, multi-phase implementation period given the time needed to conduct the required assessments and the time and cost of installing any required automatic protection measures." However, it does not address the fact that such costs, as well as the cost of compliance with mandatory Reliability Standards in general, are often out-of-market costs for many generation facilities, such as those operated by merchant generators that do not serve retail customers and do not go before state public utility commissions. The Commission should address this issue in its Final Rule by allowing ISOs/RTOs to make tariff filings that permit generators to recover these types of costs.

The Trade Associations believe such an action would be consistent with the Commission's *Policy Statement on Matters Related to Bulk Power System Reliability*, 107 FERC ¶ 61,052 at P 27 (April 19, 2004), wherein the Commission acknowledged that public utilities may need to expend significant amounts of money to implement measures necessary to maintain BPS reliability, including vegetation management, improved grid monitoring and management tools, and improved operator training. The

[49] Note that APPA and NRECA do not join in the section of these comments addressing recovery of out-of-market costs.

Commission specifically assured public utilities that it would approve applications to recovery prudently incurred costs necessary to ensure BPS reliability including compliance with NERC standards. *Id.* at P 28.

Some of these types of costs likely to be required as a result of the proposed Stage Two Reliability Standard are likely to be extraordinary and certainly to be imbued with the interest of national security. Investments to protect equipment for an event that may occur once in one hundred years or more will most likely not be compensated in the markets. While Trade Associations do not suggest that all reliability investments are out-of-market, certain extraordinary investments qualify at such (*e.g.*, replacing generator step-up transformers, investing in more spare transformers than normal for the purpose of sharing spare transformers during a national emergency). Thus, the Commission might consider a method to cover such costs. For example, in Order No. 761, the Commission noted that it had conditionally accepted a proposal by PJM to allow generators providing blackstart service to recover cost related to compliance with CIP Reliability Standards.[50] The existing Commission-approved cost-based mechanism for merchant generators to recover cost for the provision of reactive power is another potential model that could be pursued for the recovery of costs associated with GMD Reliability Standards. Accordingly, the Trade Associations urge the Commission to encourage the ISOs/RTOs to develop via their respective stakeholder processes recovery mechanisms that are appropriate to extraordinary investments that are in the national interest and would not be compensated through other market means.

[50] *See PJM Interconnection, L.L.C.*, 138 FERC ¶ 61,020, at P 47 (2012).

CONCLUSION

WHEREFORE, for the foregoing reasons, the Trade Associations urge the Commission to consider these Comments and ensure that any future action ordered as a result of this proceeding is consistent as discussed above.

Respectfully submitted,

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APPENDIX A

I. EPRI SUNBURST Project

The EPRI SUNBURST project was initiated shortly after the March 13, 1989 solar event that precipitated the Quebec Hydro Blackout. Since that time, EPRI and industry has sought to better understand how geomagnetically-induced currents ("GIC") impact electrical equipment. The SUNBURST network is both an organized method for measuring GICs and their effects, and a source of data for continued research studying the cause, effects and mitigation of GIC impacts on electrical power systems. While the primary focus is operating the monitoring network for purposes of providing better situational awareness, the data collected in this project is beginning to be used to provide feedback into new prediction models that will serve as more directed advance warning systems, that is, the NASA Solar Shield project.

The SUNBURST network consists of a consortium of utilities who have allowed the near-real-time continuous monitoring of GIC on selected large power transformers largely placed to provide a broad perspective of GIC impacts across North America. By measuring these GICs along with current harmonics, the SUNBURST network helps to communicate the breadth, intensity, and localized transformer saturation impact as these storms occur. From the beginning this system was developed to "collect high-quality, readily accessible data related to geomagnetically-induced currents (GIC) associated with geomagnetic disturbances (GMD)" in order to better understand the effects and develop effect methods of modeling and ultimately more remediation.

II. NASA, NOAA, CCMC Industry Collaboration

Although efforts conducted by NASA[51], NOAA[52] and the Goddard Space Flight Center's Community Coordinated Modeling Center (CCMC) [53] go well beyond any effort possible by the industry on its own, it is only through these federal government agencies and the support and data they supply is the electric utility industry able to effectively respond to solar events. Furthermore, these collaborations are hoped will improve industry situational awareness over time. Presently, alerts generated from these systems, along with GIC monitoring, provide necessary notifications to the industry informing system operators in advance and throughout a solar storm.

III. EPRI GMD Project

Project Plan**:** The initial objective will be to determine the state of knowledge of GMD. This will include a review of the available literature and interviews of industry experts, to collect and validate industry data on the probability of extreme events and the extent to which storms can reasonably be anticipated.

Since the initiation of this project, EPRI has developed and released a "first release" of its open source modeling software which is hoped will help the industry determine how systems and equipment respond to various storm scenarios as well as

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[51] NASA owns and operates a group of solar satellites whose data is used by the industry to inform and prepare for possible solar events which might negatively impact BPS operations. Among these systems include SOHO (http://sohowww.nascom.nasa.gov), Stereo (http://www.nasa.gov/mission_pages/stereo/main/index.html),and SDO (http://sdo.gsfc.nasa.gov).

[52] NOAA owns and operates the ACE Satellite which provides 30 – 60 minutes of advance warning of incoming space weather. Alerts from this system are often used by system operators to inform and prepare their operations in response to an incoming solar storm.

[53] The Goddard CCMC works with a variety of organizations and industries including the electric utility industry. Their role for the electric utility industry is to assist and improved their understanding, situational awareness and response. *See* http://ccmc.gsfc.nasa.gov/index.php. The Solar Shield Project is a collaborative project between the CCMC and the electric utility industry which intends to help better protect the electric power industry.

evaluate candidate mitigation technologies.

The project is also intended to evaluate the various new technologies and approaches being developed to help mitigate the impacts of GMDs on industry systems and assets. Ultimately, it is hoped that this center of expertise will be used to provide a knowledge base where the industry can test and assess mitigation technologies, perform system studies, answer industry questions and assess technical concerns.

Among the technologies EPRI will be testing are GIC blocking devices and assessing various operational strategies. Additionally, EPRI will assess mitigation solutions and strategies that purport to include technologies that may reduce the impact or duration of outages. EPRI also plans to consider how mitigation techniques might impact protected equipment, along with possible impacts to the BPS.

As a final deliverable, EPRI plans to develop a guidebook covering mitigation and recovery practices and emerging technologies for forecasting, early warning, operations, and restoration, as well as the various mitigation technologies.

APPENDIX B

I. The Trade Associations do not support the findings of the Oak Ridge National Laboratory Report -Meta-R-319 ("ORNL/Metatech Report") believing it to be flawed and lacking necessary peer review.

A. The Severe Geomagnetic Storm Scenario appears to use anecdotal evidence in ways that is unsupportable by the current body of scientific evidence.

Although the geophysical analysis assumed to be used in the ORNL/Metatech Report is valid and has been used in scientific papers and journals to analyze GIC impacts at a localized level, similar application on a broader scale as depicted in this report appears to be flawed and unsubstantiated by the current body of science. Specifically, spatially isolated observations used to infer severe geomagnetic storm levels of 4800nT/min appear to be based solely on such evidence, *i.e.*, isolated observations. For this reason, the Trade Associations believe the scenario to be flawed since the report extends pocketed localized measurements into very large, possibly continent wide, storms that extend into lower geomagnetic latitudes and does so without any known rigorous technical basis. The result is a storm scenario that lacks a scientifically defendable basis.

Furthermore, the Trade Associations understand that very intense upper atmospheric electrical currents (*i.e.*, electrojets) are manifested as a result of severe GMD events. The results are fluctuating currents that translate into spatial extensions of extreme geoelectric fields driving GIC of a very complex nature. The spatial extensions of complex extreme geoelectric fields are at this time poorly known. Specifically, given the current state of the science, the Trade Associations believe that to imply it can be known with any degree of certainty how an extreme storm would manifest itself over a broad region based on a limited number of peak historic measurements exaggerates what is presently known in the current body of science.

The Trade Associations also find other inaccuracies and inappropriate technical leaps made in the report. For example, the following statement is made in the report, "the observation of a ~2000 nT/min dB/dt was observed in March 13, 1989 in Denmark, ~2700 nT/min in mid-Sweden in July 1982, ~2200 nT/min again in March 24, 1991 in southern Finland, and on Aug 4, 1972 in North America. This sampling indicates that a disturbance of this size class can be expected at a frequency of approximately once or twice per solar cycle, *i.e.*, about a 1 in 10 year probability."[54] The Trade Associations believe that the assertion that a 2000 nT/min dB/dt can occur with a frequency of once every 10 years does not appear to be based on any rigorous statistical analysis, but on simple conjecture.

The Trade Associations are also concerned about apparent broad leaps within the ORNL/Metatech Report that appear to link separate and isolated events without the use of rigorous statistical analyses, and then use those links to speculate the outcome of a low frequency event. Specifically, the report justifies some observations and anecdotal information about the May 1921 storm[55] and then uses such information to justify inferences about the July 1982 Storm. For example, the report states that "based on the July 1982 paired observations and the linear behavior of geo-electric field response to the incident magnetic field environment, it is plausible to project that the disturbance

[54] *See* Meta-R-319, Geomagnetic Storms and Their Impacts on the U.S. Power Grid, Prepared for Oak Ridge National Laboratory at 3-13.

[55] *See id.* at 3-8.

intensity approached a level of ~5000 nT/min."[56] Given the proprietary nature of this report, it is impossible to say how this conclusion was made.

Finally, based on all of the noted conjecture, the ORNL/Metatech Report supports the 5000 nT/min as an observational fact, stating "as previously reviewed, the large ~5000 nT/min observed in May 1921 has occurred before and therefore is likely to occur again."[57] The Trade Associations believe this to be misleading since we are not aware of any rigorous statistical analysis that was performed to provide support for the selected extreme dB/dt and geoelectric field levels that were presented in the report and used as basis for the conclusions that were provided.

B. Voltage collapse due to increased reactive power demand does not appear to be based on any planning study and utilizes obsolete methods.

It is well-known that half-cycle saturation of transformer cores causes an increase in reactive power losses which can lead to a reduction in system voltage[58], and in some cases total system collapse if adequate reactive power resources are unavailable.[59] In order to determine if voltage collapse is likely (or even possible) during a specified GMD scenario, a power flow analysis, in concert with a GIC analysis, must be performed.[60] In such an analysis, GIC flow in transformer windings is used to estimate the resulting

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[56] *See id.* 3-8.

[57] *See id.*. 3-13.

[58] *See* V. D. Albertson, J. M. Thorson, "Power System Disturbances During a K-8 Geomagnetic Storm: August 4, 1972," IEEE Transactions on Power Apparatus and Systems, July 1974, PAS-93, Issue 4, at 1025-1030.

[59] *See* NERC 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System; February 2012; at iii.

[60] *See* V. D. Albertson, J. G. Kappenman, N. Mohan, G. A. Skarbakka, "Load-Flow Studies in the Presence of Geomagnetically-Induced Currents," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2, February 1981, at 594-607; *see also* Investigation of Geomagnetically Induced Currents in the Proposed Winnipeg-Duluth-Twin Cities 500 kV Transmission Line Final Report, EPRI Research Project EL-1949, July 1981. Available at www.epri.com.

reactive power loss. Using the estimated reactive power loss, transformers are then modeled as constant current reactive loads in the power flow. Therefore, accurate mapping of GIC to Mvar loss is essential to obtaining accurate results.

The analysis conducted as part of ORNL/Metatech Report failed to meet these basic requirements. First, power flow simulations were not performed as part of the analysis.[61] Secondly, the best available data[62] was not used to map GIC flows to reactive power losses. Third, no comprehensive assessment of harmonics load flows was conducted to support assessments of risk in this report. [63]

Figure 1-18 of ORNL/Metatech Report describes how the GIC were mapped to reactive power losses in three voltage classes of single-phase transformers. The linear mapping provided in Figure 1-18 of the ORNL/Metatech Report can be approximated using the following equation:

$$Q \approx \frac{\sqrt{3} \cdot k \cdot I_{gic} \cdot V}{10^6}$$

Equation 1

where Q is the three-phase reactive power loss (Mvars), k is equal to 2.0, I_{gic} is the

[61] *See* Meta-R-319; Appendix 1; Subsection A1.1; Overview of US Transmission Grid Design Criteria; at A1-4.

[62] *See* R. A. Walling, A. H. Khan, "Characteristics of Transformer Exciting-Current During Geomagnetic Disturbances," IEEE Transactions on Power Delivery, Vol. 6, No. 4, October, 1991, at pp. 1707-1714; *see also* R. A. Walling, A. H. Khan, "Solar-Magnetic Disturbance Impact on Power System Performance and Security Proceedings": EPRI Geomagnetically Induced Currents Conference, November 8-10, 1989, TR-100450. Available at www.epri.com; *and see also* D. H. Boteler, R. M. Shier, T. Watanabe, R. E. Horita, "Effects of Geomagnetically Induced Currents in the B.C. Hydro 500 kV System," IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989, at 818-823.

[63] *See* Meta-R-319; Appendix 1; Subsection A1.1; Overview of US Transmission Grid Design Criteria at A1-4.

per-phase GIC (Amps/phase) and *V* is the nominal line-to-line voltage of the system (Volts). Choosing a value of 2.0 for *k* suggests that the reactive power loss was computed using the *rms* value of the exciting-current instead of its 60 Hz component only. This is further evidenced by the following statement in Appendix 4 of ORNL Report: "Once the harmonics currents are available, it is straightforward to calculate the reactive power."[64] This method of computing reactive power losses due to half-cycle saturation has its roots in earlier works [65] but has since been proven obsolete. [66] Inclusion of harmonic exciting-current components in the reactive power loss definition, and then using such results as reactive load models to represent half-cycle saturated transformers in a power flow analysis that is limited to fundamental frequency representation yields erroneous results by grossly overestimating the reactive losses.[67] The reactive losses computed using Equation 1 are overestimated by approximately 60% or more when compared to those estimated using the 60 Hz exciting-current based methods.[68]

[64] *See* Meta-R-319; Appendix 4 at A4-1.

[65] *See* V. D. Albertson, J. G. Kappenman, N. Mohan, G. A. Skarbakka, "Load-Flow Studies in the Presence of Geomagnetically-Induced Currents," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2, February 1981, at pp. 594-607. *Also see,* Investigation of Geomagnetically Induced Currents in the Proposed Winnipeg-Duluth-Twin Cities 500 kV Transmission Line Final Report, EPRI Research Project EL-1949, July 1981. Available at www.epri.com.

[66] *See* R. A. Walling, A. H. Khan, "Characteristics of Transformer Exciting-Current During Geomagnetic Disturbances", IEEE Transactions on Power Delivery, Vol. 6, No. 4, October, 1991, at 1707-1714. *Also see,* R. A. Walling, A. H. Khan, "Solar-Magnetic Disturbance Impact on Power System Performance and Security Proceedings": EPRI Geomagnetically Induced Currents Conference, November 8-10, 1989, TR-100450. Available at www.epri.com. *And also see,* D. H. Boteler, R. M. Shier, T. Watanabe, R. E. Horita, "Effects of Geomagnetically Induced Currents in the B.C. Hydro 500 kV System," IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989, at 818-823.

[67] *See* R. A. Walling, A. H. Khan, "Characteristics of Transformer Exciting-Current During Geomagnetic Disturbances," IEEE Transactions on Power Delivery, Vol. 6, No. 4, October, 1991, at 1707-1714.

[68] R. A. Walling, A. H. Khan, "Solar-Magnetic Disturbance Impact on Power System Performance and Security, Proceedings": EPRI Geomagnetically Induced Currents Conference, November 8-10, 1989, TR-100450. Available at www.epri.com. *And see also* D. H. Boteler, R. M. Shier, T. Watanabe, R. E. Horita, "Effects of Geomagnetically Induced Currents in the B.C. Hydro 500 kV System," IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989, at 818-823.

Additionally, the reactive losses provided in the ORNL/Metatech Report assume nominal system voltage. During a GMD, the system voltage will become depressed resulting in further reduction in reactive loss.

Finally, the method used to compute reactive power losses assumes a linear relationship between GIC and *Q* for all transformer types. Work by Walling and Khan illustrates that a non-linear relationship exists for certain types of three-phase transformers, in particular five-legged core construction.[69] The non-linear relationship has the effect of significantly reducing the reactive power loss caused by half-cycle saturation of the core. The resulting reactive power loss can be on the order of 50% of that estimated by a standard linear mapping for three-phase transformers. [70]

C. Transformer Damage due to Increased Hot-Spot Heating appears to be based on arbitrary limits that have no known basis.

The transformer vulnerability assessment that was performed in ORNL/Metatech Report appears to have used an arbitrarily chosen limit of 90 Amps per phase to define GIC withstand of transformers. The Trade Associations are unaware of any theoretical foundation for the use of the limit as provided.

It is well-known that time-independent criteria are not suitable for the assessment of GIC impacts to power transformers.[71] Time constants of transformer windings and

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[69] *See Figure 7* of R. A. Walling, A. H. Khan, "Solar-Magnetic Disturbance Impact on Power System Performance and Security Proceedings": EPRI Geomagnetically Induced Currents Conference, November 8-10, 1989, TR-100450.

[70] *See id.*

[71] *See, e.g.*, L. Marti, A. Rezaei-Zare, A. Narang, "Simulation of Transformer Hotspot Heating due to Geomagnetically Induced Currents," IEEE Transactions on Power Delivery, 2012, 10.1109/TPWRD.2012.2224674; *see also* T. Ngnegueu, F. Marketos, F. Devaux, T. Xu, R. Bardsley, S. Barker, "Behavior of Transformers under dc/GIC Excitation: Phenomenon, Impact on Design/Design Evaluation Process

metallic parts are usually on the order of 3-5 minutes[72] meaning that it takes approximately 15-25 minutes for the winding or metallic hotspot temperature to reach their steady-state values. Large GIC associated with a severe GMD are of short duration with pulse widths typically less than the thermal time constant of the transformer windings. Thus, transformer hotspot temperatures would not reach steady state levels during a GMD. To illustrate, Fig. 1 depicts the resulting GIC and hotspot temperature associated with a 20V/km geoelectric field.

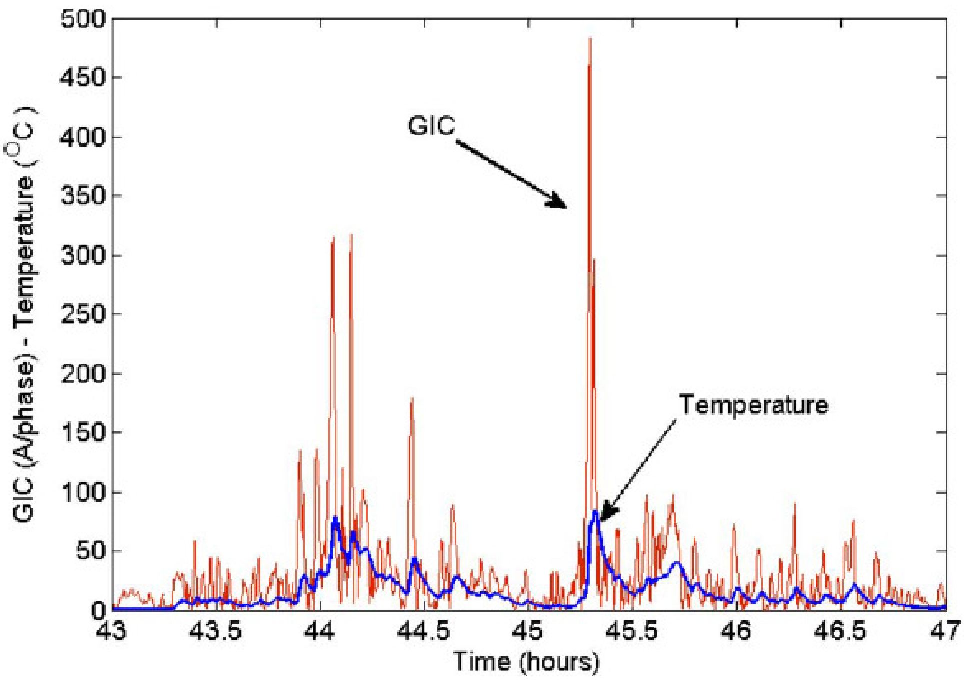

Figure 1. Transformer tie-plate hotspot temperature rise versus time.[73]

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and Modeling Aspects in Support of Design", CIGRE 2012; *and see also* P. Picher, L. Bolduc, A. Dutil, V. Q. Pham, "Study of the Acceptable dc Current Limit in Core-Form Power Transformers," IEEE Transactions on Power Delivery, Vol. 12, No. 1, January 1997, at 257-265; *and see also* R. Girgis, K. Vedante, K. Gramm, "Effects of Geomagnetically Induced Currents on Power Transformers and Power Systems,"A2-304, CIGRE 2012.

[72] *See* P. Hurlet, F. Berthereau, "Impact of Geomagnetic Induced currents on power transformer design," IEEE Conference MATPOST'07 - LYON (France).

[73] *See figure 10 in* L. Marti, A. Rezaei-Zare, A. Narang, "Simulation of Transformer Hotspot Heating due to Geomagnetically Induced Currents," IEEE Transactions on Power Delivery, 2012,

GIC of approximately 475 Amps/phase was not sufficient to raise the hotspot temperature beyond the critical threshold of 130ºC (based on short-time emergency limits provided in the IEEE Guide[74] for Loading Mineral-Oil-Immersed Transformers. Similar results can be found in an IEEE Transaction paper titled "Calculation Techniques and Results of Effects of GIC Currents as Applied to Two Large Power Transformers;"[75] This underscores the importance of using time-domain based thermal models as opposed to arbitrary limits when assessing the performance of transformers subjected to GIC.

II. The Trade Associations find errors of omission in the ORNL/Metatech Report.

The Trade Associations believes the three key events in the ORNL/Metatech report which do not fully disclose information which is necessary to fully assess the risk posed by GICs resulting from a severe GMD event. The three events that the Trade Associations have focused on include the Hydro Quebec Blackout, the PSEG/Salem transformer failure and the Eskom transformer failures. Each having played a role in shaping current concerns over the risks associated with GMD events yet each contain nuances if not fully understood can lead to incorrect conclusions.

A. March 13, 1989 Hydro-Quebec Blackout lessons learned vary greatly between the ORNL/Metatech Report and PNNL Report.

The Trade Associations believe that the ORNL/Metatech Report minimized important improvements made by Hydro Quebec after the 1989 blackout. Although the report does acknowledge these improvements in Section 2 of the report, it goes on to

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10.1109/TPWRD.2012.2224674.

[74] *See* IEEE Std. C57.91-1995 IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

[75] *See* R. Girgis, K. Chung-Duck, "Calculation Techniques and Results of Effects of GIC Currents as Applied to Two Large Power Transformers", IEEE Transactions on Power Delivery, Vol. 7, No. 2, April 1992.

suggest events of an even greater magnitude could occur risking the U.S. grid.[76] For example, in the report it states that "[d]uring the process of collapse, permanent damage was inflicted on the Quebec power grid."[77] The ORNL/Metatech report also taints equipment such as a static var compensator ("SVC") as posing a risk to "widespread grid collapse"[78], while the Trade Associations do not dispute that the loss of SVCs were a large contributor to the Hydro Quebec Blackout, the cause (23 years later) is more thoroughly understood and recognized to be completely manageable. Furthermore, the Trade Associations believe that SVCs if properly configured should not contribute to collapse but will greatly aide in maintaining system stability during GMD events. To this point, the Trade Associations offer a significantly different set of findings as provided in the PNNL Report.

Among the lessons learned by Hydro Quebec, as detailed in the PNNL Report include:

- SVCs were found to be capable of handling the GIC effects but the settings did not allow them to provide protection. Settings have since been adjusted.
- Additional SVCs have been added to provide additional support.
- Large power transformers were found to be much more tolerant of dc in the windings than had been expected.
- A scheme for blocking dc in transformer neutrals was developed, and pilot was

[76] *See* Meta-R-319 at 2-5 to 2-6, which acknowledges both hardware and operational improvements have been made. However, the Trade Associations believe that had these improvements been more thoroughly described in the report it may have arrived at different conclusions. Furthermore, rather than discussing these improvements the report suggests the possibility of even larger threats than before.

[77] *See* Meta-R-319; at 2-12, paragraph 1, wherein equipment damage is highlighted rather than methods of mitigation which the Trade Associations believe were the real lessons for the industry.

[78] *See id.* at 2-12, paragraph 1 where the report highlights the risks of SVC as new technology which is certainly no longer the case and other reports highlight their value in stabilizing GMD events if properly utilized and protected.

installed. However, the need for these devices was later determined to be unnecessary because other more proven methods were used.

- Additional series line capacitors were added to further mitigate the risk of GICs in the region.[79]

B. Hydro Quebec Blackout Damaged Equipment

The 1989 Hydro Quebec Blackout, is often used in the ORNL/Metatech Report to assert that wide spread collapse and permanent equipment damage is a likely outcome of a severe GMD event.[80] Although the Trade Associations agree that both are potential risks of a severe GMD event, the Trade Associations find the conclusions of the GMD Task Force, which states that "the most likely worst-case system impacts from a severe GMD event and corresponding GIC flow is voltage instability caused by a significant loss of reactive power support,"[81] to be more credible and based on the scientific facts. The Trade Associations also note that while Section 2 of the ORNL/Metatech Report appears to properly characterize the Hydro Quebec incident, the Trade Associations are troubled by the mixing of this event within Section 4 of the report which is largely intended to addresses equipment damage resulting from GIC and transformer heating. In the following excerpts from Section 4.0 of the ORNL/Metatech Report, the Trade Associations note the following scenario presented to the reader when assessing the impacts of a severe GMD event:

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[79] *See* Pacific Northwest National Laboratory, Report No. PNNL-21033, Section 5.3; Hydro Quebec Follow Up at 17.

[80] *See* Meta-R-319 Geomagnetic Storms and Their Impacts on the U.S. Power Grid at 2-12; paragraph 1. In this section there is a description of the damage that occurred during the Hydro Quebec Blackout which appears to conform to the sequence of events as documented by NERC. *However, in contrast* Section 4 of this report (at 4-2) contains a description of a severe GMD event that describes large numbers of transformers that are permanently damaged. Following this description, the Hydro Quebec Blackout is discussed which we find inappropriate since no transformers were damaged directly by GICs during this event.

[81] *See* NERC 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System; February 2012; at Subsection I.9 - Conclusions, at vi.

- This extended recovery would be due to permanent damage to key power grid components used by the unique nature of the electromagnetic upset.[82]

- Both HEMP and space weather disturbances, however, can have a sudden onset and cover large geographic regions. They therefore cause near simultaneous, correlated, multipoint failures in power system infrastructures, allowing little or no time for meaningful human interventions that are intended within the framework of the N–1 criterion. This is the situation that triggered the collapse of the Hydro Quebec power grid on 13 March 1989, when their system went from normal conditions to a situation where they sustained seven contingencies (*i.e.*, N–7) in an elapsed time of 57 seconds. The province-wide blackout rapidly followed, with a total elapsed time of 92 seconds from normal conditions to a complete collapse of the grid."[83]

- The more difficult aspect of this threat is the determination of permanent damage to power grid assets and how that will impede the restoration process. As previously mentioned, transformer damage is the most likely outcome (although other key assets on the grid are also at risk).[84]

- In particular, transformers experience excessive levels of internal heating brought on by stray flux when GICs cause the transformer's magnetic core to saturate and to spill flux outside the normal core steel magnetic circuit.

Although the Trade Associations do not dispute that two transformers were damaged during the Hydro Quebec network collapse, none of this equipment was damaged as a direct result of GICs.[85] The Trade Associations believe this is an important fact that is lost in the case being made in Section 4[86] that is intended to suggest transformers as those elements most at risk and most likely to cause extended system

[82] *See* Meta-R-319 at 4-1; paragraph 1. The Trade Associations note that no equipment was damaged as a direct result of GIC during the Hydro Quebec Blackout.

[83] *See id.* at 4-1 to 4-2; paragraph 2. The Trade Associations are concerned that the Hydro Quebec incident is inappropriately used to provide a scenario for damage resulting directly from GICs when none occurred.

[84] *See* Meta-R-319 at 4-2; paragraph 1. The Trade Associations note that no transformers were damaged through GIC heating during the Hydro Quebec Blackout.

[85] In the NERC Report, Page 42; Column 2, which detailed the event of the "March 13, 1989 Geomagnetic Disturbance/Hydro Quebec Blackout," identifies that the transformers were damaged due to overvoltage. Damage to Equipment http://www.nerc.com/files/1989-Quebec-Disturbance.pdf; *see also* PNNL-21033 at 16 (stating that "no equipment damage resulted directly from the GIC").

[86] In Section 4 of Meta-R-319, at 4-1 to 4-23, wherein the case is made that GICs pose a large risk to power transformers due to heating effects of GICs on large power transformers. Including the Hydro Quebec Blackout in this section only serves to confuse the issue since there were no transformers damaged due to the direct effect of GICs.

outages extending into years due largely to transformer heating. This is also an important fact given the only transformer known to have failed over the last 23 years in North America as a direct result of GICs was the PSEG/Salem transformer which was particularly vulnerable to such effects.[87] Furthermore, in the PNNL Report it notes in Section 5.3 (Hydro Quebec Follow up) "large power transformers were found to be much more tolerant of dc in the windings than had been expected."[88] This is a fact that was never mentioned in the ORNL/Metatech Report.

C. PSEG/Salem Nuclear Power Plant Transformer Damage

The Trade Associations believe that the PSEG/Salem Nuclear Power Plant transformer damage that occurred during the March 13-14, 1989 Geomagnetic Storm due to GICs is a poor example of transformer risks across North America.

The Trade Associations also understand that the PSEG/Salem generator step-up ("GSU") transformer that was damaged during the March 1989 solar storm represents a poor example for use in assessing industry GMD/GIC risks. Although this transformer was damaged due high levels of GIC currents, it was an obsolete transformer design which is now known to have vulnerabilities to GICs.[89] Additionally, the Trade Associations understand this design has not been used by transformer manufacturers since the mid-1970s.[90] The Commission should recognize that given the vintage of this transformer design, it likely does not represent a large risk to BPS reliability.

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[87] *See* description of PSEG/Salem Nuclear Power Plant Transformer Damage.

[88] PNNL-21033, at 17, bullet 3.

[89] Effects of GICs on Power Transformers and Power Systems, R Girgis, ABB Power Transformers, St. Louis, MO, at 5.

[90] *See id.*

Furthermore. GIC risks are not based solely on transformer design but require significant GICs modeling developed through transmission planning studies and detailed transformer GIC withstand capability studies of which none were done in support of the ORNL/Metatech Report.

The Trade Associations observe that the response of the PSEG/Salem GSU to GIC appears to be extrapolated to represent the thermal performance of the transformer fleet resulting in what appears to be an unrealistic conclusion. Salem GSU had known design flaws that made it uniquely susceptible to hot-spot heating caused by half-cycle saturation. The excessive hotspot temperatures that the Salem GSU experienced are attributed to a low-voltage lead consisting of about a hundred strands and connected by massive welding joints to two parallel sections of the low-voltage winding allowing a considerable circulating current to be established once half-cycle saturation occurred.[91]

D. Eskom (South Africa) Transformer failures may have failed due to contaminated transformer oil with GICs only acting as a secondary contributor.

The Trade Associations are concerned by the depiction of transformer failures at Eskom as detailed in the ORNL/Metatech Report. In this report it states that "Eskom grid (South Africa) sustained the loss of 14 large 400kV transformers over the October 29-31, 2003 geomagnetic storm. Therefore, these lower latitude regions in combination with high latitude regions of North America and Europe could all experience substantial disruptive events from an extreme storm, effects that could include permanent damage to key power system apparatus."[92] Although this characterization is in part accurate, it does

[91] R. Girgis, K. Chung-Duck, "Calculation Techniques and Results of Effects of GIC Currents as Applied to Two Large Power Transformers," IEEE Transactions on Power Delivery, Vol. 7, No. 2, April 1992.

[92] *See* Meta-R-319, at 3-27

not tell the entire story or detail other mechanisms that likely contributed to these failures. Specifically, what is known is that the levels of GICs, appears to be insufficient to have caused these transformer failures. [93] The Trade Associations also understand, but cannot confirm, that copper sulfides were discovered in the transformers that failed.[94] In furtherance of this understanding the Trade Associations note the following:

> "Other cases were reported in Reference [5] [95] of significant winding overheating in a number of large core form power transformers in S. Africa during the period between 2003 and 2004. These incidents were found to coincide with failures caused by the phenomenon of the conducting Copper Sulphide forming and causing failures of transformers world – wide; related to the Sulphur content in the mineral oil used in these transformers." [96]

The Trade Associations also note that the copper sulfide (sulphide) phenomenon is more widely understood and that transformer oil contaminated with corrosive sulfur can over time through heating create copper sulfide that is highly corrosive and is known to damage transformer paper insulation often leading to premature transformer failures. [97] Furthermore, these effects have been widely studied worldwide and it in North America it

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[93] *See* Effects of GIC on Power Transformers and Power Systems, Section IV Reported Transformer Damage/Overheating Contributed to GIC, R. Girgis, ABB Power Transformers, St. Louis, MO, at 6, paragraph 1.

[94] *See* Transformer Failures in regions incorrectly considered to have low GIC-risk, CT Gaunt, G Coetzee, IEEE Transaction, 978-1-4244-2190-9/07 © 2007. The Trade Associations have been given some circumstantial evidence regarding that transformer failures in South Africa that indicate that Copper Sulfides may have contributed to the transformer failures at Eskom. We also received a presentation at a Cigre event which cites some transformer failures in South Africa resulting from copper sulphides. *See* Cigre SC-A2 Colloquium "Transformer Reliability and Transients," at 20-24 June, 2005, Moscow, Russia.

[95] *See* C. T Gaunt, G. Coetzee, "Transformer failures in regions incorrectly considered to have low GIC-risk," Mat Post 07, 3rd European Conference on MV & HV Substation Equipment, Nov 15-17, 2007, Lyon, France, Proceedings of Power Tech, July 15, 2007, Lausanne, Switzerland, at p. 4 VI. Contained in this paper includes a description of other possible causes of damage.

[96] *See* Effects of GIC on Power Transformers and Power Systems, Section IV Reported Transformer Damage/Overheating Contributed to GIC, R. Girgis, ABB Power Transformers, St. Louis, MO; at 6, Paragraph 1.

[97] *See* The Role of Corrosive Sulfur in Transformers and Transformer Oil, Lance R. Lewand, Doble Engineering Company, USA – 2002; s*ee also* Investigating Copper Sulfide Sulfide Contamination in a Failed Large GSU Transformer, Lance Lewand, Doble Engineering Company – 2005; *and* Update on the Corrosive Sulfur Issue in Oil-Filled Electrical Equipment, Lance R. Lewand and Paul J. Griffin; Doble Engineering Company - 2006.

appears that the risks are well managed through routine maintenance practices including routine oil sampling and testing, chemical mitigation processes and testing. Therefore, the Trade Associations believe any assertion that these transformers failed in mass solely due to GICs is conjecture and is no more a proven fact than copper sulfides are known to be the root cause of these failures.