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A geomagnetic disturbance (GMD) is a natural hazard that can occur during solar events. A solar magnetic disturbance in the direction of earth causes short term variations in the earth's magnetic field. The changes in magnetic field create electric fields over the surface of the affected region. This electric field induces voltages in the high voltage transmission lines. The induced voltages in transmission lines cause Geomagnetically Induced Currents (GICs) to flow if there is a closed path for currents to circulate. Depending on severity of the GMD storm, these events can have potentially severe, widespread effects on reliable grid operation, including blackouts and damage to critical or vulnerable equipment. These solar storms can wreak havoc on high voltage power grids. A large GMD event can lead to voltage instability of the entire power system network, or in some instances can lead to a blackout as experienced by Hydro-Quebec’s system in March 1989 and damaged transformers as far south as New Jersey.

The Federal Energy Regulatory Commission (FERC) issued Order 779 in 2013 which directed NERC to develop and implement operational procedures to mitigate the effects of GMD’s and to conduct initial and ongoing assessments of the potential impact of benchmark GMD events. FERC approved TPL-007-1 in Order 830 which was issued September 22, 2016. TPL-007-1 requires entities to conduct assessments of the impact of GMD events on their system. Each entity must develop and implement plans to mitigate the risk to their systems.

TPL-007-1 is applicable to all Planning Coordinators, Transmission Planners, Transmission Owners and Generator Owners with facilities that include power transformers with a high side, wye grounded winding operated at 200kV or above. It has seven requirements and measures that have six different enforcement dates. The requirements, per the standard, are as follows:

**R1:** Identify individual or joint responsibilities of the Planning Coordinators and Transmission Planners in the Planning coordinator’s planning area for maintaining models and performing studies needed to complete GMD Vulnerability Assessment required in R4.

**M1:** The responsible entities must provide documented information on their roles and responsibilities.

- **Enforcement Date:** July 1, 2017

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1 Enforcement dates are subject to change and are dependent on the NERC implementation plan of this standard.
R2: Responsible entities maintain system models and GIC System (DC) models of the responsible entity’s planning area for performing the studies needed to complete GMD vulnerability assessment(s).

M2: The responsible entities must have system models and GIC system models in either electronic or hard copy format

- **Enforcement Date:** July 1, 2018

R3: Responsible entities have criteria for acceptable system steady state voltage performance for its System during the benchmark GMD event.

M3: The responsible entities must have acceptable system steady state voltage performance criteria documented in either electronic or hard copy format.

- **Enforcement Date:** January 1, 2022

R4: Responsible entities complete a GMD Vulnerability Assessment of the Near-Term Transmission Planning Horizon once every 60 calendar months. This GMD Vulnerability Assessment studies based on models identified in Requirement R2, document assumptions, and document summarized results of the steady state analysis.

4.1 The network conditions include:

4.1.1 System On-Peak Load for at least one year within the Near-Term Transmission Planning Horizon; and

4.1.2 System Off-Peak Load for at least one year within the Near-Term Transmission Planning Horizon.

4.2 The studies are conducted based on the benchmark GMD event to determine whether system meets performance requirements (in Table 1 of TPL-007-1).

4.3 Within 90 calendar days of completion of the studies, the GMD Vulnerability Assessment is provided to responsible entity’s Reliability Coordinator, adjacent Planning Coordinators, adjacent Transmission Planners and any functional entity that requests it and has a reliability related need.

4.3.1 Any documented comments by a recipient of these studies, the responsible entity provide documented response within 90 calendar days.

M4: The responsible entities must have dated evidence in either electronic or hard copy format of actions performed to fulfill requirements R4

- **Enforcement Date:** January 1, 2022

R5: Responsible entities provide GIC flow information to be used for the transformer thermal impact assessment specified in Requirement R6. The GIC flow information includes:

5.1 The maximum effective GIC value for the worst case geoelectric field orientation for the benchmark GMD event. This value is provided to the Transmission Owner or Generator Owner that owns BES power transformer in the planning area.

5.2 Responsible entities provide the effective GIC time series, GIC (t), calculated using the benchmark GMD event upon request from Transmission Owner or Generator Owner within 90 calendar days.

M5: The responsible entities must have dated evidence in either electronic or hard copy format of actions performed to fulfill requirements R5

- **Enforcement Date:** January 1, 2019

R6: Transmission Owner and Generator Owner conduct a thermal impact assessment for applicable power transformers where the maximum effective GIC value provided in Requirement R5.1 is 75 A per phase or greater. The thermal impact assessment shall:
6.1 Be based on the effective GIC flow information provided in R5
6.2 Document assumptions used in the analysis;
6.3 Describe suggested actions and supporting analysis to mitigate the impact of GICs, if any
6.4 Be performed and provided to responsibilities entities within 24 calendar months of receiving GIC flow information.

M6: Transmission Owners and Generator Owners must have dated evidence in either electronic or hard copy format of actions performed to fulfill requirements R6.

- Enforcement Date: January 1, 2021

R7: Responsible entities develop a Corrective Action Plan addressing how the performance requirements will be met in case of the GMD Vulnerability Assessment conducted as in R4 shows that the System does not meet the performance requirements of Table 1 (R4).

7.1 List system deficiencies and the associated actions needed to achieve required system performance. Examples of such actions include:

- Installation, modification, retirement or removal of transmission and generation facilities and any associated equipment.
- Installation, modification, or removal of protection systems or special protection systems.
- Use of operating procedures, specifying how long they will be needed as part of corrective action plan.
- Use of demand-side management, new technologies etc.

7.2 Review corrective action plans in subsequent GMD vulnerability assessments until it is determined that system meets performance requirements

7.3 Provide corrective action plans to responsible entity’s Reliability Coordinator, adjacent Planning Coordinators, adjacent Transmission Planners and any functional entity that request it and has a reliability related need within 90 calendar days after completing GMD vulnerability assessments.

7.3.1 Any documented comments by a recipient of these Corrective Action Plans, the responsible entity provide documented response within 90 calendar days.

M7: The responsible entities must have dated evidence in either electronic or hard copy format of actions performed to fulfill the requirements of R7

- Enforcement Date: January 1, 2022

In order to comply with the requirements of TPL-007-1 the responsible parties will have to perform the following tasks. In order to comply with Requirement 1, the responsible entities must coordinate with one another to create policy statements that accurately portray each party’s role and the coordination that will be accomplished between responsible parties.

Requirement 2 requires the responsible entities have system models and GIC system models. There are accurate electronic system models of the Eastern and Western Interconnections, the Canadian Provinces and ERCOT in North America. The GIC system model requires the creation of a GIC system (DC equivalent system model) data file to be used with the power flow system model.

Note: FERC order 830 directed NERC to include one-year deadline for the development of corrective action plans and two and four-year deadlines to complete mitigation actions involving non-hardware and hardware mitigation, respectively.
Requirement 3 mandates that the responsible entities must have acceptable system steady state voltage performance criteria documented for their systems. R3 requires a system GIC model by July 1, 2018 but the operating criteria for system voltages are not required for another four (4) years on January 1, 2022. This gives the responsible parties time to study and assess how vulnerable to a GMD event their systems are. Keep in mind that a GIC weakness in a neighboring system can cause low voltages and outages in surrounding systems depending on the direction of the GMD event and the orientation of long high voltage lines in the participating systems.

Requirement 4 is the heart of TPL-007-1 which requires a complete GMD vulnerability assessment be completed every 5 years. It requires evaluation of On-Peak load for at least one year and Off-Peak load for at least one year within the near-term planning horizon to be completed. The studies must be based on the benchmark GMD event for the responsible entity’s geographic area. Requirement 4 also requires that within 90 days of completion of the vulnerability assessment that each entity shares its results with coordinating entities and any entity that requests them and has a reliability-related need.

Requirement 5 covers another specific aspect of the vulnerability assessment to be completed. In order to complete an effective GIC vulnerability assessment study, the storm orientation creating the largest amount of GIC current must be determined. The geography of the high voltage lines, especially long high voltage lines, has the effect of creating higher values of GIC’s in the system. Determining the orientation of the system is the first step in a vulnerability assessment. Once that has been required the effective GIC time series, GIC (t), must be calculated and made available to coordinating entities and transformer owners in the region. PSS®E has developed a module that will calculate the GIC (t).

Figures 1 and 2 show a typical geoelectric field over the course of approximately 30 hours. Figure 1 shows the eastward component and Figure 2 shows the northward component. The currents resulting from a GMD event are modeled as DC currents. Note how the waveshapes have different peaks at different times. This is why the resulting orientation of both the storm and the system are very important since the orientation of both the storm and system creates different levels of GIC. Imagine identical GMD storms whose directions are 90 degrees apart. The one oriented the same as the dominant long high voltage lines in the system under study will have much higher level of GIC than the one at right angles to the dominant orientation of the system under study.

Figure 1 – Eastward Geoelectric Field
Requirement 6 deals with any transformer 200kV or above that has a GIC flow 75 Amps per phase or greater based on the results of Requirement 5. For any transformer with GIC above 75 Amps/phase the thermal response capability of each transformer must be evaluated. The primary impact of GMDs on large power transformers occurs since the quasi-DC current that is the GIC changes the 60 cycle sinusoidal wave and results in half-cycle saturation in the transformer. Half-cycle saturation results in hot spot heating of windings and non-current carrying metallic part in the transformer, harmonics, increase in vibration and noise level and an increase in reactive power absorption. All these can be harmful to the transformer and even if they do not cause failure of the transformer they can cause loss of life. Much research is currently being conducted in this area.

Requirement 7 requires the development of a corrective action plan which will detail the actions required to achieve acceptable system performance during a GMD event. These plans are to be updated periodically as the individual system and the adjacent and surrounding systems have new facilities installed and older facilities modified or removed from service.

Our solution
Power system planners and operators will require technical tools and/or consultative services to conduct studies to assess the impact of GIC currents in the power grid and prepare mitigation measures. Siemens PTI’s comprehensive expertise in power system planning allows us the ability to offer both consulting solutions, as well as software tools, specifically tailored to the client’s particular needs in regards to compliance with NERC TPL-007.

The experts at Siemens PTI are globally renowned for their in-depth knowledge built over decades of experience. By contributing actively to national and international committees and bodies, such as the NERC Reliability Standards Committee and IEEE Standards Working Groups, our consultants have an active role in shaping the future of technical developments and standards. Having this deep understanding allows for Siemens PTI to provide recommendations and alternative missing data or other challenges that may arise during a GMD Vulnerability Assessment.

North American transmission owners seeking a timely, cost effective and proven solution can leverage Siemens PTI’s vast industry expertise, from planning through operations, to comply with the TPL-007 reliability standard with a customized solution that fits their needs.