2021 Geomagnetic Disturbance Vulnerability Assessment

Executive Summary

The 2021 Geomagnetic Disturbance (GMD) Vulnerability Assessment (GMDVA) is the result of a coordinated planning process performed by ERCOT System Planning with extensive review and input by NERC-registered Transmission Planners (TPs), Transmission Owners (TOs), Generator Owners (GOs), and other stakeholders. The GMDVA addresses ERCOT System reliability needs following the occurrence of the benchmark and supplemental GMD events defined in Attachment 1 of NERC Reliability Standard TPL-007-4. This report documents the results of the assessment, in part, to comply with the requirements of NERC Reliability Standards and the ERCOT Planning Guide.

ERCOT worked with the TPs and TOs to develop the steady-state voltage performance criteria to be used for GMDVA, and obtained ERCOT Technical Advisory Committee (TAC) approval for the criteria. The approved steady-state voltage performance criteria are consistent with the existing post-contingency voltage performance and voltage deviation criteria set forth in ERCOT Planning Guide Section 4.1.1.4.

The GMDVA was performed for the near-term transmission planning horizon. The 2021 GMDVA assessed ERCOT's steady-state transmission needs under 2022 Summer peak and off-peak conditions. The analyses in the 2021 GMDVA included:

- steady-state power flow analysis to identify steady-state voltage criteria violations based on the TAC-approved steady-state voltage performance criteria and
- cascading analysis to identify potential system cascading conditions.

The potential impacts from the GMD events were incorporated into the study cases, which include increased reactive power absorption (i.e., losses) from transformers, reactive power compensation devices and other transmission facilities removed from service based on the assumption that these devices and facilities may trip as a result of protection system operation or mis-operation due to harmonics during GMD events, and any actions to mitigate the impacts of the GMD events proposed by TOs in response to the results of transformer thermal impact assessments.

The GMDVA results showed that there are no steady-state voltage performance criteria violations, voltage collapse, or cascading and uncontrolled islanding for the ERCOT system following the occurrence of either the benchmark or supplemental GMD events. Therefore, no Correction Action Plans (CAPs) are needed.

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1. Introduction

This report documents the GMDVA performed by ERCOT System Planning. As required by NERC Reliability Standard TPL-007-4, the 2021 GMDVA included power flow analysis and cascading analysis of 2022 summer peak and off-peak conditions.

1.1. Stakeholder Involvement

The development of the GMDVA is a collaborative process. ERCOT worked with NERC-registered TPs, TOs, and GOs, as well as other stakeholders to develop the input assumptions and the scope of technical studies that define the GMDVA. These assumptions are described in the GMDVA Scope and Process document, and were presented to the stakeholder community at Regional Planning Group (RPG) and Planning Geomagnetic Disturbance Task Force (PGDTF) meetings. The GMDVA Scope and Process document and input assumptions can be found in Appendices A and B. Stakeholders were provided routine updates on the input assumptions and supporting analysis performed for the 2021 GMDVA in RPG and PGDTF meetings. Feedback and comments from the RPG were incorporated into the GMDVA Scope and Process document.

The RPG is responsible for reviewing and providing comments on new transmission projects in the ERCOT Region. Under ERCOT Protocols Section 3.11.3, participation in the RPG is required of all Transmission Service Providers (TSPs) and is open to all Market Participants, consumers, other stakeholders, and Public Utility Commission of Texas (PUCT) Staff.

ERCOT worked with TPs, TOs, GOs, and other stakeholders to study the transmission system with the incorporation of impacts from the benchmark and supplemental GMD events to identify any system upgrades and new transmission projects needed to ensure continued system reliability during the GMD events.

1.2. Standards and Regulations

ERCOT performed its GMDVA in accordance with NERC Reliability Standard TPL-007-4, Transmission System Planned Performance for Geomagnetic Disturbance Events, and ERCOT Planning Guide Sections 3.1.1.5, 3.1.8, and 6.11.

ERCOT Planning Guide Section 3.1.8 provides guidelines regarding completion of the GMDVA, including CAP development and extension requests.

1.3. Confidentiality and Report Posting

The GMDVA report is shared with internal and external stakeholders. The full version of the GMDVA report including confidential information is posted to the ERCOT Market Information System (MIS) Certified Area for TSPs. A redacted version of the GMDVA report is created by removing, at a minimum, any confidential data. This report is shared with ERCOT stakeholders via the MIS Secure area. A public version of the GMDVA report is also created by removing, at a minimum, any confidential

data and ERCOT Critical Energy Infrastructure Information (ECEII). This report is shared with ERCOT stakeholders via the ERCOT website.

2. 2021 Geomagnetic Disturbance Vulnerability Assessment Process

The GMDVA study process is described in Figure 1. The start cases for the GMDVA were built by the PGDTF using the 2019 Steady State Working Group (SSWG) 2022 summer peak and minimum load cases with GIC data incorporated. The start cases were used to produce the preliminary maximum effective Geomagnetically Induced Current (GIC) and the effective GIC time series for transformers modeled in the cases under both the benchmark and supplemental GMD events. This information was posted on the MIS Secure site for market participants to provide comments and feedback. ERCOT then incorporated all the comments from the market participants and posted the final maximum effective GIC flows and the effective GIC time series as required by the NERC Reliability Standard TPL-007-4 and ERCOT Planning Guide Section 3.1.8. The information was then used by the TPs, TOs, and GOs to perform transformer thermal impact assessments, if applicable.

TPs, TOs, and GOs also used the posted information to assess their equipment and provide ERCOT a list of reactive power compensation devices and other transmission facilities to be removed as a result of protection system operation or mis-operation due to harmonics during the benchmark and supplemental GMD events. PGDTF developed the "Methodology for Assessing GMD Impacts on ERCOT Power Systems"[1] document, which was approved by the ERCOT Reliability and Operations Subcommittee (ROS), to facilitate TPs, TOs, and GOs in performing their assessments. The list of equipment collected via this process is also referred to as equipment outages in this report.

The potential impacts from the GMD events such as increased reactive power losses, equipment outages due to harmonics, and any actions to mitigate the impacts of the GMD events proposed by TOs in response to the results of transformer thermal impact assessments were incorporated into the study cases. Power flow and cascading analysis were then performed to determine the ERCOT System's vulnerability to the effects of the benchmark and supplemental GMD events and if CAPs were needed to meet the ERCOT and NERC Reliability Standard requirements.

The GMDVA process is illustrated in Figure 1, and the detailed scope, process, and input assumptions used in conducting both the power flow and cascading analyses are available in Appendices A and B.

[1] https://www.ercot.com/files/docs/2019/08/13/Methodology_for_Assessing_GMD_Impacts_ROS_Approved_080819.docx

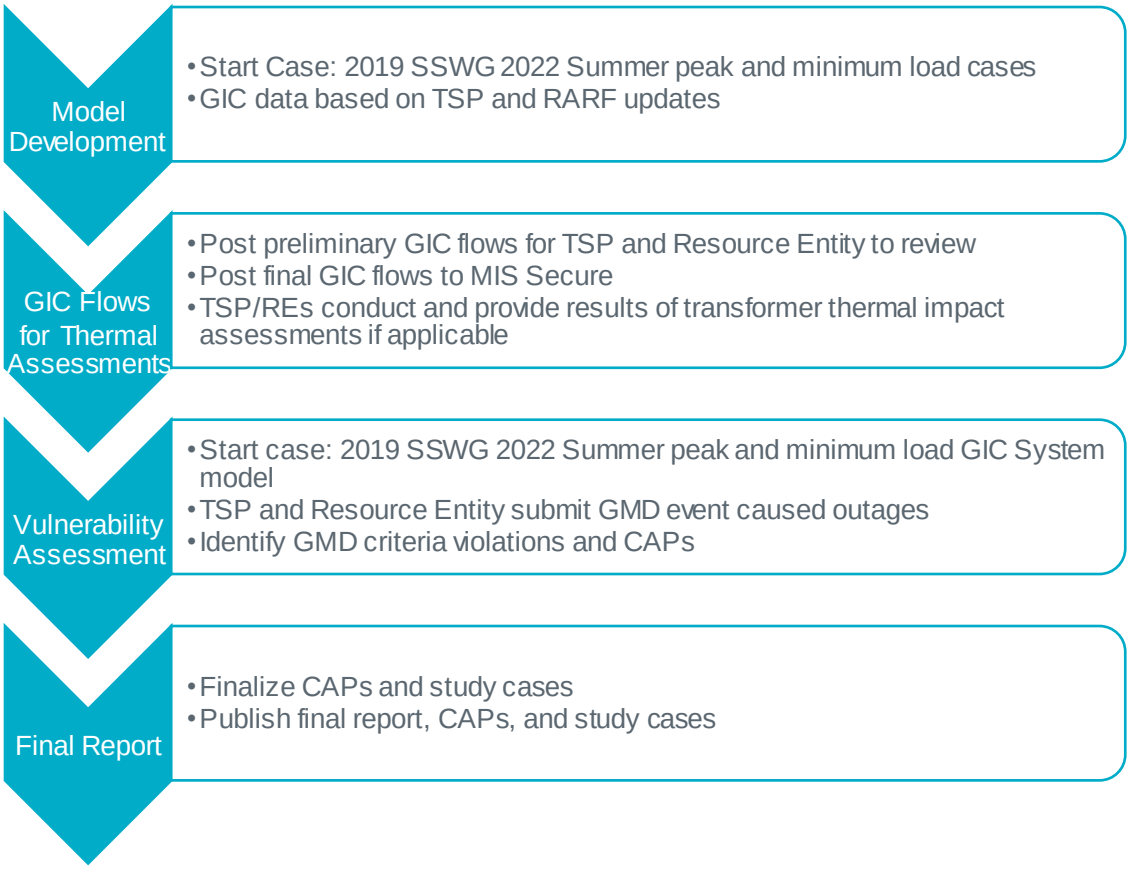

Figure 1: 2021 GMDVA Process

ERCOT utilized the following software tools while performing the 2021 GMDVA:

- PSS/E version 34 was used to calculate the maximum effective GIC flows and effective GIC time series. It was also used to perform degree scans to obtain the reactive power losses from transformers following the benchmark and supplemental GMD events.
- PowerWorld version 21 was used to perform power flow analysis and cascading analysis.

2.1. Steady-State Voltage Criteria Development

In accordance with the NERC Reliability Standard TPL-007-4 steady-state performance requirements, the system shall meet the steady-state voltage performance criteria, and voltage collapse, cascading and uncontrolled islanding shall not occur following the benchmark and supplemental GMD events. The Standard also requires the steady-state voltage performance criteria following the GMD events be developed by each responsible entity.

ERCOT Planning Guide Section 3.1.8(3) requires that ERCOT and TSPs develop and seek ERCOT TAC approval of criteria for acceptable steady-state voltage performance following the benchmark and supplemental GMD events. TAC approved the following steady-state voltage criteria to be used in the GMDVA:

1. The steady-state voltage criteria outlined in Planning Guide Section 4.1.1.4, specifically the post-contingency voltage performance criteria, will be used following the occurrence of the benchmark or supplemental GMD events.
2. The voltage deviation criteria outlined in Planning Guide Section 4.1.1.4 will be used following the occurrence of the benchmark or supplemental GMD events.

2.2. Start Case and Information Collection

The GIC system models, which include both the GIC AC model and the GIC DC model developed by ERCOT in collaboration with the TSPs and Resource Entities, were used as the start cases for the GMDVA. The GIC system models for the 2021 GMDVA included the 2022 summer peak load case and the 2022 minimum load case.

The start cases were used to produce the preliminary maximum effective GIC flows and the effective GIC time series for transformers modeled in the cases under both the benchmark and supplemental GMD events. The information was posted on the MIS Secure site for market participants to provide comments and feedback. ERCOT then incorporated all the comments from the market participants and posted the final maximum effective GIC flows and the effective GIC time series as required by NERC Reliability Standard TPL-007-4 and ERCOT Planning Guide Section 3.1.8. This information was then used by the TPs, TOs, and GOs to facilitate the following information collection to be used by ERCOT in conducting the GMDVA:

1. Transformer thermal assessment results and associated actions, if applicable.
2. Reactive power compensation devices and other transmission facilities removed from service as a result of protection system operation or mis-operation due to harmonics during the benchmark and supplemental GMD events. This information was collected through Market Notices, and categorized as described in Table 1.

Table 1: Outage Categories

Equipment Outage Category	Description	Study Methodology
Category A equipment outages	Equipment that is highly likely to be tripped offline due to harmonics during the GMD events	Applied simultaneously to the base cases
Category B equipment outages	Equipment that may have a low probability of being tripped offline due to harmonics during the GMD events, but the possibility cannot be fully ruled out	Applied individually to the base cases with all Category A equipment outages already applied

2.3. Study Case Creation

The GMDVA start cases were updated to incorporate the potential impacts from the GMD events to create the study cases.

The collected category A outages and any suggested actions from the transformer thermal impact assessments were incorporated into the GIC System models.

The benchmark and supplemental GMD events were then applied to the entire ERCOT footprint, and a degree scan was performed in 10-degree increments to determine the reactive power losses for each electric field orientation. The reactive power losses were then added to the GIC AC models to create a study case for each electric field orientation. Category B outages were added to the study cases to be studied individually.

2.4. Case Conditioning and Updates

Before GMDVA was conducted, case conditioning and updates were also performed on the GIC AC models, which included but were not limited to the following:

1. Update the Summer peak case with the ERCOT system-wide coincident peak load forecast.
2. Update the renewable dispatch in both the Summer peak and minimum load cases based on historical data analysis.
3. Incorporate applicable stability interfaces and limits.
4. Perform generation redispatch as needed to ensure that modeled stability limits are respected.
5. Update bus voltage System Operating Limits (SOL) based on the ERCOT SOL methodology[2] and bus voltage SOL corrections collected through the Regional Transmission Plan (RTP) process.

2.5. Power Flow and Cascading Analysis

The following analyses were performed for both the benchmark and supplemental GMDVAs.

1. Power flow analysis: Power flow analysis was first performed for each electric field orientation with category A outages and reactive power losses incorporated for both the benchmark and supplemental GMD events under both the summer peak and minimum load conditions. The power flow analysis was performed by incorporating category B outages one at a time for each electric field orientation with both category A outages and reactive power losses already applied. The steady-state voltage performance criteria documented in section 2.1 was used in the power flow analysis.
2. Cascading analysis: Cascading analysis was performed for each electric field orientation for both the benchmark and supplemental GMD events under both the Summer peak and

[2] https://www.ercot.com/misapp/GetReports.do?reportTypeId=13423&reportTitle=ERCOT%20System%20Operating%20Limit%20(SOL)Methodology&showHTMLView=&mimicKey

minimum load conditions to identify any cascading events. The criteria and methodology for cascading analysis is included in the scope and process Document.

3. Results

3.1. Transformer Thermal Impact Assessment

The quasi-DC GIC flows in transformer windings during a GMD event may cause half-cycle saturation on transformers, which may lead to both winding and structural hot spot heating in transformers connecting to the extra-high voltage (EHV) transmission system. NERC Reliability Standard TPL-007-4 requires entities that own wye-grounded transformer(s) with the high side terminal operated at 200 kV or above conduct a thermal impact assessment to determine if the transformer(s) can withstand the thermal transient effects during the benchmark and supplemental GMD events when their maximum effective GIC flows exceed the NERC-defined threshold. The threshold is defined as 75 Amps per phase for the benchmark GMD event, and 85 Amps per phase for the supplemental GMD event.

ERCOT published the preliminary maximum effective GIC flows and effective GIC time series in October 2019, and the final maximum effective GIC flows and effective GIC time series in November 2019 on the MIS Secure site for the applicable TSPs and Resource Entities to use in their transformer thermal impact assessment after addressing all stakeholder comments. The results showed that no transformer exceeded the 75 Amps per phase threshold for thermal impact assessment under the benchmark GMD event, and one transformer exceeded the 85 Amps per phase threshold for thermal impact assessment under the supplemental GMD event. The entity that was required to perform a transformer thermal impact assessment provided its assessment results to ERCOT in May 2021. The assessment results showed that the transformer was able to withstand the thermal transient effects during the supplemental GMD event, and no actions need to be taken to mitigate the impacts from the GMD event.

Based on the transformer thermal impact assessment results, no related actions were incorporated in the 2021 GMDVA.

3.2. Increased Reactive Power Losses and Impacts from Harmonics

Besides the hot spot heating in transformers, GMD events also cause increased reactive power losses in transformers, and the removal of reactive power compensation devices and other transmission facilities because of protection system operation or mis-operation due to harmonics generated during the GMD events. The increased reactive power losses and the loss of reactive power compensation devices may lead to voltage collapse. As a result, these impacts from the GMD events needed to be incorporated into the GMDVA.

The list of equipment removed from service due to harmonics was collected via Market Notices from the TSPs and Resource Entities. Since there is currently no commercial software available to simulate harmonics during the GMD events, PGDTF developed the “Methodology for Assessing GMD Impacts on ERCOT Power Systems” document approved by ROS to help TPs, TOs, and GOs perform their assessment. Based on the data collected through the Market Notices, most of the devices susceptible to harmonics were generators and cap banks. Among them, most of them were in category B, and were taken out of service individually to study the impact to the transmission system. Due to the higher

reference peak geoelectric field amplitude of the supplemental GMD event, more devices were susceptible to harmonics during the supplemental GMD event compared with the benchmark GMD event.

The increased reactive power losses were calculated using the GIC module of PSSE. Based on the simulation results, the increased reactive power losses can be up to around 1300 Mvar for the ERCOT region during the benchmark GMD event and 1800 Mvar during the supplemental GMD event. Since the electric field orientation with the maximum reactive power losses may not be the electric field orientation with the most severe system impacts, to thoroughly assess the impacts from the GMD events a degree scan was performed in 10-degree increments to obtain the reactive losses for each electric field orientation, and one study case was created for each electric field orientation.

Both the equipment removal due to harmonics and the increased reactive power losses were incorporated into the 2021 GMDVA.

3.3. Power Flow and Cascading Analysis

After the incorporation of impacts from the benchmark and supplemental GMD events, both power flow and cascading analysis were performed for each electric field orientation included in the GMDVA to determine if the ERCOT transmission system meets the steady-state voltage performance criteria outlined in section 2.1 and to identify any potential voltage collapse, cascading, or uncontrolled islanding conditions.

Power flow analysis was first performed for each electric field orientation with category A outages and reactive power losses incorporated for both the benchmark and supplemental GMD events under both the Summer peak and minimum load conditions. The study results showed that no steady-state voltage performance criteria violations were observed. Then power flow analysis was performed by incorporating category B outages one at a time for each electric field orientation with both category A outages and reactive power losses already applied. No steady-state voltage performance criteria violations were observed under category B outages.

After the power flow analysis, cascading analysis was performed for each electric field orientation for both the benchmark and supplemental GMD events under both the summer peak and minimum load conditions. No voltage collapse, cascading, or uncontrolled islanding was observed under category B outages.

Based on both the power flow analysis and cascading analysis results, the ERCOT transmission system is expected to meet steady-state performance criteria during both the benchmark and supplemental GMD events under both the Summer peak load and minimum load conditions. As a result, no CAPs are needed.

4. Appendices

Index	Description	Document	Access
A	GMDVA Scope and Process Document	Appendix_A_2021_Benchmark_Supplemental_GMDVA_Scope_and_Process_Final.pdf <file included in the public version>	Public
B	Input assumptions for the 2021 GMDVA	Appendix_B_2021_GMDVA_Input_Assumptions.xlsx <file included in the public version>	Public
C	Reactive power losses for each electric field orientation	Appendix_C_2021_GMDVA_Reactive_Power_Losses.zip <file available in the MIS Secure Area>	MIS Secure
D	Initial GIC System Model	Appendix_D_2021_GMDVA_Initial_GIC_System_Model.zip <file available in the MIS Certified Area for TSPs>	MIS TSP Certified
E	TSP and Resource Entity identified Category A and B outages in PSSE file format	Appendix_E_2021_GMDVA_Outages.zip <file available in the MIS Certified Area for TSPs>	MIS TSP Certified