To ensure the reliability of the North American bulk power system

- Develop and enforce reliability standards
- Assess current and future reliability
- Analyze system events and recommend improved practices
- Encourage active participation by all stakeholders
- Accountable as ERO to regulators in the United States (FERC) and Canada (NEB and provincial governments)
Vision for Mitigating GMD Impacts

• The ERO Enterprise reduces risks to the Bulk Power System from severe GMD events through evolving efforts:
  ▪ Reliability Standards
  ▪ Partnerships to pursue leading-edge research and tool development
  ▪ Development of data collection programs

• NERC works with diverse stakeholders throughout North America to carry out its vision

• Carry out the charge
    o Cyber Attack
    o Coordinated Physical Attack
    o Geomagnetic Disturbances (GMD)
Geomagnetic Disturbances

- Solar Flare
- CME
- Interaction with Earth’s Magnetic Field
- \( \frac{\partial B}{\partial t} \)
- Maxwell Eq. & Earth Cond. Model
- \( E \)
- Grid Model
- GIC

Space

Near Earth’s Surface
System and Transformer Impacts

• System
  ▪ Transformer saturation
  ▪ Overloading capacitors
  ▪ Incorrect protection system operation
  ▪ Static compensators, DC links, other electronics (e.g., Inverters)

• Transformer
  ▪ Overheating
  ▪ Reactive power consumption
  ▪ Voltage distortion

The amount of heating that develops in the windings and structural parts of a transformer depends on:
  • Magnitude, frequency, and duration of GICs
  • Geology
  • Design

The loss of life from GIC to a transformer is dependent on:
  • Transformer condition
  • Past Performance
  • Operational Loading
• When power systems experience significant GIC:
  ▪ Transformers experience half-cycle saturation
  ▪ Protection and control devices may experience elevated harmonic distortion and increase the risk of current-transformer saturation

• GIC leads to incorrect or undesired operation of protection and control devices
  ▪ Unintentionally isolating equipment at times when it provides critical support to the system

• SVCs and capacitor banks are also vulnerable to harmonics if the protection device operates on peak
Guidance
NERC Conclusions from 2012 Task Force Report

Major Conclusion No. 1
- Most likely result from a severe GMD event in North America will elevated risk voltage instability or collapse

Major Conclusion No. 2
- System operators and planners need analytic tools and information sharing to understand impacts and develop mitigation strategies

Major Conclusion No. 3
- Some transformers may be damaged or experience reduced life, depending on design and current health
Task Force Developed a Series of Guidance Documents for Planners

Application Guide for Calculating GIC in the Bulk-Power System

- Describes theory and details to perform GIC calculations or explain the basis of commercial products

GMD Planning Application Guide

- Describes recommended approach for performing GMD system and equipment impact studies

Transformer Modeling Guide

- Provides a generic magnetic model for planners to use in the absence of a manufacturer validated model
- Testing and model validation of limited assets began in June 2013

Guide for Assessing GIC Mitigation Measures

- Provides a recommended approach for evaluating system effects of hardware mitigation measures
GMD Reliability Standards
### EOP-010-1: Operating Procedures

- Requires grid operators to have procedures for mitigating GMD impacts
  - Increased situational awareness
  - System posturing
  - Reconfiguration

- Operators receive alerts from NOAA Space Weather Prediction Center and Space Weather Canada

### Identification

<table>
<thead>
<tr>
<th>CME on the Sun</th>
<th>Magnetic Deviation Detected by ACE</th>
<th>NOAA and STDN Issue Warnings</th>
<th>Eastern Inter.</th>
<th>MISO RC</th>
<th>Western Inter.</th>
<th>WECC RC</th>
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### Notification

- Balancing Authorities Notified
- NERC GOP and TOP Functions Notified

### Mitigation

- Real-Time System Operations Actions Taken

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**Time**

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**RELIABILITY | ACCOUNTABILITY**
• Addresses risks of voltage collapse and equipment damage in the Bulk Electric System (BES) caused by GMD events

• Applicable Entities:
  - Planning Coordinator (PC) and Transmission Planner (TP)—perform geomagnetically-induced current (GIC) calculation and network analysis (i.e., Vulnerability Assessments) on Facilities
  - Transmission Owner (TO)—that own Facilities
  - Generator Owner (GO)—that own Facilities

• Facilities
  - Transformer(s) with a high-side, wye-grounded winding with terminal voltage greater than 200 kV

• Benchmark & Supplemental GMD event
• GMD Vulnerability & Transformer Thermal Assessment
• Corrective Action Plan (CAP)
GMD Research
• Federal Energy Regulatory Commission (FERC) Order initiates further actions to address geomagnetic disturbances (GMD)
  ▪ Additional research
  ▪ Data collection

• Two-year research effort with Electric Power Research Institute (EPRI)
  ▪ Funding support from utilities
  ▪ Promotes further knowledge of severe GMD event impacts

• EPRI makes reports and tools available to the public at no charge
• EPRI Project is scheduled to address specific research objectives by Q1 2020

• Support TPL-007 standard

• EPRI publishes technical reports for each objective
**Task Objective:** Improve the accuracy of earth conductivity models used for GIC modeling

**Issue:** Deep earth structure strongly affects GMD risk to the BPS

- Historical Earth conductivity models referenced in TPL-007 need to be validated with new data

  *EPRI Report: Use of Magnetotelluric Data to Validate/Improve Earth Models*

**Outcomes:** Updated model regions could improve GMD studies

**Next Steps:**

- Evaluation of results is ongoing including GIC measurement comparisons using updated earth models
- EPRI research team will calculate geoelectric field scaling factors for updated regions (related activity in EPRI Geoelectric Field Tool Evaluation Report)
Recent Tool: Harmonics Assessment

- **Task Objective:** Develop tools for system-wide GMD harmonics assessment
- **Issue:** GIC-related harmonics can impact transformers and equipment needed for voltage support during GMD events
  - GMD Vulnerability Assessments required by TPL-007 include harmonic impacts
  - Industry needs tools and guidelines for wide-area harmonic impact assessments
- EPRI released a Beta version of open source software (public)
- **Next Steps:**
  - Incorporate user feedback and enhancements
  - Use tool to examine effects on tertiary winding harmonic heating
  - EPRI expects to release final tool and documentation Q1 2020
• **Task Objective:** Assess potential impacts of vibrations and other GMD-related harmonic issues on BPS equipment

• **Issue:** GMD-related harmonics can lead to increased vibrations in large power transformers

• **EPRI Report:** [Transformer Vibration Analysis](#)

• **Outcomes:** Factory and field tests to-date have indicated vibrations due to GIC have minimal impact on mechanical integrity

• **Next Steps:**
  - EPRI performing long-term field monitoring of large transformer tank vibrations
Order No. 830 includes directives for collecting data to “improve our collective understanding” of GMD risk
- Includes GIC and Magnetometer data
- NERC is to make data available to the public
- NERC developed a Rules of Procedure Section 1600 data request with GMD Task Force (GMDTF) and technical committee input
- Approved by NERC Board in August 2018
• Use data to improve e-field modeling
  ▪ Earth models
  ▪ Latitude scaling

• Use data to improve GIC system models and risk assessments
  ▪ Determine duration and intensity of GIC pulses
  ▪ Evaluate transformers susceptibility to half-cycle saturation
  ▪ Assess vulnerability of operating assets and facilities
  ▪ Define acceptable levels of risk tolerance

• Support research into GMD event characteristics

Why collect GMD data

$E_{\text{peak}} = 8 \times \alpha \times \beta \ (V/km)$
• Data will be collected for GMD events that meet or exceed $K_p$-7
  ▪ Historical events back to May 2013
  ▪ Future events from implementation of data collection program
  ▪ On average, 200 $K_p$-7 GMD events occur in 11-year solar cycle

• Transmission Owners and Generator Owners with GIC and/or magnetometer data are applicable entities
  ▪ Non-U.S. entities are not obligated to participate but are encouraged
  ▪ Reporting by an entity (e.g., EPRI) on behalf of applicable entities is acceptable

• NERC will make data available to researchers
Final Thoughts

- The BPS is well-protected and the industry is becoming increasingly confident that the risks are mitigated.
- Continue to refine technical guidance and requirements as research and tools emerge.
- Technologies continue to be advanced that can help mitigate risks.
Questions and Answers
Reference Slides: Research Tasks
Task 1 - Analyze Spatial Averaging Used in Benchmark GMD Event

- Further evaluate the Benchmark GMD Event used in TPL-007-1
- Improve understanding of the physics and spatial scales of localized geoelectric field “hotspots”
  - Analysis of measurement data
  - Compare to simulated predictions
- Determine impacts of spatial averaging assumptions on bulk-power system reliability
  - GIC analysis
  - Power flow analysis
  - Transformer thermal assessments
• Evaluate geomagnetic latitude scaling factors associated with severe GMD events
• Perform analysis to provide:
  ▪ Additional technical support for existing latitude scaling factors, or
  ▪ Propose new values as appropriate

• Determine if the earth conductivity scaling factors in TPL-007-1 need to be revised using more complex modeling

• Develop techniques and guidelines for using GIC and magnetometer data to perform model validation

• Establish a working group on modeling non-uniform geoelectric fields
• Perform analysis to evaluate the ability of GIC flow calculated as specified in TPL-007 to represent worst-case transformer hot-spot heating conditions
  ▪ Evaluate 75 A per phase criteria
  ▪ Evaluate effects of harmonic currents

• Develop enhancements to models and data to improve accuracy of transformer thermal impact assessments
  ▪ Improve models
  ▪ Additional modeling parameters
  ▪ Guidance, Performance Criteria

• Develop a Transformer Thermal Modeling Tool (2017)
• Order No. 830 includes directives for collecting data to “improve our collective understanding” of GMD risk
  ▪ Includes GIC and Magnetometer data
  ▪ NERC is to make data available to the public
• EPRI project will develop guidance for the measurement of GIC and geomagnetic field
Task 7 – Geoelectric Field Calculation Tool

- Evaluate commercially available tools for calculating geoelectric field from magnetic field data for given earth conductivity structure
- Develop open source tool capable of performing geoelectric field calculations using more complex earth conductivity models and time series geomagnetic field data
- Perform time-series simulations to evaluate scaling factors
• Develop harmonics analysis guidelines and tools for system-wide assessments
• Develop models and methods to improve capability of performing harmonic assessments of benchmark GMD events
Task 9 – Harmonic Impact Studies

- Impacts of harmonics on power system equipment (power transformers)
- Perform transformer tank vibration measurements on transformers when subjected to GIC
- Determine:
  - Feasibility of using tank vibration measurements to monitor GIC impact
  - Impact of vibrations due to GIC on integrity of the transformers
- May result in additional screening and/or monitoring criteria that can be used to determine GMD impacts