Geomagnetic Disturbances
Managing Risk to the North American Power Grid

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The North American Electric Reliability Corporation is a not-for-profit entity with authority in the U.S. and Canada:

- Develops and enforces reliability standards
- Annually assesses seasonal and long-term reliability
- Monitors the transmission system
- Educates, trains, and certifies industry personnel

NERC is subject to oversight from the Federal Energy Regulatory Commission (FERC) and authorities in Canada.
Space Weather and the Power System
On March 11, 1989, astronomers reported a very large solar flare. At 2:44 a.m. on March 13, 1989, seven Static Var Compensators (SVC) on the 735 kV Hydro-Quebec transmission system tripped. Voltage collapse and blackout occurred 25 seconds later.
Coronal Mass Ejections

- Energetic Charged Particles
- Magnetosphere
- Heliosphere
- Ionosphere
Geomagnetic Disturbances

Solar Flare → CME → Interaction with Earth’s Magnetic Field → Maxwell Eq. & Earth Cond. Model → Grid Model → GIC
Effects of GIC in EHV Network

- GIC flows in lines
  - Transformer half-cycle saturation
  - Harmonics
  - Controls misoperation
  - Generator overheating and tripping

- Transformer heating
  - Capacitor bank tripping – loss or reactive support

- Reactive power loss
  - Voltage control, limits, contingency management
  - Voltage and angle stability

Equipment

System
ISES Solar Cycle Sunspot Number Progression
Observed data through Aug 2013
Relative positions of SOHO & both STEREO spacecraft.
STEREO spacecraft attained 90° separation on January 24, 2009.
(Diagram not to scale)
Industry Response
Addressing Unique Risks

- Class of rare risks outlined in the Department of Energy-NERC joint report on *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System* (June 2010)

- The HILF report recommended task force creation to evaluate and prioritize mitigation and restoration options
  - Industry
  - Equipment manufacturers and vendors
  - Risk experts
• A task force of experienced planners and operators is focused on improving the tools for industry to address GMD impacts

• NERC GMD Task Force collaborates with agencies and utilities across North America
  - Electric Power Research Institute
  - North American Transmission Forum
  - NASA, Canadian Space Agency
  - U.S. Geological Survey, Natural Resources Canada
  - NOAA, Space Weather Canada
  - Utilities from all regions in North America
In 2012 the task force published a report on GMD effects that outlined four recommendations

- **Recommendation 1:** Improvement of tools for industry planners to develop GMD mitigation strategies
- **Recommendation 2:** Improvement of tools for system operators to manage GMD impacts
- **Recommendation 3:** Education and information exchanges between researchers and industry
- **Recommendation 4:** Review the need to enhance NERC Reliability Standards
Tools to Support GMD Studies

GMD TF Phase 2 Project


Operating Procedure Template

Geomagnetic Field

Earth Conductivity Model

Geomagnetic Field

E(t)

dc System Model

GIC(t)

Transformer Model (Electrical)

vars

Power Flow Analysis

Line Loading & var Reserves

Bus Voltages

Assessment Criteria

Pass

Operating Procedures and Mitigation Measures (if needed)

Fail

Temp(t)

Hot Spot Temp.

Transformer Model (Thermal)
GIC Calculations

GIC Flow in a Simplified Power System

GIC Flow in a Simplified Power System
Planning Study Overview

• Assess the performance of protection and control (P&C) systems
  ▪ Harmonic estimates
  ▪ Security
  ▪ Dependability

• Assess system behavior
  ▪ Voltage limits,
  ▪ Potential voltage collapse
  ▪ Cascading outages

• Assess impact on equipment
  ▪ Hot spot heating of transformers
Planning Study Steps

- Initial Screening
- System Impact Assessment
- Equipment Impact Assessment
- Integration of system and equipment assessments
- Mitigation
- Monitoring
  - Situational awareness
  - Triggers
  - Model and study validation
Tools to Support GMD Studies

GMD TF Phase 2 Project

|---------------------|-----------------------|-----------------------------|-------------------|---------------------|

- **Geomagnetic Field**
  - **B(t)**
  - **E(t)**

- **Geoelectric Field**
  - **dc System Model**
    - **GIC(t)**
    - **Transformer Model (Electrical)**
      - **vars**
      - **Power Flow Analysis**
        - **Bus Voltages**
        - **Line Loading & var Reserves**
        - **Assessment Criteria**
          - **Pass**
          - **Fail**
            - **Operating Procedures and Mitigation Measures (if needed)**

- **Transformer Model (Thermal)**
  - **Temp(t)**
  - **Hot Spot Temp.**

- **Earth Conductivity Model**
The GMD TF and EPRI are taking steps to address the limited availability of validated transformer models.

Quality of modeling data varies:
- Measurement-based models
- Manufacturer-provided models
- Generic models

Emphasis on the validation of manufacturer models:
- In-factory tests
- On site measurements of instrumented transformers during an event
Transformer Modeling

• The GMD TF, EPRI, and some asset owners have contributed to developing generic GIC capability curves for thermal impact screening using conservative measurements and assumptions

• Additional coordinated effort between manufacturers and asset owners is needed to expand the test population

• There are no commercially-available tools to support incorporating thermal impact of GIC into GMD studies
Mitigating the Effects
Industry Risk Management

Phase One
Assess and Baseline the Risk

Phase Two
Perform Technical and Programmatic Analysis

Phase Three
Develop Integrated Solutions

Phase Four
Implement Solutions and Adjust System Procedures

Continuous Monitoring
System Resiliency
Operating Procedures

• Increased situational awareness, safe system posturing, and reconfiguration may be implemented by operators
  ▪ System studies and monitoring enhance the effectiveness
• Improvements in forecasting and warning are needed
Hardware Mitigation

- Manufacturers are developing and testing devices to block GIC from entering the transmission system
- Planning studies are necessary to understand system effects and reduce the likelihood of unintended consequences
The Future

• Power system engineers will have tools to include GMD effects in planning studies
  ▪ Power flow simulation tools are now available...Thermal modeling, harmonic studies, and transient stability tools are needed

• GIC capability requirements may be included in new transformer specifications

• Additional science data about solar storm occurrence will inform design and risk decisions

• Improvements in space weather prediction, forecasting, and warning are being developed
Questions and Answers

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