



Update on the recent geomagnetically induced currents work in the US

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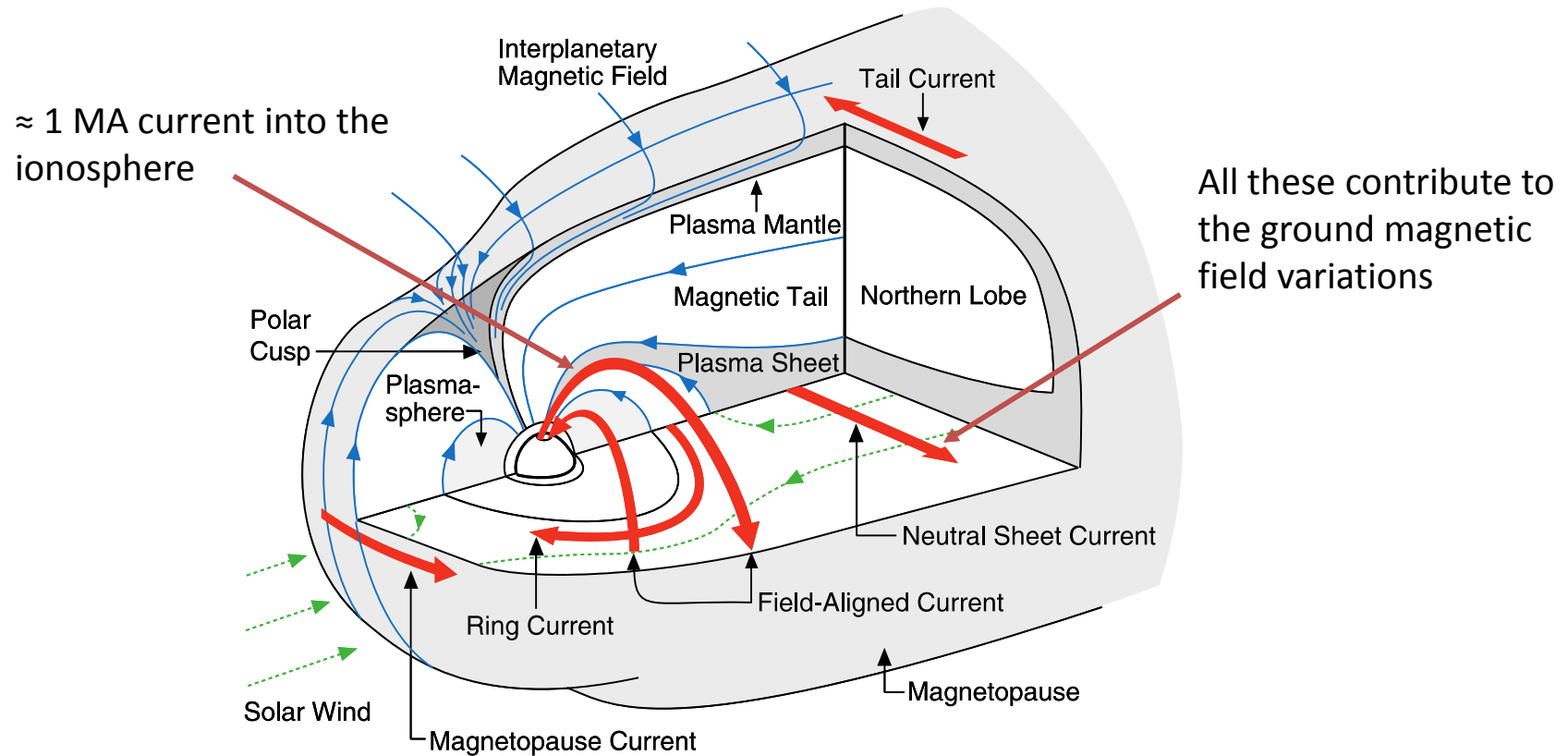


Contents

- Background: science, impacts.
- Brief history of US interest and work on the topic.
- How bad can it get?
- Some key future challenges.



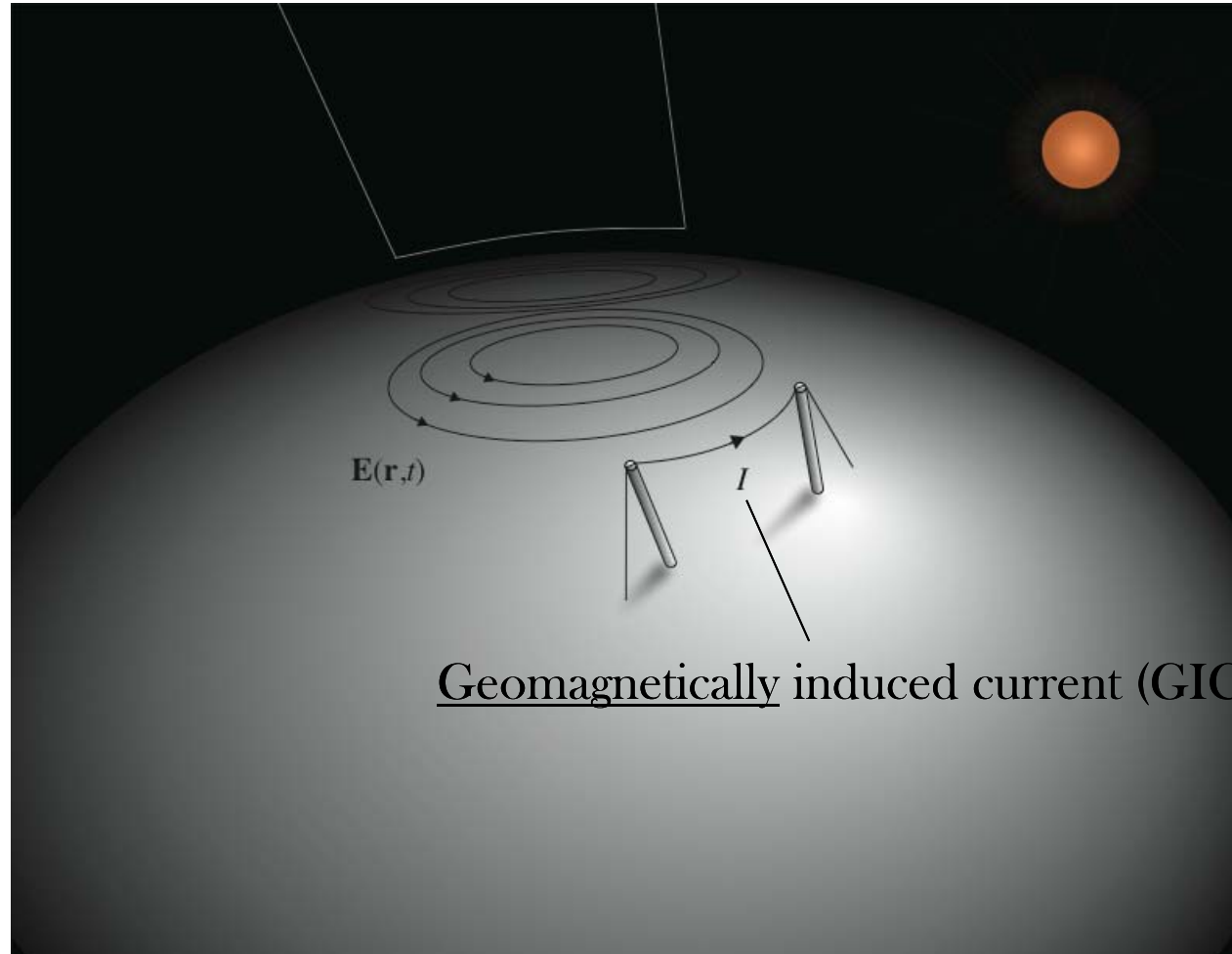
Storms within the Earth's magnetic cloak



Source: Russell, C. (IEEE Trans. on Plasma Science, 2000)



GIC / GMD





GIC impact



- GIC-driven half-cycle saturation of power transformers can cause:

- Leakage magnetic fields.

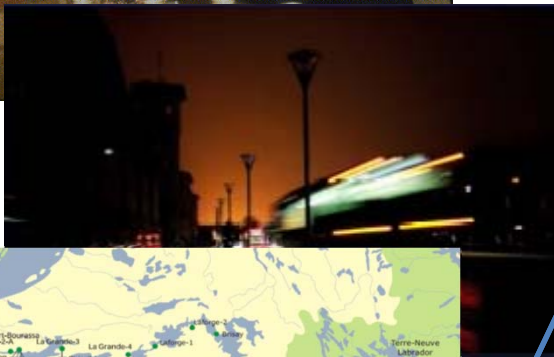
- ➔ Transformer heating

- Harmonic currents.

- ➔ Relay tripping

- Increased reactive power consumption.

- ➔ Voltage instability

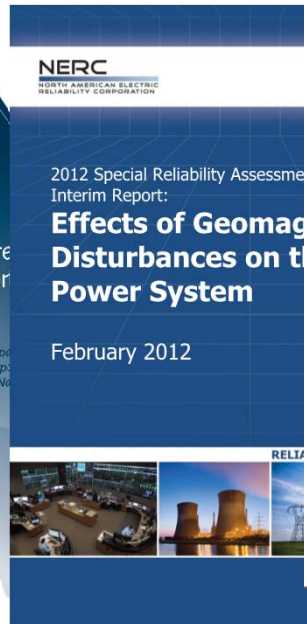
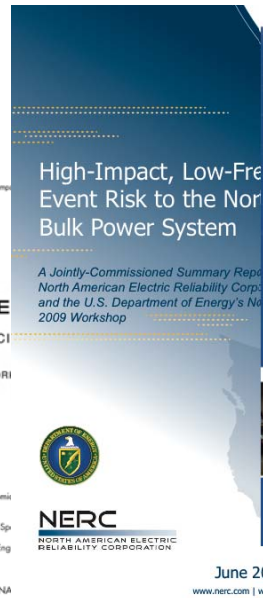


Hydro-Québec March 1989



Brief history of the high-level US interest in the topic

NERC-DOE report 2010



NERC report 2012

143 FERC ¶ 61,147
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 39

[Docket No. RM12-22-0001]
Reliability Standards for Geomagnetic Disturbance Operations

(Issued May 18, 2012)

AGENCY: Federal Energy Regulatory Commission

ACTION: Final Rule.

SUMMARY: Under section 215 of the Federal Energy Regulatory Commission (Commission) directs

Corporation (NERC), the Commission certifies

submit to the Commission for approval proposed

impact of geomagnetic disturbances (GMD) on the

System. The Commission directs NERC to, in its

first stage, NERC must submit, within six months

one or more Reliability Standards that require the

System to develop and implement operational

consistent with the reliable operation of the Bulk

NERC must submit, within 18 months of the effective

more Reliability Standards that require owners

to conduct initial and on-going assessments of

FERC order 2013

EOP-010-1 — Geomagnetic Disturbance Operations

A. Introduction

- Title:** Geomagnetic Disturbance Operations
- Number:** EOP-010-1
- Purpose:** To mitigate the effects of geomagnetic disturbance (GMD) events by implementing Operating Plans, Processes, and Procedures.
- Applicability:**

4.1. Functional Entities:

- 4.1.1 Reliability Coordinator**
- 4.1.2 Transmission Operator** with a Transmission Operator Area that includes a power transformer with a high side wye-grounded winding with terminal voltage greater than 200 kV.

5. Background:

Geomagnetic disturbance (GMD) can impact the reliable operation of interconnecting transmission lines, causing geomagnetically-induced current (GIC) damage, loss of Reactive Power Protection System Misoperation, collapse and blackout.

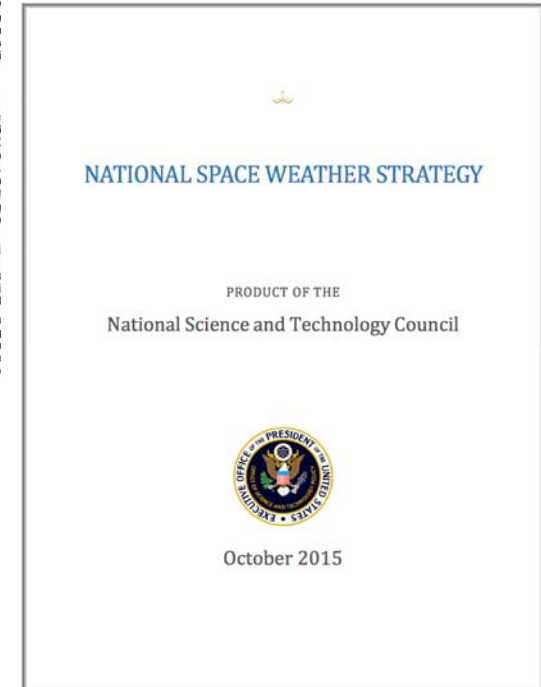
B. Requirements and Measures

R1. Each Reliability Coordinator shall maintain, and implement a GMD Plan that coordinates GMD Operations Procedures or Operating Procedures, Reliability Coordinator Area GMD Operating Plan shall include: [Violation Risk Factor: Medium-High; Horizon: Long-term Planning, Same-day Operations]

- 1.1** A description of activities to mitigate the effects of GMD on the reliable operation of interconnected transmission lines within the Reliability Coordinator Area.
- 1.2** A process for the Reliability Coordinator to review the GMD Operations Procedures or Operating Procedures with the Transmission Operator Reliability Coordinator.

Draft 3: October 25, 2013

FERC Phase I Standard 2014



SEVERE SPACE WEATHER
UNDERSTANDING SOCIETY

A WORKING

Committee on the Societal and Economic Impacts of Severe Space Weather Events

Staff Report

Division of Engineering and Physical Sciences

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NRC workshop report 2008

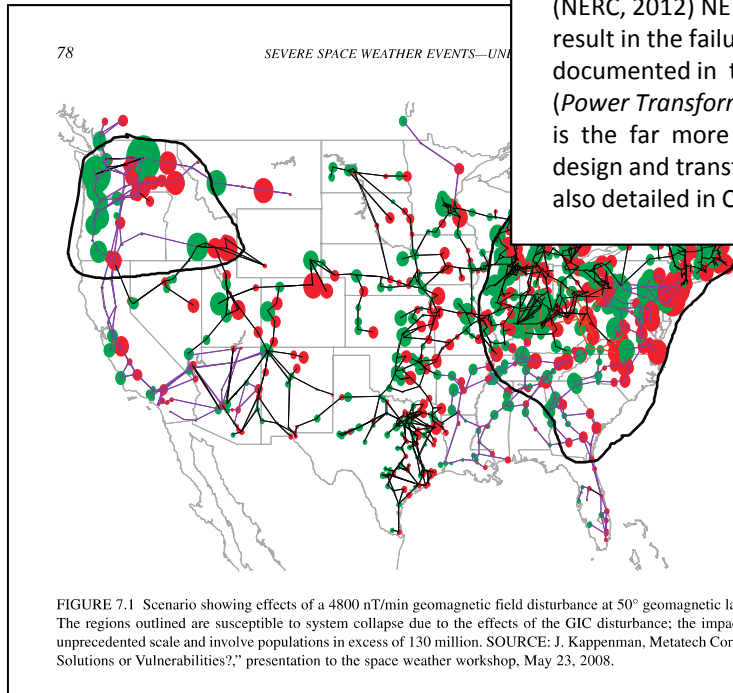
NSWS 2015



How bad can it get?

NERC report 2012

(NERC, 2012) NERC recognizes that other studies have indicated a severe GMD event would result in the failure of a large number of EHV transformers. The work of the GMD Task Force documented in this report does not support this result for reasons detailed in Chapter 5 (*Power Transformers*), and Chapter 8 (*Power System Analysis*). Instead, voltage instability is the far more likely result of a severe GMD storm, although older transformers of a certain design and transformers near the end of operational life could experience damage, which is also detailed in Chapter 5 (*Power Transformers*).



NRC workshop report 2008

NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Benchmark Geomagnetic Disturbance Event Description

Project 2013-03 GMD Mitigation
Standard Drafting Team
December 5, 2014

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NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Transformer Thermal Impact Assessment White Paper

Project 2013-03 (Geomagnetic Disturbance Mitigation)
TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events

Background
On May 16, 2013, FERC issued Order No. 779, directing NERC to develop Standards that address risks to reliability caused by geomagnetic disturbances (GMDs) in two stages:

- Stage 1 Standard(s) that require applicable entities to develop and implement Operating Procedures. EOP-010-1 – Geomagnetic Disturbance Operations was approved by FERC in June 2014.
- Stage 2 Standard(s) that require applicable entities to conduct assessments of the potential impact of benchmark GMD events on their systems. If the assessments identify potential impacts, the Standard(s) will require the applicable entity to develop and implement a plan to mitigate the risk.

TPL 007.1 is a new Reliability Standard to specifically address the Stage 2 directives in Order No. 779.

Large power transformers connected to the EHV transmission system can experience both winding and structural hot spot heating as a result of GMD events. TPL-007-1 will require owners of such transformers to conduct thermal analyses of their transformers to determine if the transformers will be able to withstand the thermal transient effects associated with the Benchmark GMD event. This paper discusses methods that can be employed to conduct such analyses, including example calculations.

The primary impact of GMDs on large power transformers is a result of the quasi-dc current that flows through wye-grounded transformer windings. This geomagnetically-induced current (GIC) results in an offset of the ac sinusoidal flux resulting in asymmetric or half-cycle saturation (see Figure 1).

Half-cycle saturation results in a number of known effects:

- Hot spot heating of transformer windings due to harmonics and stray flux;
- Hot spot heating of non-current carrying transformer metallic members due to stray flux;
- Harmonics;
- Increase in reactive power absorption; and
- Increase in vibration and noise level.

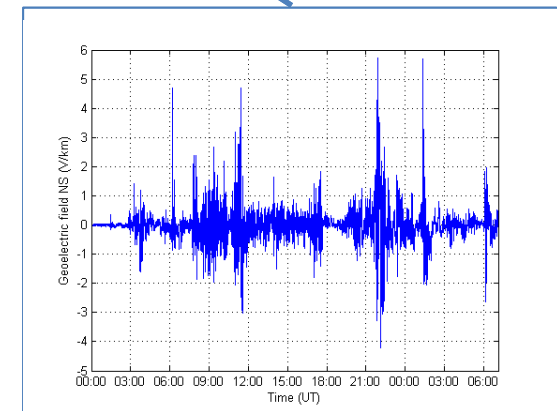
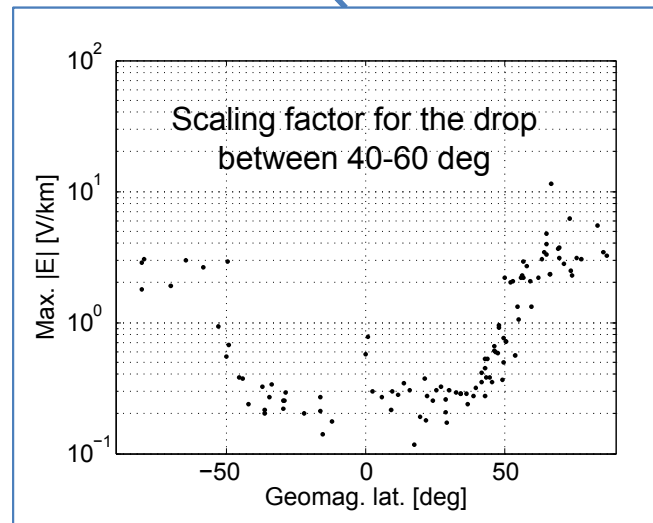
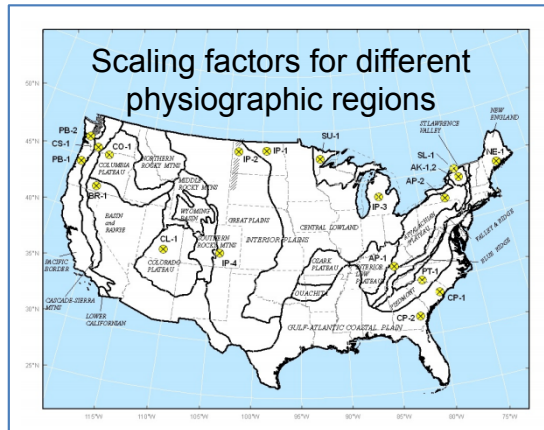
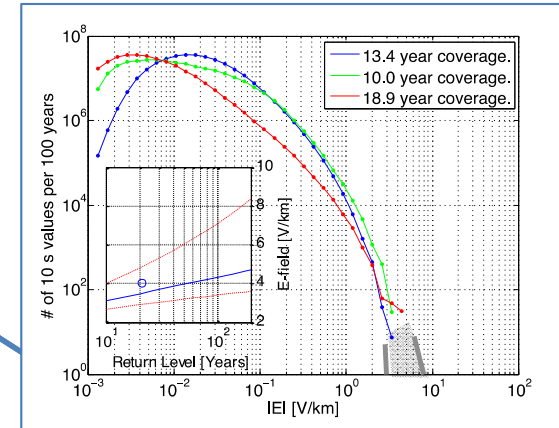
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NERC benchmark and corresponding engineering analyses – Phase II of the standard



Extreme E-field scenario for the proposed standard

- Element 1: amplitude
- Element 2: spatial structure
- Element 3: reference temporal waveform
- Element 4: geomagnetic latitude dependence
- Element 5: dependence on the local ground conductivity



Data acknowledgements: USGS, NRCan, FMI



Some key future challenges

- Low magnitude GIC impacts? (Forbes et al. and Schrijver et al. papers)
- Smart grid vulnerability via phasor measurement units (PMUs)?
- Improved extreme GIC event scenarios.
- 3D geomagnetic induction.
- Improved long lead-time forecast capacity.



Summary

- GIC are one of the key space weather problems.
- There is high-level US interest in addressing the problem:
 - GMD Standards work.
 - Core piece of the National Space Weather Strategy.
- We have made significant progress to understand the science and engineering of the impacts. Establishing common language and understanding between scientists and power engineers one of the key advancements.
- Many interesting science and engineering challenges lie ahead: NASA LWS Institute GIC Working Group (PI A. Pulkkinen) has worked to identify and address the key questions.