# Update on the recent geomagnetically induced currents work in the US

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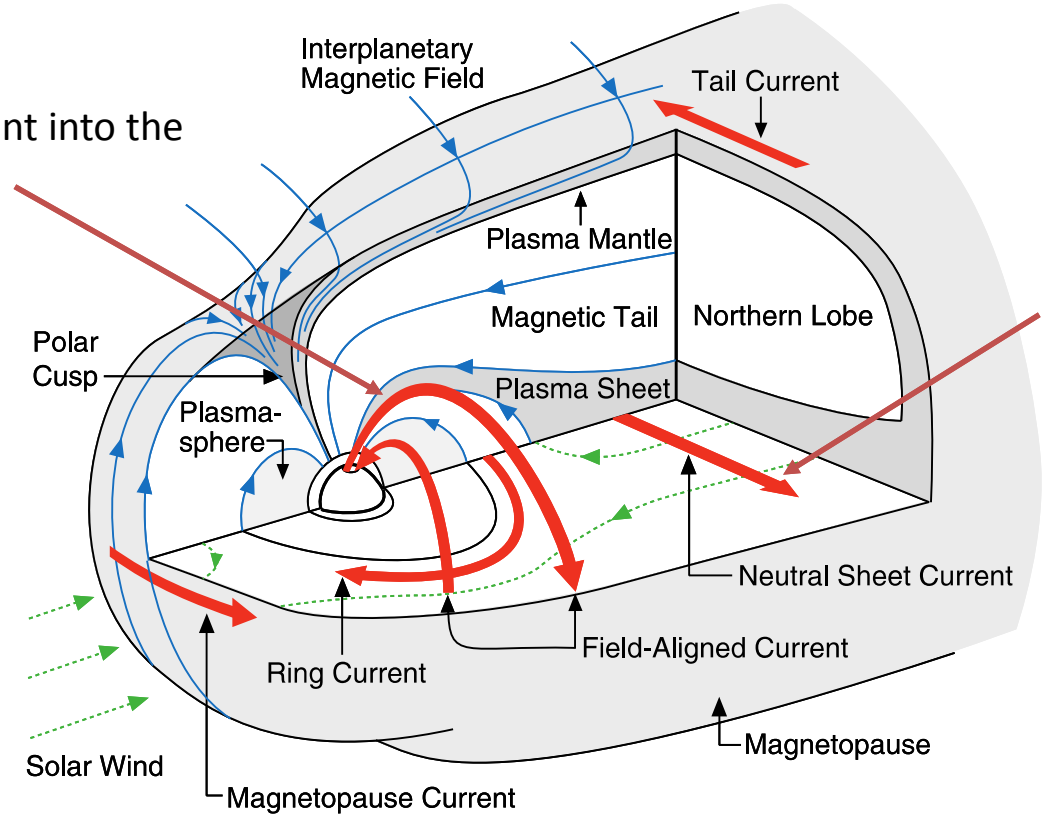
- Background: science, impacts.
- Brief history of US interest and work on the topic.
- How bad can it get?
- Some key future challenges.

# Storms within the Earth's magnetic cloak

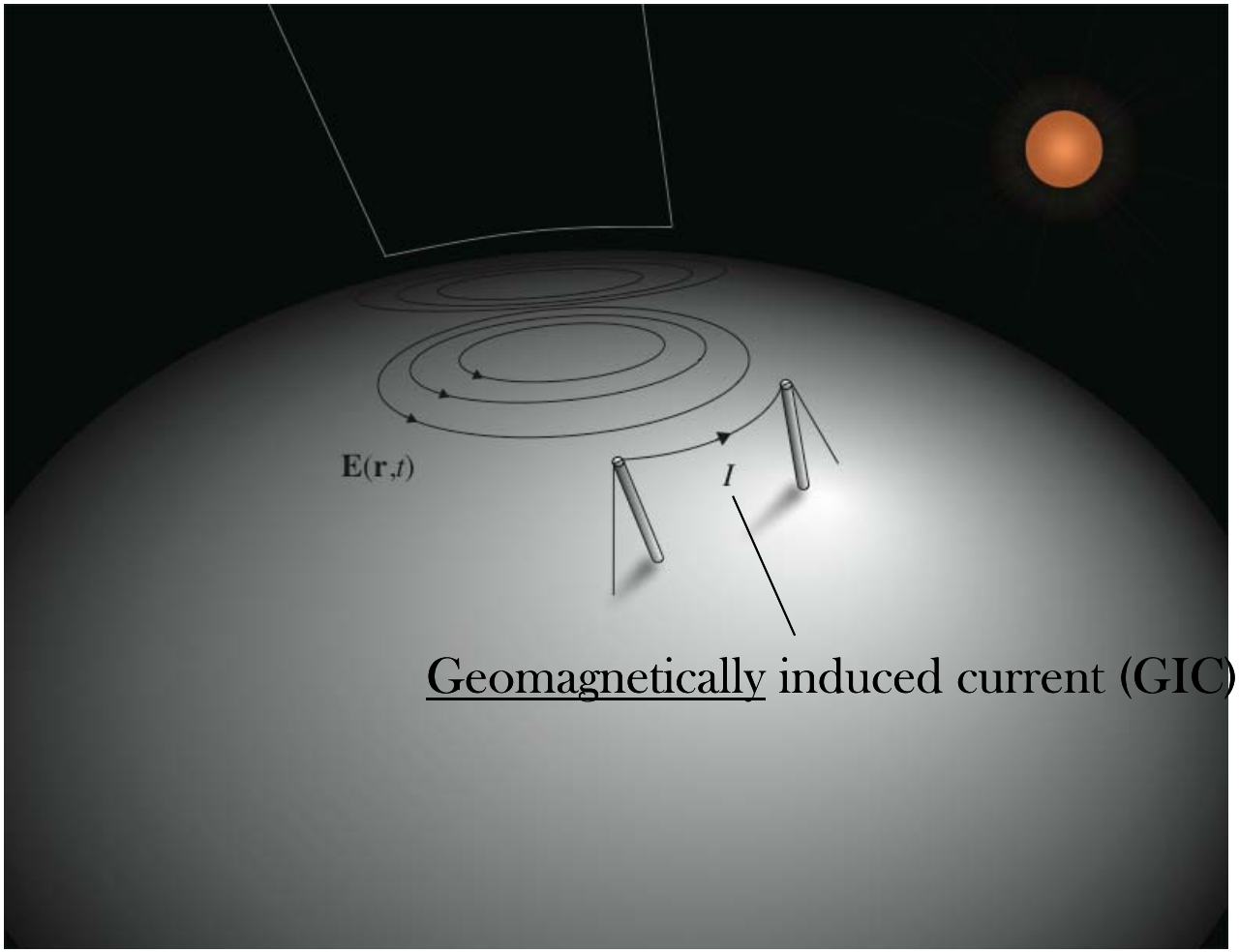
≈ 1 MA current into the ionosphere




All these contribute to the ground magnetic field variations

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

# GIC / GMD



# GIC impact


Hydro-Québec March 1989

- 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

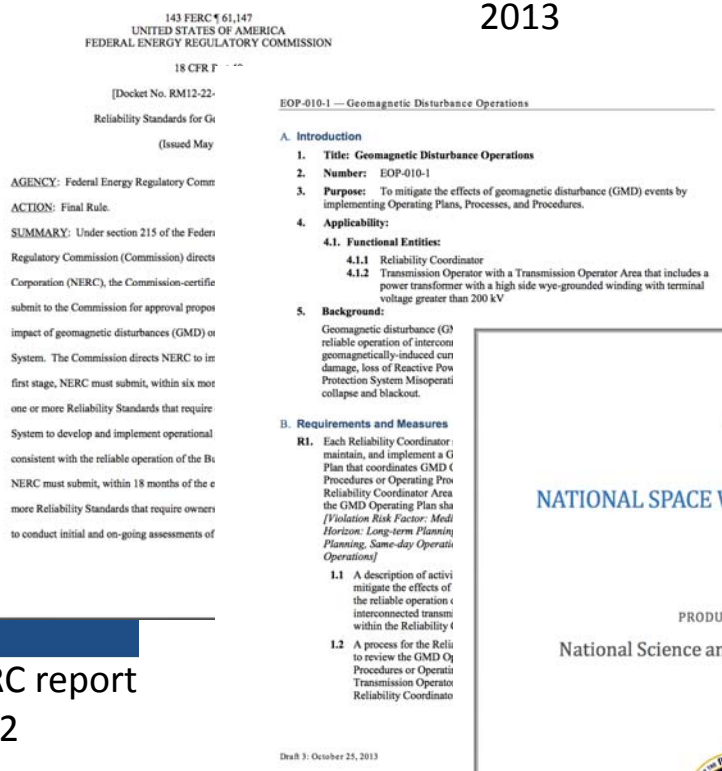
# Brief history of the high-level US interest in the topic

NERC-DOE report 2010


NRC workshop report 2008

NERC report 2012

FERC order 2013


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

[Docket No. RM12-22-

Reliability Standards for G

(Issued May

AGENCY: Federal Energy Regulatory Comm

ACTION: Final Rule.

SUMMARY: Under section 215 of the Feder

Regulatory Commission (Commission) directs

Corporation (NERC), the Commission-certifie

submit to the Commission for approval propos

impact of geomagnetic disturbances (GMD) o

System. The Commission directs NERC to in

first stage, NERC must submit, within six mot

one or more Reliability Standards that require

System to develop and implement operational

consistent with the reliable operation of the Bu

NERC must submit, within 18 months of the e

more Reliability Standards that require owners

to conduct initial and on-going assessments of

FERC Phase I Standard 2014


EOP-010-1 — Geomagnetic Disturbance Operations

A. Introduction

1. Title: Geomagnetic Disturbance Operations
2. Number: EOP-010-1
3. Purpose: To mitigate the effects of geomagnetic disturbance (GMD) events by implementing Operating Plans, Processes, and Procedures.
4. 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 (G
reliable operation of intercon
geomagnetically-induced cur
damage, loss of Reactive Pow
Protection System Misoperati
collapse and blackout.

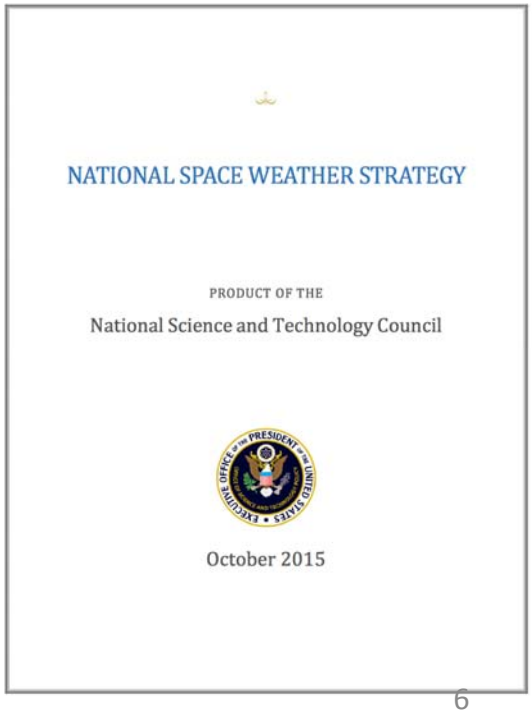
B. Requirements and Measures

R1. Each Reliability Coordinator
maintain, and implement a G
Plan that coordinates GMD (
Procedures or Operating Pro
Reliability Coordinator Area
the GMD Operating Plan sha
*[Violation Risk Factor: Medi*
*Horizon: Long-term Planni*
*Planning, Same-day Operati*
*Operations]*

1.1 A description of activi
mitigate the effects of
the reliable operation
interconnected transm
within the Reliability

1.2 A process for the Reli
to review the GMD Op
Procedures or Operati
Transmission Operato
Reliability Coordinato

Draft 3: October 25, 2013

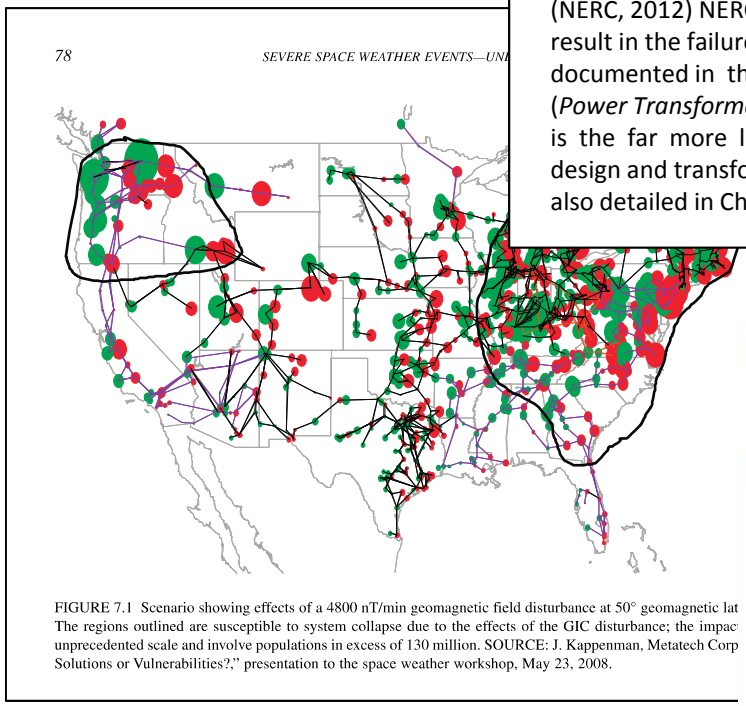



NSWS 2015

# How bad can it get?

(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)*.

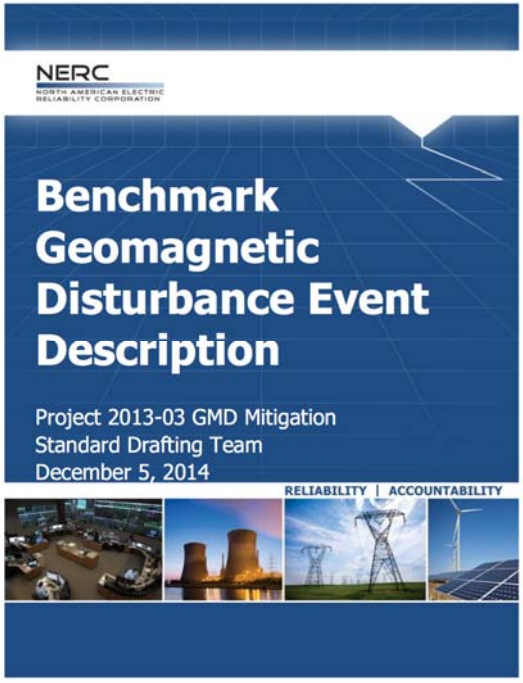
NERC report 2012

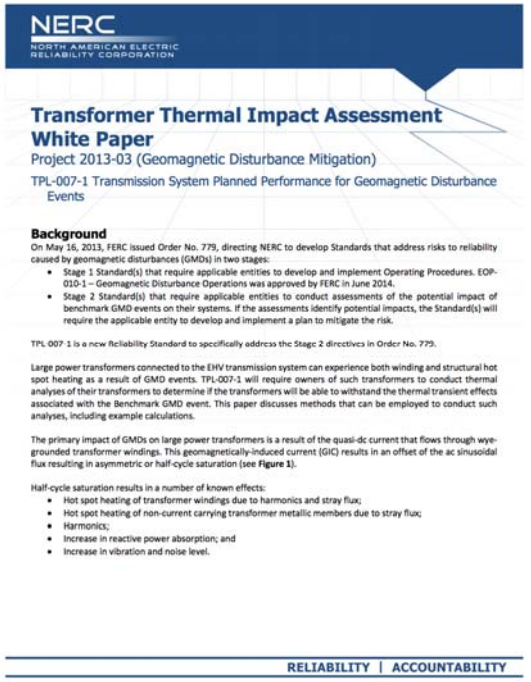


78 SEVERE SPACE WEATHER EVENTS—UNI

FIGURE 7.1 Scenario showing effects of a 4800 nT/min geomagnetic field disturbance at 50° geomagnetic lat The regions outlined are susceptible to system collapse due to the effects of the GIC disturbance; the impac unprecedented scale and involve populations in excess of 130 million. SOURCE: J. Kappenman, Metatech Corp Solutions or Vulnerabilities?," presentation to the space weather workshop, May 23, 2008.

NRC workshop report 2008

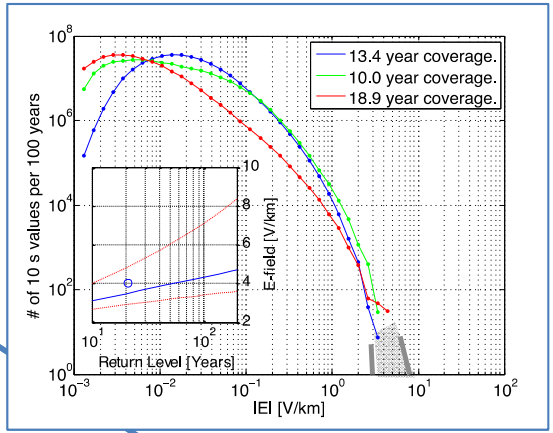


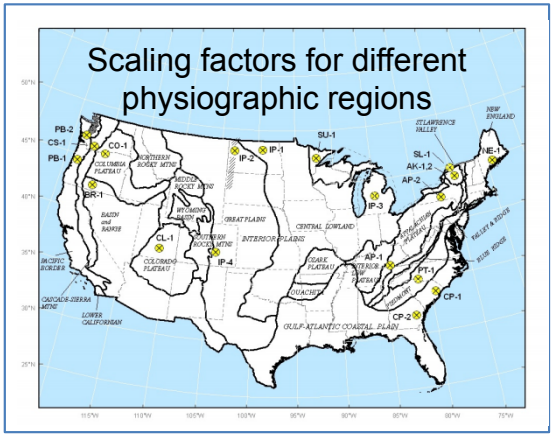



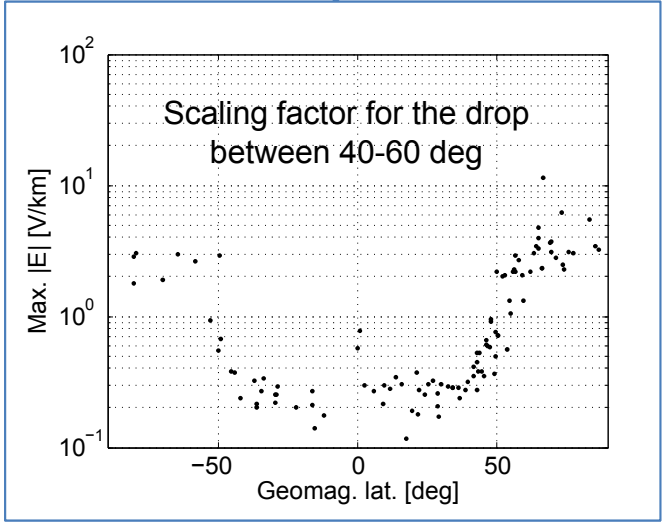

NERC benchmark and corresponding engineering analyses – Phase II of the standard

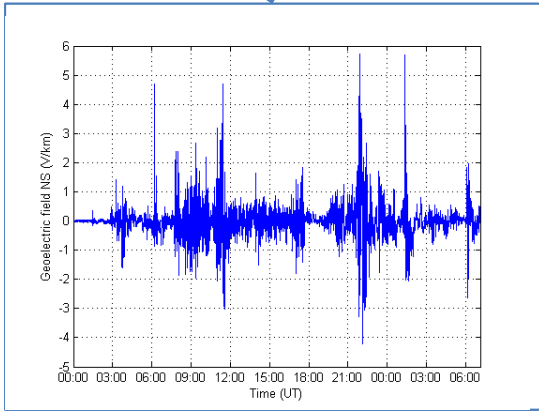
# Extreme E-field scenario for the proposed standard

- 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.