Electric Reliability Standards for Solar Geomagnetic Disturbances

Comments submitted to the Federal Energy Regulatory Commission

by Thomas S. Popik, George H. Baker, and William R. Harris

July 2017

Report to the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack

REPORT TO THE COMMISSION TO ASSESS THE THREAT TO THE UNITED STATES FROM ELECTROMAGNETIC PULSE (EMP) ATTACK

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The cover photo depicts Fishbowl Starfish Prime at 0 to 15 seconds from Maui Station in July 1962, courtesy of Los Alamos National Laboratory.

This report is a product of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. The Commission was established by Congress in the FY2001 National Defense Authorization Act, Title XIV, and was continued per the FY2016 National Defense Authorization Act, Section 1089.

The Commission completed its information-gathering in June 2017. The report was cleared for open publication by the DoD Office of Prepublication and Security Review on June 4, 2018.

July 2017

Dr. William R. Graham
Chairman
Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack

Dear Dr. Graham:

As you have requested, the nonprofit Foundation for Resilient Societies, Inc. has approved the transmittal of that organization's documentary filing on a **Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events** as a Staff Report to the Congressionally-mandated EMP Commission.

This Staff Report was originally produced in July 2015 and then filed as corrected on August 10, 2015 in public Docket RM15-11-000 of the Federal Energy Regulatory Commission (FERC). The document provides a set of research findings and supporting evidence relating to the then-proposed NERC Standard TPL-007-1. This standard utilizes a benchmark model and a set of threat thresholds to assess the need for hardware protection of critical electric equipment within the U.S. bulk power system. Our docket filing expressed concerns that an overly-optimistic threat benchmark would result in no required hardware protection and therefore leave the U.S. electric grid vulnerable to solar storms. Had a higher and more uniform threat benchmark been established by NERC, Standard TPL-007-1 could have also provided a significant degree of protection against man-made EMP.

On September 22, 2016, FERC approved the proposed NERC Standard TPL-007-1 in FERC Order No. 830. Despite multiple requests for rehearing, FERC reaffirmed that standard in FERC Order No. 830-A on January 19, 2017.

Authors of the Staff Report to the EMP Commission dated August 10, 2015, comprising 91 pages, are Thomas S. Popik, Chairman of the Foundation for Resilient Societies, and two of the Senior Advisors to the later-reconstituted EMP Commission, Dr. George H. Baker and William R. Harris.

Respectful submitted by

Wm. R. Harris

William R. Harris
Senior Advisor

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Reliability Standard for	)	
Transmission System Planned Performance	)	**Docket No. RM15-11-000**
for Geomagnetic Disturbance Events	)	

COMMENTS OF THE FOUNDATION FOR RESILIENT SOCIETIES

Submitted to FERC on July 27, 2015
Corrected Comments submitted on August 10, 2015

Introduction

Pursuant to the Federal Energy Regulatory Commission's ("FERC" or "Commission") Notice of Proposed Rulemaking ("GMD NOPR") issued on May 16, 2015,[1] the Foundation for Resilient Societies ("Resilient Societies") respectfully submits Comments on the Commission's proposal to approve the framework of Reliability Standard TPL-007-1 of the North American Electric Reliability Corporation (NERC) as "just and reasonable," to approve specific requirements of the standard, and to direct NERC to develop modifications to Reliability Standard TPL-007-1 and submit informational filings.

[1] *Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events*, Notice of Proposed Rulemaking (NOPR), 151 FERC ¶ 61,134 (May 14, 2015) ("GMD NOPR"), 80 FR 29990 (May 26, 2015).

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Background

In FERC Order 779, FERC directed NERC to develop Second Stage Geomagnetic Disturbance (GMD) Reliability Standards:[1]

> The Second Stage GMD Reliability Standards must identify *benchmark GMD events* that specify what severity GMD events a responsible entity must *assess for potential impacts* on the Bulk-Power System. If the assessments identify potential impacts from benchmark GMD events, the Reliability Standards should require owners and operators to develop and implement a plan to protect against instability, uncontrolled separation, or cascading failures of the Bulk-Power System, caused by damage to critical or vulnerable Bulk-Power System equipment, or otherwise, as a result of a benchmark GMD event. (Emphasis added.)

As we will show in this comment, both the Benchmark GMD Event and the assessment criteria to identify potential impacts from the Benchmark GMD Event are fatally flawed. As a result, it is exceedingly unlikely that GMD Vulnerability Assessments by owners and operators will result in any significant protection against instability, uncontrolled separation, or cascading failures of the Bulk-Power System, except by voluntary action beyond the requirements of this standard.

Framework of Standard TPL-007-1

Overlapping Thresholds for Solar Storm Threat and Assumed Invulnerability of Transformers

The fundamental framework of Standard TPL-007-1 is defective because it overlaps a low solar storm threat or "Benchmark GMD Event," expressed in volts per kilometer, with a very high assumed invulnerability of transformers (also known as "Geomagnetically Induced Current (GIC) withstand rating") expressed in amps per phase. Only transformers having a lower withstand rating than the modeled GIC from the Benchmark GMD event would undergo "thermal assessment" to determine if hardware protection might be required.

If Standard TPL-007-1 were to use the same units of measure for both the assumed transformer invulnerability (GIC withstand rating) and the Benchmark GMD Event, it would be obvious that

[1] *Reliability Standards for Geomagnetic Disturbances*, Docket No. RM12-22-000; FERC Order No. 779, 143 FERC ¶ 61,147 (May 16, 2013) ("FERC Order 779"), 78 FR 30747 (May 23, 2013), p. 2.

these limits have been imprudently set and are inconsistent with available real-world data. Unfortunately, the methodology implicit in the standard's framework is inherently difficult for the casual observer to understand, perhaps intentionally so. We can illustrate with an analogy to automobile crash testing.

For example, suppose the National Highway Traffic Safety Administration (NHTSA) asked automobile manufacturers to set a standard to determine if automobiles should have airbags installed as a protective measure against "high speed crashes." Further suppose that the NHTSA avoided a mandate to the industry by not specifying the miles per hour of a "high speed crash" but instead let the auto industry set this benchmark. Finally suppose that the NHTSA also let the auto industry determine a threshold limit for assumed resilience or invulnerability of cars and their occupants to crashes. For example, this threshold limit for assumed invulnerability to crashes might be 15 miles per hour.

As a first step, the automobile industry might propose a reasonable figure for a "high speed crash" by taking a survey of the radar gun readings on major highways to determine the upper speeds at which people actually drive. Using upper speeds, the resulting benchmark for a "high speed crash" might be quite substantial—for example, 75 miles per hour. If this were the "high speed crash benchmark," all cars would probably need airbags installed. As an alternative, if the auto industry were to average the speed of travel on all types of roads, the benchmark could be considerably lower—for example, 50 miles per hour.

In the analogous case of Standard TPL-007-1, if the Benchmark GMD Event were to be set at the maximum threat level that had been estimated by the respected space weather scientists previously engaged in the NERC standard-setting process (30-40 volts/kilometer), many transformers might need hardware protection. Instead, the NERC Standard Drafting Team, consisting all of industry representatives except for one scientist, downwardly averaged the Benchmark GMD Event to 8 volts/kilometer. And instead of using maximum readings of geomagnetic disturbances recorded in the United States, the NERC standard-setting team opted to use averaged data from Northern Europe over a limited time period lacking any major solar storms.

Returning to the automobile airbag analogy, as a second step the industry might set a threshold limit for assumed invulnerability of cars and their occupants to crashes. Suppose in the absence of test data, this limit was initially set at 15 miles per hour. However, with the apparent goal of avoiding cost and redesign hassle of airbag implementation, further suppose the auto industry decided to reference tests of three automobile designs for crash resilience. After examining tests on *only three automobile designs*—the first test at 17 miles per hour, the second test without crash test dummies in the car and at 200 miles per hour, and the third test at speeds and conditions unavailable in a published paper or otherwise—the industry then extrapolated the results to determine that *every automobile design* would protect human occupants at crashes up to *75 miles per hour*.

In the analogous case of Standard TPL-007-1, the assumed invulnerability of transformers to damage from GIC was set in initial drafts of the standard at *15 amps per phase*. When industry representatives in the ballot body refused to vote in favor of a standard with this low GIC withstand threshold, the industry found tests on *only three transformer designs* and then extrapolated the results to conclude that *all transformer designs* are invulnerable to GIC up to *75 amps per phase*. Notably, none of the transformer tests referenced actually injected currents of 75 amps into a transformer under fully operational electrical load conditions—this asserted invulnerability to solar storms was based on paper studies using mathematical models.

Returning to the automobile airbag analogy, if the benchmark for a high-speed crash were set at 50 miles per hour and the assumed invulnerability of cars and their occupants to crashes were set at 75 miles per hour, then no cars would require airbags, because the vulnerability threshold (75 mph) exceeds the stress threshold (50 mph). The imprudent result would be obvious to the public—by personal real world observation, most people would know that cars commonly travel over 50 miles per hour and that passengers often die in crashes at speeds well below 75 miles per hour.

However, in the analogous case of Standard TPL-007-1, because the units for the solar storm threat and associated Benchmark GMD Event (in volts per kilometer) have been expressed differently than the units of assumed transformer invulnerability to GIC (in amps per phase), the imprudent result is not obvious to most casual observers. In fact, to make the units equivalent for comparison, one must have access to proprietary data of electric utilities and sophisticated modeling software.[2] Likewise, members of the public do not commonly observe GIC readings nor do they see transformers overheat and catch fire during solar storms.

In this docket comment, we will show that for nearly all transformers in two major networks, the modeled threat to large power transformers is below the assumed level of invulnerability. Moreover, we will show that purportedly invulnerable transformers in a major network, PJM Interconnection, have already experienced failure during solar storms far smaller than the Benchmark GMD Event.

Modeling of GIC Impacts

As utilities model their networks in advance of the standard's effective date and selectively release the results, it is becoming clear that the assumed transformer invulnerability to solar storms under the standard's "withstand rating" of 75 amps is almost always greater than the modeled GIC under the Benchmark GMD Event. As a result, the number of transformers needing thermal assessment under Standard TPL-007-1 would be trivial. It is also becoming clear that when networks are modeled using a more prudent benchmark event of 20 V/km and a more justifiable threshold for thermal assessment—for example, the "30 Amps At-Risk Threshold" in the FERC-sponsored Metatech-R-319 report[3]—significant numbers of transformers would need thermal assessment and potential hardware protection.

Below we present modeling results for three major networks: PJM Interconnection (PJM), Central Maine Power, and American Transmission Company (ATC). PJM modeling under the

[2] The electric utility industry is in possession of GIC readings that would likely show the modelled GIC for the Benchmark GMD Event at particular transformer locations are below readings that have been already observed during smaller solar storms. However, GIC data that could expose the NERC standard as technically unjustified has been withheld from the standard-setting process, withheld from independent scientific study, and withheld from public view. For example, the Electric Power Research Institute (EPRI) has GIC readings from locations in the U.S. and Canada dating back to 1991, but nearly all of this data has been held as confidential and not used in NERC standard-setting.

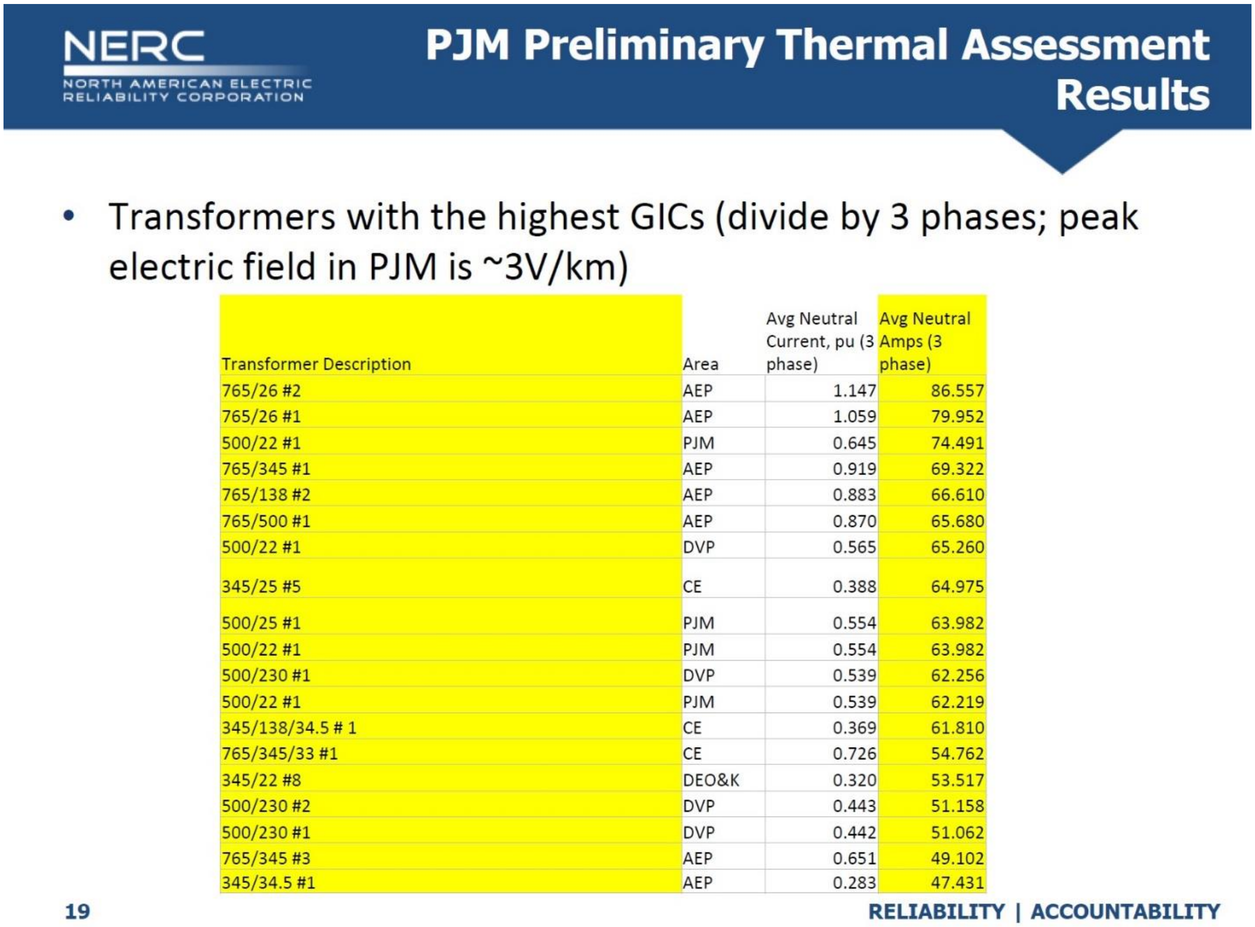
[3] "Metatech R-319, Geomagnetic Storms and their Impact on the US Power Grid," John Kappenman, Metatech Corporation, Oak Ridge National Laboratory, January 2010, available at http://web.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-319.pdf, last accessed on July 26, 2015,

NERC Benchmark GMD Event shows only two transformers in their network would need thermal assessment.[4] Central Maine Power modeling shows that only one transformer out of 15 in their network would need thermal assessment under the NERC Benchmark GMD Event, but that 8 transformers, or 53%, would need thermal assessment under a 20 V/km benchmark event. ATC modeling shows that 24 out of 62 transformers, or 39%, would need thermal assessment under a 20 V/km benchmark event with a 30 amp "at-risk" threshold.

PJM System

As an example, we show modeling of estimated GIC for transformers during the benchmark solar storm within the PJM system spanning from Illinois to New Jersey. The modeling results below, presented by NERC Standard Drafting Team Chair Frank Koza, show that only two transformers in the PJM system have modeled GIC above the assumed transformer invulnerability of 75 amps.[5] Restated, only two transformers out of approximately 560 extra high voltage transformers within the PJM system would need vulnerability assessment—all other transformers within PJM would be assumed to be immune from GIC during the Benchmark GMD Event.

[4] A third transformer is modeled at over 74 amps per phase, so effectively three of about 560 extra high voltage transformers in the PJM system need formal assessment under the proposed TPL-007-1 standard.
[5] "NERC GMD Reliability Standards," Frank Koza, PJM, Chair of NERC GMD Standard Drafting Team, INL Space Weather Workshop, Idaho Falls, ID, April 8, 2015, accessible at https://secureweb.inl.gov/gmdworkshop/pres/F_Koza_NERCGMDReliabilityStandards.pdf, last accessed July 26, 2015. The Frank Koza presentation is separately filed in this Docket as Resilient Societies' Reference Document No. 4.


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

PJM Preliminary Thermal Assessment Results

- Transformers with the highest GICs (divide by 3 phases; peak electric field in PJM is ~3V/km)

Transformer Description	Area	Avg Neutral Current, pu (3 phase)	Avg Neutral Amps (3 phase)
765/26 #2	AEP	1.147	86.557
765/26 #1	AEP	1.059	79.952
500/22 #1	PJM	0.645	74.491
765/345 #1	AEP	0.919	69.322
765/138 #2	AEP	0.883	66.610
765/500 #1	AEP	0.870	65.680
500/22 #1	DVP	0.565	65.260
345/25 #5	CE	0.388	64.975
500/25 #1	PJM	0.554	63.982
500/22 #1	PJM	0.554	63.982
500/230 #1	DVP	0.539	62.256
500/22 #1	PJM	0.539	62.219
345/138/34.5 # 1	CE	0.369	61.810
765/345/33 #1	CE	0.726	54.762
345/22 #8	DEO&K	0.320	53.517
500/230 #2	DVP	0.443	51.158
500/230 #1	DVP	0.442	51.062
765/345 #3	AEP	0.651	49.102
345/34.5 #1	AEP	0.283	47.431

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Figure 1: Page 19 from presentation titled "NERC GMD Reliability Standards, Frank Koza, PJM, Chair of NERC GMD Standard Drafting Team, INL Space Weather Workshop, Idaho Falls, ID, April 8, 2015."[6]

As might be expected, PJM's modeling result is out of line with other published studies such as the Metatech R-319 study conducted by Oak Ridge National Laboratory and sponsored by FERC. The Metatech study showed approximately 330 transformers at risk, out of approximately 560 transformers in total, within the states of Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, Kentucky, Ohio, and Indiana, and Illinois that roughly overlay the PJM network.[7]

[6] Area abbreviations are as follows: AEP is American Electric Power, DVP is Dominion, CE is ComEd, DEO&K is Duke Energy Ohio and Kentucky. Notably, PSEG, owner of the Salem 1 and 2 nuclear plants with failed transformers during GMD events, is not among PJM "Transformers with the highest GICs" and not above a mandatory transformer Screening Criterion.

[7] PJM transformer at-risk estimates developed from "30 Amp At-Risk Threshold" tables on pages 4-15 and 4-15 of "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Oak Ridge National Laboratory, available at http://web.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-319.pdf, last accessed on July 26, 2015, filed as a reference document on FERC Docket No. RM15-11-000.

Had the NERC Standard Drafting Team collected and analyzed GIC data for transformers within the PJM network, and transformers in other areas of the United States, these data would have shown that the Benchmark GMD Event and its associated scaling factors for latitude and ground models have been set to estimate GIC levels far below real world observations. In fact, the July 30, 2014 analysis of John Kappenman and William Radasky in the NERC standard-setting comment, "Examination of NERC GMD Standards and Validation of Ground Models and Geo-Electric Fields Proposed in this NERC GMD Standard," shows that real world GIC readings are two to five times higher than what the NERC ground model and latitude scaling factors in the Benchmark GMD Event would predict.[8]

Had the NERC Standard Drafting Team collected, analyzed, and disclosed failure data for all transformers within the PJM network, and for transformers in other areas of the United States, these data would have shown that multiple transformer failures have occurred during geomagnetic storms far smaller than the storm of the Benchmark GMD Event. According to NERC's own incident report, the Phase "A" and Phase "C" Generator Step Up (GSU) transformers at the Salem 1 nuclear plant in New Jersey failed during the 13 March 1989 solar storm.[9] The magnitude of the March 1989 storm was about one-quarter of the magnitude of the Benchmark GMD Event and one-fifth the magnitude of the 1-in-100 year event estimated in the Metatech R319 report. Yet these same transformers, modeled by PJM at less than 75 amps during the Benchmark GMD Event, are exempted from mandatory thermal assessment and any consideration of required hardware protection under the NERC-FERC proposed standard. By PJM modeling and NERC standard setting, the Salem 1 nuclear plant transformers have now become invulnerable to solar storms:

[8] Examination of NERC GMD Standards and Validation of Ground Models and Geo-Electric Fields Proposed in this NERC GMD Standard," John Kappenman and William Radasky, Comment in NERC GMD Phase 2 Standard Setting, July 30, 2014.

[9] "March 13, 1989 Geomagnetic Disturbance," North American Electric Reliability Council, July 9, 1990, available at http://www.nerc.com/files/1989-Quebec-Disturbance.pdf, last accessed on July 26, 2015, p. 19.

Figure 2: Melted Windings of Phase 1A Transformer at Salem Nuclear Plant in New Jersey in Aftermath of March 1989 Solar Storm

Source: Photo as displayed on page 2-29 of Metatech-R-319 Report

Central Maine Power

Because the NERC Standard Drafting Team set the Benchmark GMD Event at a fraction of observed data and because the assumed transformer invulnerability or "GIC withstand" is a high 75 amps, one would expect that only a few transformers might need protection under the requirements of the standard in other regions of the U.S. In fact, Central Maine Power (CMP) has modeled their system under the "NERC 1-in-100 year Benchmark" and found only one transformer in their whole network that would need assessment for solar storm vulnerability: the transformer at Chester, Maine.[10]

[10] "2014 Maine GMD/EMP Impacts Assessment, A Report Developed for the Maine Public Utilities Commission," Central Maine Power Co., December 2014, available as a reference document, p. 26.

Effective GIC A/phase for Maine transformers		Degree Amp Max	4.53 V/km NERC 1 in 100 year Benchmark	14 V/km Study team assumed 1 in 50 year event	20 V/km Study team assumed 1 in 100 year event	23.5 V/km Study team assumed 1 in 200 year event	29 V/km Study team assumed 1 in 500 year event
2 winding delta - wye	Chester SVC 18/345 kV	162	76	235	336	395	487
2 winding delta - wye	Yarmouth GSU 22/345 kV #4	144	49	152	217	255	315
2 winding delta - wye	Keene Road GSU 115/345 kV	160	32	98	140	165	204
2 winding Auto Xfmrs	Orrington 345/115 kV #1	64	4	14	20	23	29
2 winding Auto Xfmrs	Orrington 345/115 kV #2	64	4	12	17	20	25
2 winding Auto Xfmrs	South Gorham 345/115 kV #1	60	1	3	5	6	7
2 winding Auto Xfmrs	South Gorham 345/115 kV #2	60	12	36	51	60	74
2 winding Auto Xfmrs	Mason 345/115 kV #1	111	6	20	28	33	41
2 winding Auto Xfmrs	Macguire Road 345/115 #1	30	27	83	120	139	172
2 winding Auto Xfmrs	Keene Road 345/115 kV #1	160	6	18	26	31	38
3 winding Auto xfmrs	Coopers Mill 345/115 kV #3	30	35	109	155	182	225
3 winding Auto xfmrs	Surowiec 345/115 kV #1	38	17	52	75	88	108
3 winding Auto xfmrs	Albion Road 345/115 #1	30	60	186	266	313	386
3 winding Auto xfmrs	Larrabe Rd 345/115 #1	135	48	149	213	250	308

Table 1: Effective GIC in transformers for variations in geoelectric field[11]

For a 20 V/km geoelectric field event in Maine, the CMP modeling shows that 8 transformers, or 53%, would need thermal assessment and potential hardware protection with a 75 amp threshold for thermal assessment. CMP's modeling result is consistent in end result with the Metatech R-319 study sponsored by FERC—the Metatech study also showed that 8 transformers would be "at risk" in Maine, albeit under the "30 Amp At-Risk Threshold" scenario.[12]

Just as we see discordance between modeled GMD impacts within the PJM system and transformer failures in the real world, we see also discrepancies between modeled risk and real-world data in Maine. GMD modeling of the Chester transformer by John Kappenman and

[11] Ibid.

[12] FERC Commissioners should also take into account the total absence of NERC Benchmark GMD Event modeling of a "coastal effect" impacting transformers proximate to saline water bodies. Both the PJM and CMP transmission systems are subject to "coastal effects" that increase quasi-DC currents in coastal zone EHV transformers. See "Coastal Effect" Section of these comments, *infra.*

William Radasky, in their July 30, 2014 comment to NERC, estimates GIC of approximately 300 amps per phase during a severe solar storm of 5,000 nT/minute, four times the GIC that would be estimated using the NERC Benchmark GMD Event.[13]

The table below supplied by Central Maine Power shows real-world impacts within Maine over the past twenty-five years, including numerous equipment trips, which are inconsistent with the modeled result that only one transformer in Maine might need hardware protection. In fact, the disclosure by Central Maine Power shows GIC of up to 58 amps/phase during storms[14] that were a fraction of the GMD Benchmark Event.

[13] **"**Examination of NERC GMD Standards and Validation of Ground Models and Geo-Electric Fields Proposed in this NERC GMD Standard," John Kappenman and William Radasky, Comment in NERC GMD Phase 2 Standard Setting, July 30, 2014.

[14] CENTRAL MAINE POWER COMPANY; SMD ACTIVITY ARCHIVE; August 1991 to Present Dates" as presented to Maine State Legislature Joint Energy and Utilities Committee in March 2013, filed as a reference document on FERC Docket No. RM15-11-000. On June 21, 2001, the Central Maine Power SMD Activity Archive shows GIC of 173.4 amps in the neutral of the Chester, Maine transformer. To get amps per phase, this figure is divided by three for a result of 58 amps per phase.

CENTRAL MAINE POWER COMPANY
SMD ACTIVITY ARCHIVE
August 1991 to Present Date

(Chester SVC SUNBURST equipment in service since March of 91)

Storm Rating (Top 10)	Event Date	Chester SVC Transformer DC Neutral (A)	Storm Severity	Comments
1	**3/13/89**	**N/A**	**Severe**	**Hydro Quebec Blackout – All Orrington caps trip; Yarm 4 and MY gen vars went over +300 MVAR each; Orrington caps would not close back in**
	6/5/91	42.9	Major	Impacts to CMP unknown/not documented
	6/17/91	31.7	Major	Impacts to CMP unknown/not documented
	7/9/91	20.7	Moderate	Impacts to CMP unknown/not documented
	7/13/91	27.4	Moderate	Impacts to CMP unknown/not documented
	10/1/91	27.7	Moderate	Impacts to CMP unknown/not documented
	10/29/91	45	Major	Impacts to CMP unknown/not documented
	11/8/91	47	Major	Impacts to CMP unknown/not documented
	2/3/92	47.5	Major	Impacts to CMP unknown/not documented
	2/8-27/92	51.2	Major	Impacts to CMP unknown/not documented
	5/10/92	50	Major	Impacts to CMP unknown/not documented
	4/5/93	19.9	Moderate	Impacts to CMP unknown/not documented
	9/13/93	26.2	Moderate	Impacts to CMP unknown/not documented
	2/21/94	31	Major	Impacts to CMP unknown/not documented
	4/17/94	18	Moderate	Impacts to CMP unknown/not documented
	5/2/94	33.5	Major	Impacts to CMP unknown/not documented
	8/23/92	33.8	Major	Impacts to CMP unknown/not documented
	2/21/94	31	Major	Impacts to CMP unknown/not documented
	5/1/94	33.5	Major	Impacts to CMP unknown/not documented
	9/8/94	42	Major	Impacts to CMP unknown/not documented
4	**5/4/98**	**74.3**	**Severe**	**2 caps tripped at Orrington; Orrington Bus @ 328kV**
8	**10/22/99**	**61.3**	**Severe**	**NKI**
	1/28/00	-12	Minor	NKI
	2/12/00	-12	Minor	NKI
3	**4/6/00**	**81.7**	**Severe**	**SVC filter banks trip; distribution customers UPS's not functioning properly in North Coastal areas**
	5/24/00	52	Major	NKI
2	**7/15/00**	**-76**	**Severe**	**MS2 declared by ISO; Orrington KC3 trip; 7kV swing on 345kv system; many Auto xfmr LTC operations**
10	8/11/00	42.8	Major	**Surowiec KC2 trip - no apparent reason other than due to GIC**
9	9/17/00	-59.5	Major	NKI
	10/5/00	-28.4	Moderate	NKI
	12/00	N/A	N/A	Entire month of December saw constant minimal activity; nothing greater than 5A neutral peak and 4.1 6th harm peak but activity was present entire month

CENTRAL MAINE POWER COMPANY
SMD ACTIVITY ARCHIVE
August 1991 to Present Date

Chester SVC SUNBURST equipment in service since March of 91)

Storm Rating (Top 10)	Date	Chester SVC Transformer DC Neutral (A)	Storm Severity	Comments
6	**3/30/01**	**76.2**	**Severe**	**MIS G1 trip but think it was due to faulty control board – no other evidence for trip**
	4/11/01	-30.9	Major	NKI
	6/13/01	32.6	Major	May be an anomaly – one time spike with very little activity before or after spike
	6/21/01	173.4 ???	**Severe**	May be an anomaly – one time spike with very little activity before or after spike
	6/25/01	<5		Spike of 6th harm and very little neutral current flowing
	9/30/01	19.3	Moderate	NKI
	10/21/01	-21.5	Moderate	NKI
7	**11/5/01**	**63.6**	**Severe**	NKI
5	**11/24/01**	**89.9**	**Severe**	**Chester SVC filter banks trip**
	4/17-18/02	-15.0	Moderate	NKI
	4/19-20/02	21.1	Moderate	NKI
	9/4/02	17.0	Moderate	NKI
	5/29-30/03	60.6	**Severe**	NKI; 5/29/03; Kp of 8
	10/24 to 11/5/03	-98.0	**Severe**	NKI; 10/29/03 Very large GIC flow but no impacts seen by CMP
	7/24-27/04	52.5	Major	NKI; 7/27/04
	11/7-10/04	-88.0	**Severe**	NKI; 11/9/04
	1/17-22/05	52.2	Major	NKI; 1/21/05
	5/15/05	83.1	**Severe**	NKI
	8/24/05	96.9	**Severe**	Chester SVC Filter banks tripped
	9/11/05	33.4	Major	NKI
	12/14-15/06	37.5	Major	NKI; 12/14/06
	1/11-13/08	12.1	Minor	NKI; 1/11/08 Associated with Kp of 6
	1/17-19/08	39.9	Major	NKI; 1/18/08 Associated with Kp of 6
	3/25-28/08	8.6	Minor	NKI; 3/27/08 Associated with Kp of 6
	4/20 to 5/1/08	14.9	Minor	NKI; 4/20/08 Associated with Kp of 6
	3/31/09	10.5	Minor	
	6/24-25/09	7.1	Minor	NKI; 6/25/09 Associated with Kp of 6
	4/5-7/10	18.6	Moderate	NKI; 4/5/10 Associated with Kp of 6
	6/4/11	5.0	Minor	NKI
	6/5-8/11	9.6	Minor	NKI; 6/8/11 Associated with Kp of 6
	8/5-6/11	11.1	Minor	NKI; 8/5/11 Associated with Kp of 7
	9/9/11	3.7	Minor	NKI; Associated with Kp of 6
	9/26-27/11	24.7	Moderate	NKI; 9/26/11 Associated with Kp of 7
	10/24-25/11	22.1	Moderate	NKI; 10/24/12 Associated with Kp of 6

CENTRAL MAINE POWER COMPANY
SMD ACTIVITY ARCHIVE
August 1991 to Present Date
Chester SVC SUNBURST equipment in service since March of 91)

Storm Rating (Top 10)	Date	Chester SVC Transformer DC Neutral (A)	Event Severity	Comments
	1/24-25/12	7.3	Minor	NKI; 1/25/12 Associated with Kp of 6
	3/7-9/12	13.6	Minor	NKI; 3/9/12 Associated with Kp of 7
	3/12-15/12	5.7	Minor	NKI; 3/12/12 Associated with Kp of 6
	4/23-24/12	6.1	Minor	NKI; 4/23/12 Associated with Kp of 7
	6/16-18/12	20	Moderate	NKI; 6/16/12 Associated with Kp of 6
	7/13-16/12	5.4	Minor	NKI; 7/15/12 Associated with Kp of 6
	9/5/12	3.8		NKI; Associated with Kp of 6
	9/30 to 10/1/12	7.1	Minor	NKI; 10/1/12 Associated with Kp of 7
	10/8-11/12	12.6	Minor	NKI; 10/11/12 Associated with Kp of 6
	10/11/12	12.6	Minor	NKI; Associated with Kp of 6
	10/13/12	2.8		NKI; Associated with Kp of 6
	11/16/12	37.9	Major	NKI; Associated with Kp of 6
	11/14/12	6.3	Minor	NKI; Associated with Kp of 6

- Event Severity class based on Chester SVC SUNBURST 2000 GIC Recording standards/criteria
  - Storm ratings are based on magnitude of both the transformer neutral and 6th harmonic currents as well as the effect the storm had on CMP's system
- N/A – Chester SVC recording instrumentation not installed at this time or data not available
- NKI – No Known Impacts to grid

Table 2: Real-world GMD impacts in Maine over past twenty-five years.

American Transmission Company

American Transmission Company (ATC), a large electric utility that operates high-voltage electric transmission for much of Wisconsin, performed GIC modeling of their system using PowerWorld™ software. Modeling results for a variety of geoelectric field scenarios were presented in February 2013 at a GMD Task Force meeting held by NERC.[15]

Under a "30 amp At-Risk Threshold" and 20 V/km and below geoelectric field scenarios, a large proportion of ATC transformers would need thermal assessment.[16] In fact, 30% of ATC auto-transformers would need thermal assessment. Sixty-seven percent of ATC member Generator Step Up (GSU) transformers would need assessment. In total, of 62 ATC transformers, 24 (39%) would need thermal assessment. Notably, these ATC model results are largely consistent with the Metatech R-319 study sponsored by FERC. The Metatech study showed 27 transformers in Wisconsin would be at risk under a 30 amp threshold, approximately 59% of MVA capacity at the time of the study.

When a less stringent 75 amp threshold is applied to the ATC model results for geoelectric fields 20 V/km and below, the number of transformers needing thermal assessment is far lower—only 19% of ATC transformers would need assessment; 13% of autotransformers and 19% of GSU transformers. And under a 75 amp thermal assessment threshold and 2 V/km geoelectric field scenario (2 V/km geoelectric field would approximate the Benchmark GMD event scaled to Wisconsin), zero transformers in the ATC network would need thermal assessment.

[15] NERC GMD Task Force presentation "Geomagnetically Induced Current (GIC) What ATC is doing about it," excerpted from slide compendium "GMD Task Force Phase 2, Ken Donohoo, Task Force Chairman, In-Person Meeting, February 25-27, 2013, p. 16 of ATC presentation.

[16] The ATC GIC table is presented in "neutral amps" that combine currents from all three phases while the at-risk threshold for a single transformer would be "amps per phase." To make comparisons, the "30 amp At-Risk Threshold" scenario would need to be multiplied by a factor of 3 for a result of 90 amps in the neutral.

Hence, it should not shock FERC Commissioners that, with the NERC proposed hardware protection standard already submitted by NERC and under review by FERC, the owners of the generation facility within the ATC transmission system with the highest projected amps of GIC during a severe GMD event – NextEra Point Beach – opted not to purchase neutral ground blocking equipment or other protective equipment when installing a replacement 345 kV GSU transformer in the Spring of 2015.[17]

[17] The new Siemens GSU transformer at Point Beach was installed without GMD hardware protective equipment during the Spring 2015 maintenance outage. A senior engineer of Next Era Juno Beach was a member of NERC's GMD Task Force and would have known that the NERC-proposed standard would exempt Point Beach from mandatory hardware protections. See "Summary GIC Table for ATC GSU transformers," *infra*, showing the Point Beach GSU transformer as having the highest magnitude modeled GIC for East-West geoelectric fields postulated at either 2400 nT/sec (sic nT/minute) or 4800 nT/sec (sic nT/minute).

Summary GIC table for ATC auto-transformers						
	480 nt/sec storm		2400 nt/sec storm		4800 nt/sec storm	
	2V/km North	1V/km South	10V/km North	6V/km South	20V/km North	12V/km South
345 kV Auto-Transformers	N-S Field	E-W Field	N-S Field	E-W Field	N-S Field	E-W Field
Arcadian 345/138 #1	-0.7	-12.8	-3.3	-64.2	-6.5	-128.4
Arpin 345/138 #1	3.0	-4.2	15.0	-20.8	30.1	-41.6
Arrowhead 230/230 #1	30.9	-7.6	154.3	-38.1	308.7	-76.2
Arrowhead 345/230 #1	31.9	-25.5	159.6	-127.5	319.1	-255.1
Bain 345/138 #4	-2.2	3.1	-10.9	15.4	-21.9	30.7
Bain 345/138 #5	0.0	2.9	-0.1	14.3	-0.2	28.7
Columbia 345/138 #1	3.0	2.6	15.2	12.8	30.4	25.5
Columbia 345/138 #2	9.2	7.7	46.2	38.7	92.3	77.5
Columbia 345/138 #3	3.1	2.6	15.4	12.9	30.7	25.8
Dead River 345/138 #1	8.2	4.6	41.2	23.2	82.3	46.5
Dead River 345/138 #1A	9.8	5.5	48.9	27.6	97.9	55.3
Edgewater 345/138 #1	-0.2	23.3	-1.0	116.6	-2.0	233.3
Edgewater 345/138 #2	-0.2	21.8	-0.9	108.8	-1.8	217.5
Fitzgerald 345/138 #1	5.0	-23.5	-25.0	-117.7	-50.0	-235.4
Forest Junction 345/138 #2	12.8	1.4	64.2	7.1	128.3	14.1
Gardner Park 345/115 #1	-3.2	5.0	-16.2	25.1	-32.4	50.1
Gardner Park 345/115 #2	-3.2	5.0	-16.2	25.1	-32.5	50.3
Granville 345/138 #1	-18.5	1.8	-92.5	9.2	-184.9	18.4
Granville 345/138 #1	6.0	2.2	29.8	11.2	59.5	22.5
Kewaunee 345/138 #1	0.0	3.0	0.0	14.8	0.1	29.7
Kewaunee 345/138 #2	0.0	8.3	0.1	41.7	0.2	83.4
Morgan 345/138 #1	-10.5	12.4	-53.0	61.9	-105.9	123.8
N. Appleton 345/138 #2	5.1	-1.9	25.5	-9.3	51.0	-18.7
N. Appleton 345/138 #3	6.3	-5.8	31.7	-29.2	63.3	-58.4
N. Appleton 345/138 #1	9.4	-0.5	46.8	-2.7	93.6	-5.4
N. Madison 345/138 #1	-3.4	-5.1	-17.2	-25.4	-34.3	-50.8
N. Madison 345/138 #2	-3.4	-5.1	-17.2	-25.5	-34.5	-51.0
Oak Creek North 345/138 #1	-9.7	22.9	-48.6	114.7	-97.3	229.3
Oak Creek North 345/138 #2	-10.8	25.4	-53.8	126.9	-107.7	253.8
Oak Creek North 345/230 #2	-1.5	1.9	-7.4	9.7	-14.7	19.5
Oak Creek North 345/230 #1	-1.1	1.5	-5.7	7.4	-11.3	14.8
Paddock 345/138 #1	-4.6	-13.4	-22.9	-66.8	-45.8	-133.7
Plains 345/138 #1	14.5	-1.4	72.5	-6.9	145.0	-13.9
Racine 345/138 #1	-4.2	3.7	-21.2	18.7	-42.3	37.4
Racine 345/138 #2	-15.9	4.7	-79.5	23.7	-159.1	47.4
Rockdale 345/138 #1	1.7	2.3	8.4	11.3	16.7	22.6
Rockdale 345/138 #2	7.4	10.0	36.9	49.8	73.7	99.5
Rockdale 345/138 #3	5.1	6.8	25.3	34.2	50.6	68.4
Rocky Run 345/115 #1	-1.2	-0.8	-5.9	-4.2	-11.9	-8.4
Rocky Run 345/115 #2	-2.7	-1.9	-13.4	-9.6	-26.9	-19.1
Rocky Run 345/115 #3	-1.7	-1.2	-8.4	-6.0	-16.8	-11.9
Saukville 345/138 #1	17.0	29.6	85.0	148.2	170.0	296.4
South Fond Du Lac 345/138 #1	0.2	0.8	1.2	3.8	2.3	7.6
South Fond Du Lac 345/138 #2	0.2	0.7	1.1	3.7	2.3	7.4
Stone Lake 345/161 #1	-50.7	-22.8	-253.4	-114.0	-506.9	-228.1
W. Middleton/Cardinal 345/138 #1	7.9	-36.2	39.6	-181.0	79.3	-361.9
Werner West 345/138 #1	-28.1	-26.8	-140.7	-134.0	-281.5	-267.9

Summary GIC table for ATC member GSUs						
	480 nt/sec storm		2400 nt/sec storm		4800 nt/sec storm	
	2V/km North	1V/km South	10V/km North	6V/km South	20V/km North	12V/km South
345 kv GSU's	N-S Field	E-W Field	N-S Field	E-W Field	N-S Field	E-W Field
Columbia (WPL) 345/22 #1	49.1	-30.4	245.3	-152.0	490.6	-304.0
Columbia (WPL) 345/22 #1	49.5	-30.7	247.7	-153.5	495.4	-306.9
Cypress 345/35 #1	-19.9	-7.1	-99.5	-35.5	-198.9	-71.0
Edgewater (WPL) 345/22 #1	11.3	18.3	56.4	91.5	112.8	183.1
Edgewater (WPL) 345/22 #1	19.4	31.5	97.1	157.6	194.2	315.3
Gardner Park 345/19 #1	10.2	-20.7	50.9	-103.3	101.9	-206.7
Kewaunee 345/20 #1	19.0	30.8	95.1	154.0	190.2	308.0
Oak Creek North 345/25 #1	6.1	9.8	30.4	48.9	60.8	97.8
Oak Creek North 345/25 #1	6.3	10.2	31.6	50.9	63.2	101.8
Pleasant Prairie 345/24 #1	-12.2	4.2	-60.9	21.1	-121.8	42.2
Pleasant Prairie 345/24 #1	-12.1	4.2	-60.7	21.0	-121.3	42.0
Point Beach 345/19 #1	12.8	36.2	64.1	181.1	128.2	362.2
Point Beach 345/19 #1	14.5	36.4	72.7	182.2	145.4	364.3
SEC 345/18 #1	-19.0	0.3	-94.8	1.7	-189.5	3.3
SEC 345/18 #1	-18.8	0.3	-94.0	1.7	-188.0	3.3

Table 3: GIC values for Auto-Transformers and Generator Step-Up Transformers in the American Transmission Company network

Electric Grid Impacts during GMD Events

Resilient Societies compiled a list of significant electric grid impacts during GMD events. The impacts include transmission substations, HVDC links, and nuclear power plants. All impacts occurred during storms that were a fraction of the magnitude of the Benchmark GMD Event. The impact at the Seabrook nuclear plant in November 1998 was a vibration related event. The impacts were concentrated in areas where the coastal effect enhancement of GMD fields is operative and at higher latitudes. Nonetheless, two impacts occurred at lower geomagnetic latitude—the Contra Costa, California substation transformer failure and tripping of the Blackwater HVDC link.

As part of the standard-setting process, NERC should have requested data on electric grid impacts during solar storms from electric utilities. Had this been done, it would have likely shown that requirements and measures of the standard will not protect against GMD events lower than the Benchmark GMD Event. We ask the Commission to remand the standard for collection of relevant data on grid impacts during GMD events and incorporation of these data into the standard-setting process.

Significant Electric Grid Impacts During Geomagnetic Disturbance Events

Storm Date	Electric Grid Facility	City	State	Impact	Source
03/13/89	Contra Costa Substation	Los Medanos	CA	Transformer failure	IEEE Survey
03/13/89	Maine Yankee Nuclear Plant	Wiscasset	ME	Transformer damage	Resilient Societies
03/13/89	Salem 1 Nuclear Plant	Lower Alloways Creek	NJ	Transformer failure	NERC 3/89 GMD Report
09/19/89	Salem 2 Nuclear Plant	Lower Alloways Creek	NJ	Transformer failure	NERC 3/89 GMD Report
03/24/91	Radisson-Sandy Pond HVDC	Radisson	Quebec	HVDC Trip	L. Bolduc article, 2002
04/29/91	Maine Yankee Nuclear Plant	Wiscasset	ME	Transformer fire	Resilient Societies
05/28/91	Radisson-Sandy Pond HVDC	Radisson	Quebec	HVDC Trip	Boteler, et.al article, 1998
10/27/91	Radisson-Sandy Pond HVDC	Radisson	Quebec	HVDC Trip	ORNL/Sub/90-SQS8
10/28/91	Blackwater HVDC Tie	Clovis	NM	HVDC Trip	ORNL/Sub/90-SQS8
10/28/91	Radisson-Sandy Pond HVDC	Radisson	Quebec	HVDC Trip	Boteler, et.al article, 1998
11/10/98	Seabrook Nuclear Plant	Seabrook	NH	Transformer damage	Pacific NW Lab Report
04/06/00	Chester SVC	Chester	ME	UPS Malfunctions	Central Maine Power
07/15/00	Hope Creek Nuclear Plant	Artificial Island	NJ	Downrating to 55%	NRC Power Reactor Status
11/24/01	Chester SVC	Chester	ME	SVC Trip	Central Maine Power
07/15/12	Seabrook Nuclear Plant	Seabrook	NH	Downrating to 68%	Reuters News Service

Table 4: Select Impacts of GMD on Electric Grid Facilities

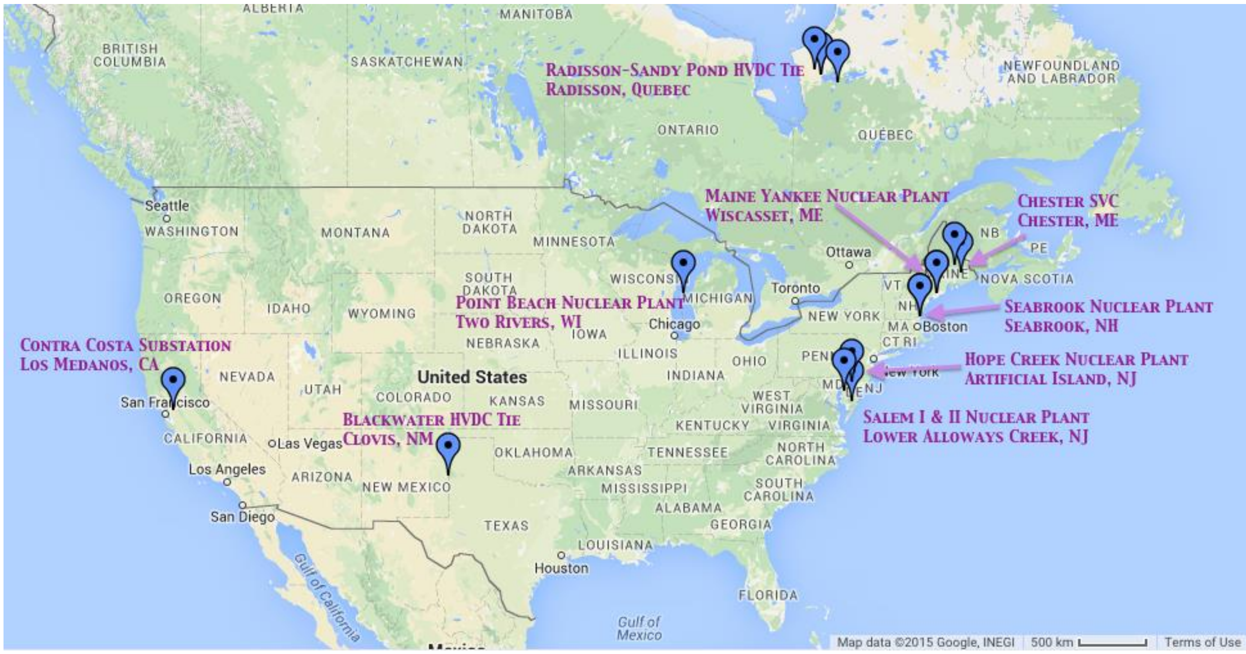

Figure 3: Select Locations of GMD Impacts on Electric Grid Facilities

Defects in Standard TPL-007-1

Technically Unjustified GMD Benchmark Event

In FERC Order 779, (p. 47):

> "71. In drafting the Commission ordered that benchmark GMD events be technically justified because responsible entities should not be required to assess GMD events (or protect against GMD events) "more severe" than the benchmark GMD (i.e., the rate of change in the GMDs magnetic fields), duration, geographic footprint of the GMD, how the GMD's intensity varies with latitude, system configuration, and the orientation of the magnetic fields produced by the GMD."

In FERC Order 779, (p. 2):

> "The Second Stage GMD Reliability Standards must identify "benchmark GMD events" that specify what severity GMD events a responsible entity must assess for potential impacts on the Bulk-Power System. The benchmark GMD events must be technically justified because the benchmark GMD events will define the scope of the Second Stage GMD Reliability Standards (i.e., responsible entities should not be required to assess GMD events more severe than the benchmark GMD events)."

The tolerant wording of this Commission order provided an incentive for NERC and members of the Standard Drafting Team to set a standard with a Benchmark GMD Event low enough for vulnerable transformers to escape mandatory hardware protection. As a regulatory body, it should be the duty of the Commissioners to recognize this end-run around the intent of the Commission and to instead ensure a technically justified Benchmark GMD Event.

Fortunately, the wording of FERC Order 779 (p. 47) provides good detail on the factors to be considered in setting the Benchmark GMD Event, including but not limited to varying severity of the GMD (i.e., the rate of change in the GMDs magnetic fields), duration, geographic footprint of the GMD, how the GMD's intensity varies with latitude, system configuration, and the orientation of the magnetic fields produced by the GMD:

> 102. We recognize that there is currently no consensus on benchmark GMD events, and the Commission does not identify specific benchmark GMD events for NERC to adopt. Instead, this issue should be considered in the NERC standards development process so that any benchmark GMD events proposed by NERC have a strong technical basis.

In our specific comments below, we show how NERC and the Standard Drafting Team have been systematically imprudent in consideration of nearly every important factor, resulting in a Benchmark GMD Event without a "strong technical basis."

Severity of GMD in 1-in-100 Year Reference Storm

In the GMD NOPR (p. 21), the Commission appropriately recognized that geoelectric field values used in assessments should reflect the real-world impact of a GMD event:

> 35. The geoelectric field values used to conduct GMD Vulnerability Assessments and thermal impact assessments should reflect the real-world impact of a GMD event on the Bulk-Power System and its components.

However, in standard setting, NERC and the Standard Drafting Team assiduously avoided collecting and/or analyzing real world data from within the United States and Canada, including magnetometer readings from United States Geological Service (USGS)[18] and Natural Resources Canada observatories;[19] measured and estimated geoelectric field data in published sources;[20]

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[18] Natural Resources Canada has geomagnetic and geoelectric field data available for display and download at http://www.geomag.nrcan.gc.ca/plot-tracee/geo-i-en.php.

[19] USGS has geomagnetic data available for display and download at http://geomag.usgs.gov/products/.

[20] For an example of published work on GMD data and impacts back to 1847, see "The Effects of Geomagnetic Disturbances on Electrical Systems at the Earth's Surface - An Update," Boteler, David, et.al, 37th COSPAR Scientific Assembly. Held 13-20 July 2008, in Montréal, Canada. (2008) p.353.

and measured GIC data from EPRI,[21] government-owned utilities (such as Tennessee Valley Authority (TVA) and Bonneville Power Administration (BPA),[22] and private utilities (such as PSEG, the owner of the Salem 1, Salem 2, and Hope Creek nuclear plants).[23]

The Standard Drafting Team also avoided using real-world GMD impact data from a variety of sources, including published reports, the Licensee Event Report (LER) database available from the U.S. Nuclear Regulatory Commission, and the Generating Availability Data System (GADS) and Transmission Availability Data System (TADS) databases held by NERC itself. NERC contracted with Storm Analysis Consultants, Inc. for production of the report "An Analysis of the Equipment Vulnerability from Severe Solar Storms, Storm-R-112," (August 25, 2011) but this report has apparently been withheld from public disclosure by confidentiality agreement. Had NERC and the Standard Drafting Team collected and analyzed available real-world data, they would have likely found that the severity of GMD in 1-in-100 Year reference storm had been set far below a technically justified level and without "strong technical basis."

The Commission was right to propose in the GMD NOPR (p. 23):

> 38. Next, the record submitted by NERC and other available information manifests a need for more data and certainty in the knowledge and understanding of GMD events and their potential effect on the Bulk-Power System. For example, NERC's proposal is based on data from magnetometers in northern Europe, from a relatively narrow timeframe with relatively low solar activity, and with little or no data on concurrent GIC flows. Similarly, the adjustments for latitude and ground conductivity are based on the limited information currently available, but additional data-gathering is needed. To address this limitation on relevant information, we propose to direct that NERC conduct or oversee additional analysis on these issues.

When a NERC committee of respected space weather scientists estimated a reference storm in February 2013,[24] the "preliminary results" were determined to be a maximum geoelectric field

[21] EPRI has operated its SUNBURST network of GIC monitors since 1991; see "Sunburst Network for Geomagnetic Currents" available at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023278.

[22] Resilient Societies has obtained GIC data from both TVA and BPA using the Freedom of Information Act. BPA currently publishes real-time GIC data on its website at http://transmission.bpa.gov/business/operations/gic/gic.aspx.

[23] Resilient Societies requested GIC data from PSEG in 2011 and this request was declined.

of 30-40 V/km, as this slide from a contemporaneous presentation to the GMD Task Force presentation shows:[25]

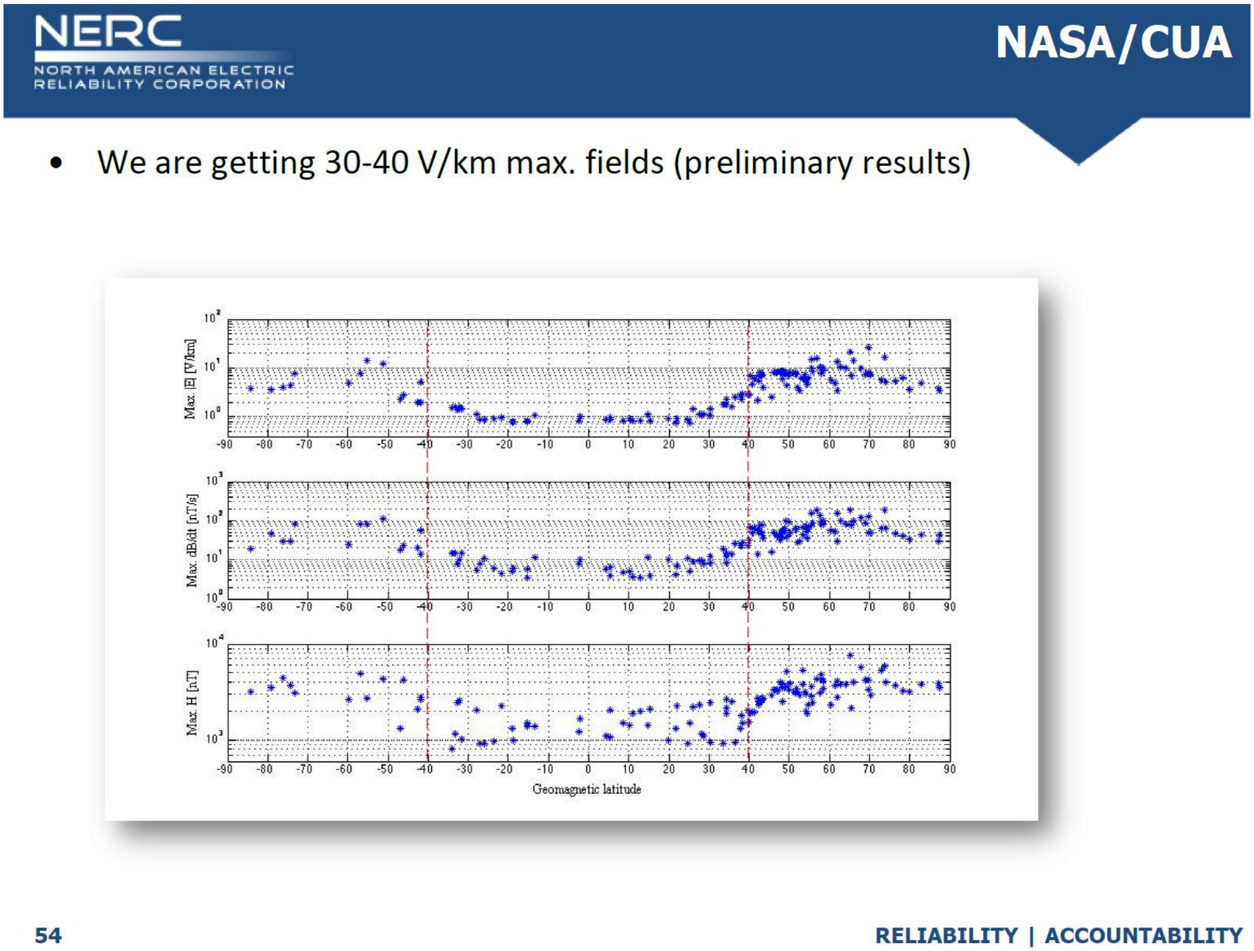

Figure 4: Slides from NERC GMD Task Force presentation

When GMD Task Force Team 3 initiated drafting of the "Application Guide" and gave a contemporaneous presentation in Vancouver in July 2013, the reference geoelectric field had been downwardly adjusted to a range between 5 V/km and 20 V/km. At this point the "Science

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[24] See presentation slides of "GMD Task Force Phase 2 Ken Donohoo, Task Force Chairman, In-Person Meeting, February 25-27, 2013", p. 52 and other relevant material available at http://www.nerc.com/docs/pc/gmdtf/MeetingSlides_25Feb_final.pdf . Space weather scientists on the "Current Science Team" at the time of the 30-40 V/km geoelectric filed estimate included A. Pulkkinen (NASA/CUA), W. Murtagh (NOAA), C. Balch (NOAA), J. Gannon (USGS), D. Boteler (NRCan), R. Pirjola (NRCan), D. Baker (U. of Colorado), and A. Thomson (BGS/EURISGIC).

[25] See "Response to NERC Request for Comments on Geomagnetic Disturbance Planning Application Guide," Resilient Societies, Comments to NERC GMD Task Force, August 9, 2013, filed as a record of standard-setting, p. 65

Working Group" of Team 3 consisted of only two scientist representatives, one from NASA/CUA and another from Oregon State University:[26]

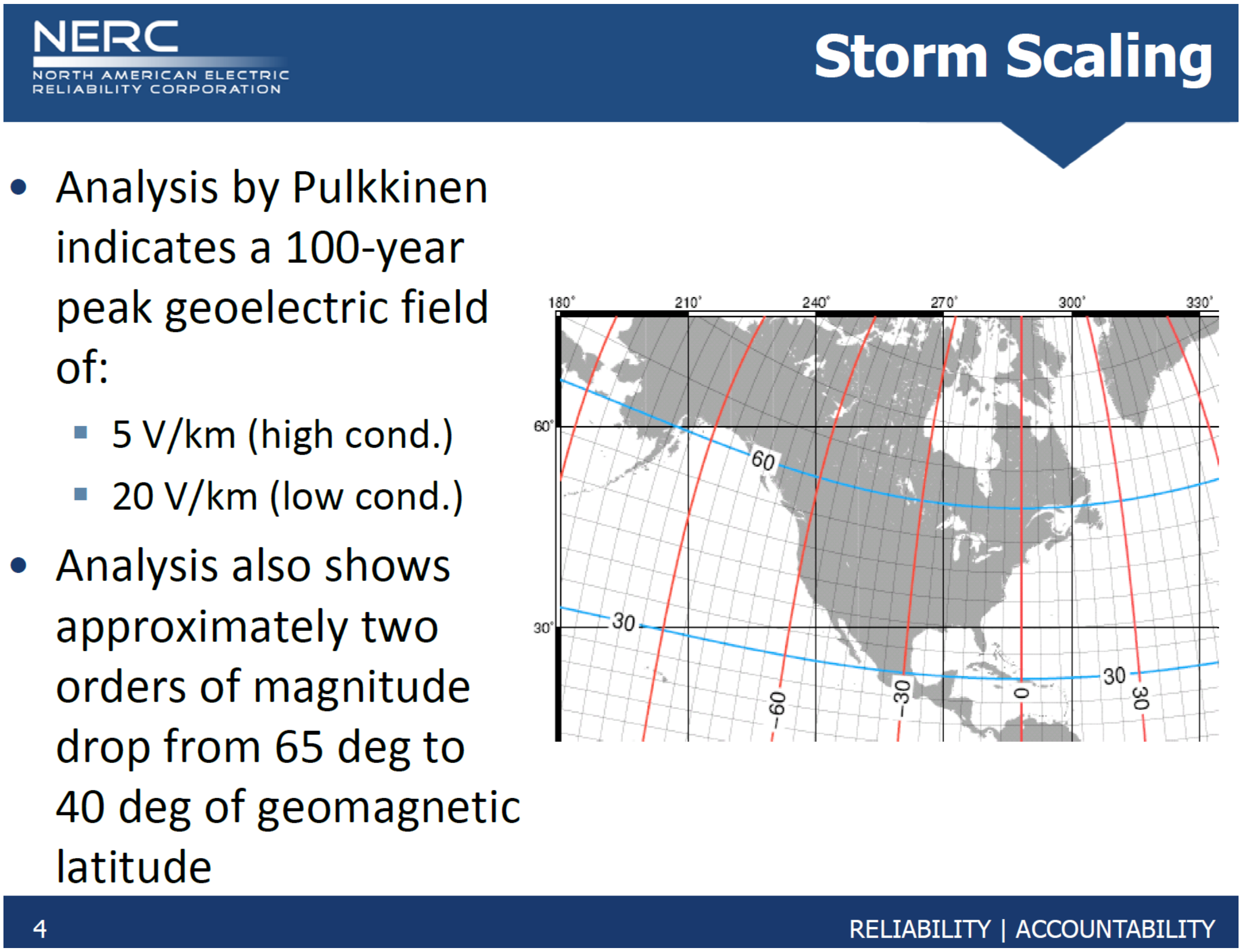

Figure 5: NERC Storm Scaling model slide

By April 2014, the Standard Drafting Team had set an even lower reference storm peak value of 5.77 V/km. approximately one fifth of the lower range preliminary estimate of 30V/km. At this time, only one scientist representative, an employee of the NASA Goddard Space Flight Center, remained on the Standard Drafting Team. The remaining team members were employed by

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[26] See "Team 3 Update, Application Guide Randy Horton, Southern Company, GMD Task Force Meeting, July 25, 2013" in the presentation slides for "GMD Task Force Phase 2, Ken Donohoo, Task Force Chairman, In-person meeting, July 25-26, 2013", available at http://www.nerc.com/comm/PC/Geomagnetic%20Disturbance%20Task%20Force%20GMDTF%202013/presentations_all.pdf , p. 2, p. 4 and other relevant material.

PJM Interconnection, Southern Company, Georgia Transmission Corporation, Dominion Resource Services, NextEra Energy, Hydro One Networks, and American Electric Power.[27]

The apparent preference for a single scientist on the Standard Drafting Team, who might seek to espouse his own published hypotheses on spatial averaging of geoelectric fields, but not necessarily represent a scientific consensus on storm modeling, is not consistent with the "balancing" and "transparency" requirements of the Energy Policy Act and the NERC by-laws. In the aftermath of the October 2003 U.S.-Canadian Blackout, the primary purpose of developing reliability standards under Section 215 of the Federal Power Act is to *improve the reliability of the bulk power system;* this purpose is not achieved by use of unconfirmed scientific hypotheses.

In the final standard, the Standard Drafting Team set the reference peak geoelectric field to 8 V/km, upwardly adjusted from 5.77 V/km by an "implicit safety margin" of 25%. Given the storied history of the severity of GMD in 1-in-100 Year reference storm peak value, FERC was right to address this issue in the GMD NOPR:

> 36. To address this issue, the Commission proposes to direct NERC to develop modifications to the Reliability Standard so that the reference peak geoelectric field amplitude element of the benchmark GMD event definition is not based solely on spatially-averaged data. For example, NERC could satisfy this proposal by revising the Reliability Standard to require applicable entities to conduct GMD Vulnerability Assessments and thermal impact assessments using two different benchmark GMD events: the first benchmark GMD event using the spatially-averaged reference peak geoelectric field value (8 V/km) and the second using the non-spatially averaged peak geoelectric field value found in the GMD Interim Report (20 V/km).

However, it would be a mistake for FERC to determine that applicable entities might conduct two GMD Vulnerability Assessments, one at 8 V/km and another at 20 V/km, relying on the engineering judgment of the entities. Instead, FERC should order GMD Vulnerability

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[27] See "NERC Standard Drafting Team Rosters, May 2014,"available at http://www.nerc.com/pa/Stand/Documents/Standard_Drafting_Team_Rosters_March_2014.pdf , p. 21. The one remaining scientist from outside the electric utility industry espoused modeling based on Finland and other Northern European IMAGE geomagnetic sites; in lieu of modeling of the North American geomagnetic network and with GIC readings from North America. The foreseeable result is a proposal that FERC adopt a standard without a technical basis confirmed by scientific consensus.

Assessments at a single peak value set for technically justified protection of the public from solar storm blackouts. There cannot be two correct reference peak geoelectric field values; if there is doubt, FERC should mandate the higher value with greater safety for the public.

Geographic Footprint and Issue of Spatial Averaging

FERC had appropriate concerns about the use of spatial averaging to set the Benchmark GMD Event, proposing in the GMD NOPR (p. 24):

> 39. In particular, we propose to direct that NERC submit informational filings that address the issues discussed below. In the first informational filing, NERC should submit a work plan indicating how NERC plans to: (1) further analyze the area over which spatial averaging should be calculated for stability studies, including performing sensitivity analyses on squares less than 500 km per side (e.g., 100 km, 200 km); (2) further analyze earth conductivity models by, for example, using metered GIC and magnetometer readings to calculate earth conductivity and using 3-D readings; (3) determine whether new analyses and observations support modifying the use of single station readings around the earth to adjust the spatially averaged benchmark for latitude; and (4) assess how to make GMD data (e.g., GIC monitoring and magnetometer data) available to researchers for study. We propose that NERC submit the work plan within six months of the effective date of a final rule in this proceeding. The work plan submitted by NERC should include a schedule to submit one or more informational filings that apprise the Commission of the results of the four additional study areas as well as any other relevant developments in GMD research. Further, in the submissions, NERC should assess whether the proposed Reliability Standard remains valid in light of new information or whether revisions are appropriate.

The Benchmark Geomagnetic Disturbance (GMD) Event whitepaper authored by the NERC Standard Drafting Team proposed a conjecture that geoelectric field "hotspots" take place within areas of 100-200 kilometers across, but that these hotspots would not have widespread impact on the interconnected transmission system. Accordingly, the Standard Drafting Team averaged geoelectric field intensities downward to obtain a "spatially averaged geoelectric field amplitude" of 5.77 V/km for a 1-in-100 year solar storm. This spatially averaged amplitude was then used for the basis of the "Benchmark GMD Event".

Even the limited amount of publicly available GIC and magnetometer data shows the NERC "hotspot" conjecture is inconsistent with real-world observations and therefore the "Benchmark GMD Event" is not technically justified. Figures A and B below show simultaneous

GIC peaks observed at three transformers up to 580 kilometers apart, an exceedingly improbable event if NERC's "hotspot" conjecture were correct.

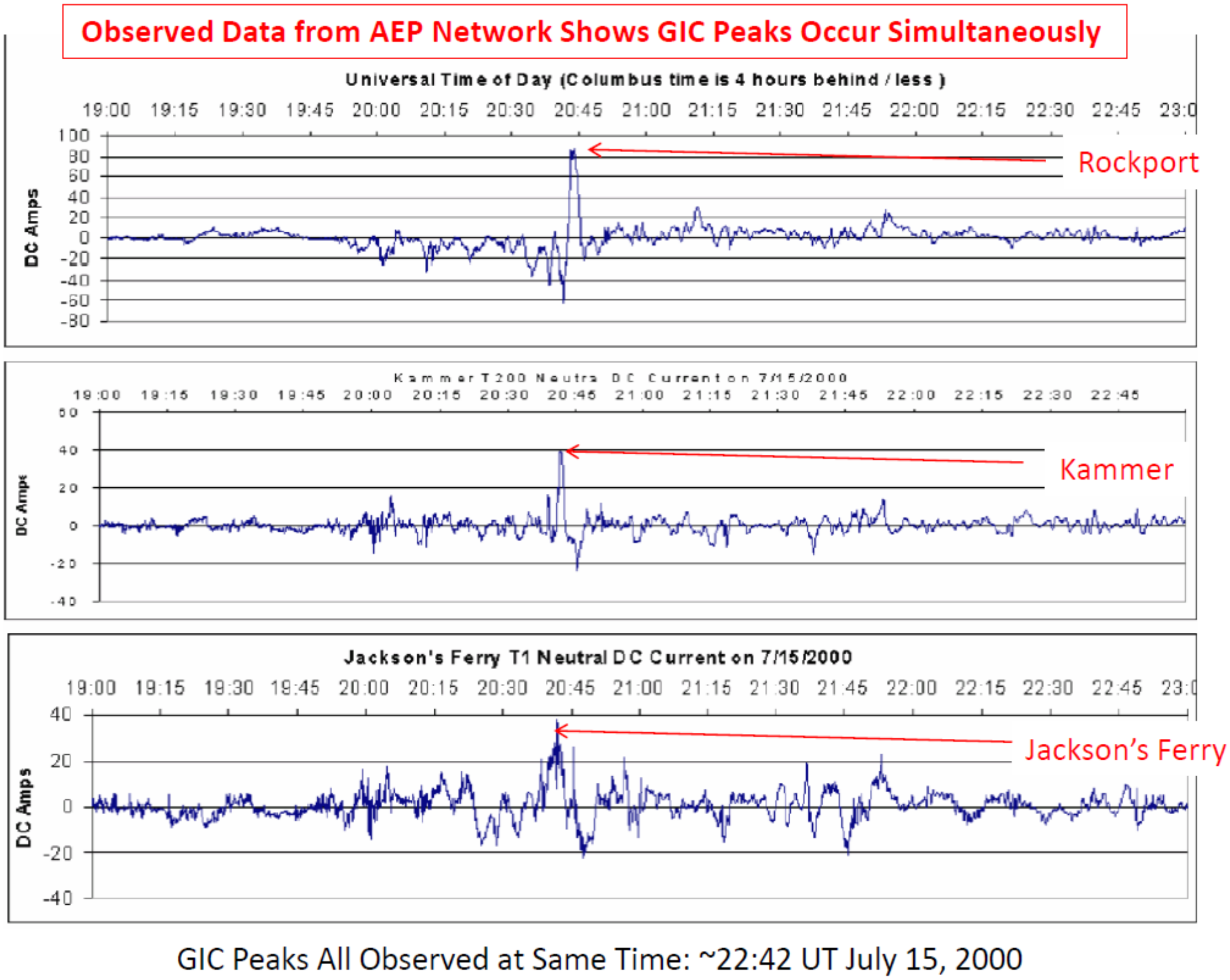


Figure 6: American Electric Power (AEP) Geomagnetically Induced Current Data Presented at February 2013 GMD Task Force Meeting

Locations and Distances for GIC Peaks at Kammer, Jackson's Ferry, and Rockport Transformers

All Peaks Observed Simultaneously at ~22:42 Universal Time on July 15, 2000

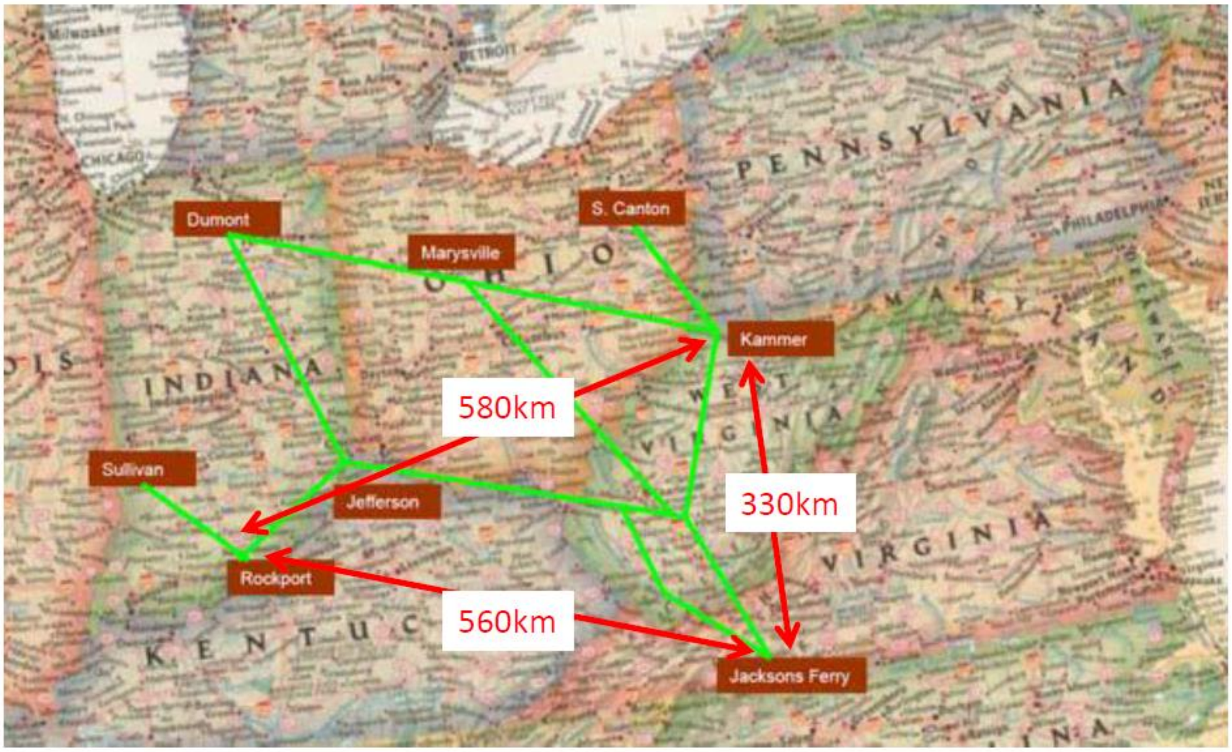
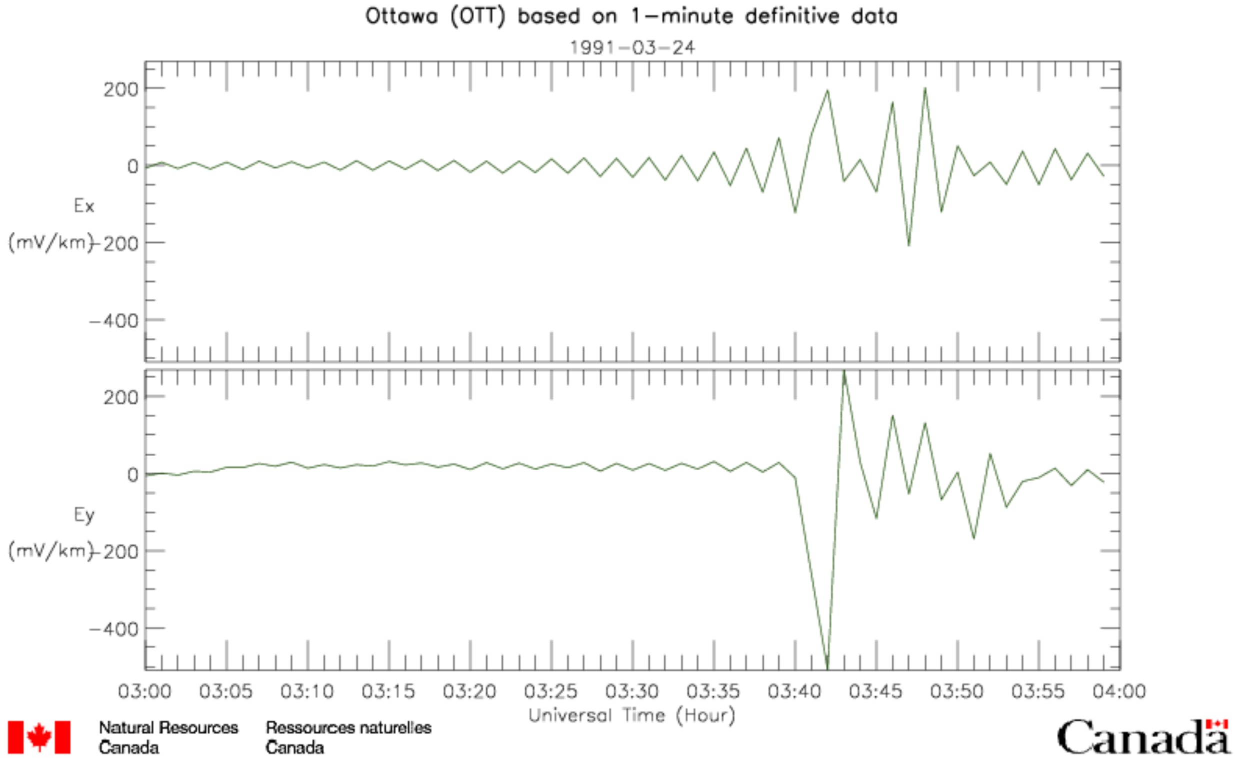


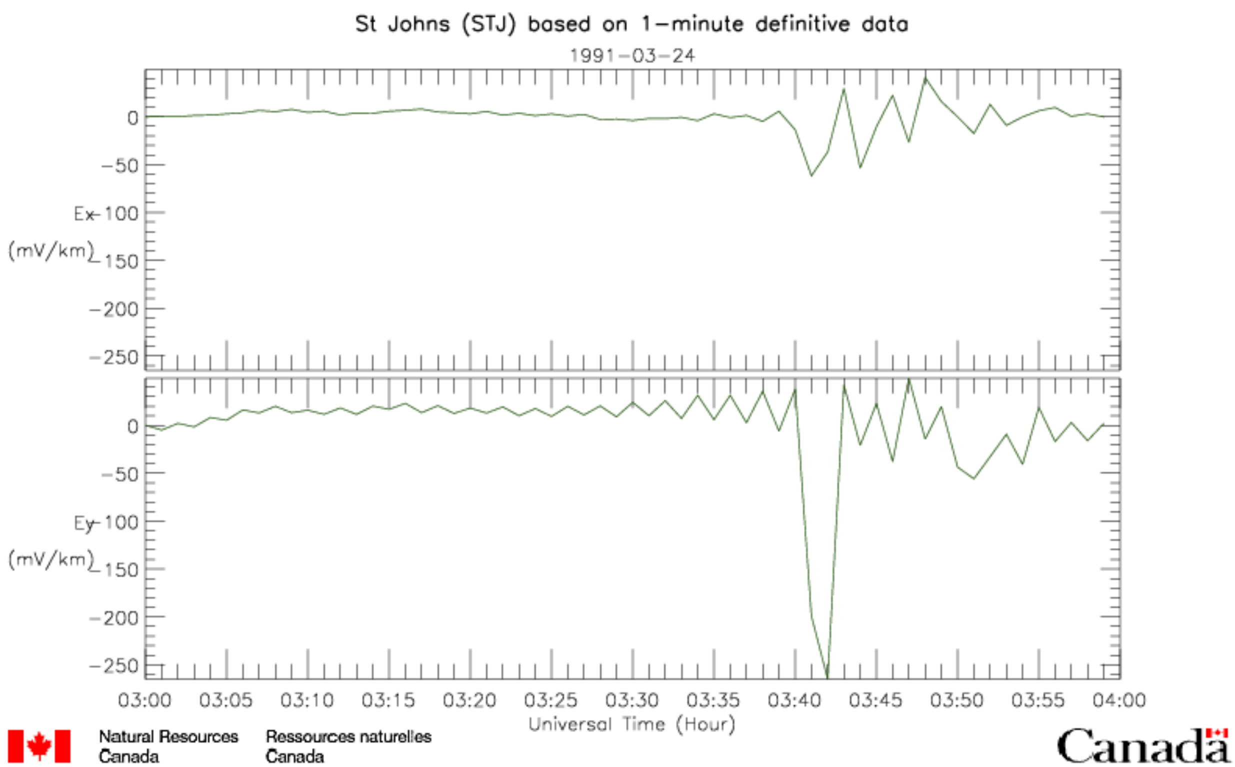
Figure 7: Location of Transformer Substations with GIC Readings on Map of States within AEP Network

According to Faraday's Law of induction, geomagnetically induced current (GIC) is driven by changes in magnetic field intensity (dB/dt) in the upper atmosphere. If dB/dt peaks are observed simultaneously many kilometers apart, then it would follow that GIC peaks in transformers would also occur simultaneously many kilometers apart, affecting reliable operation of the Bulk Power System.

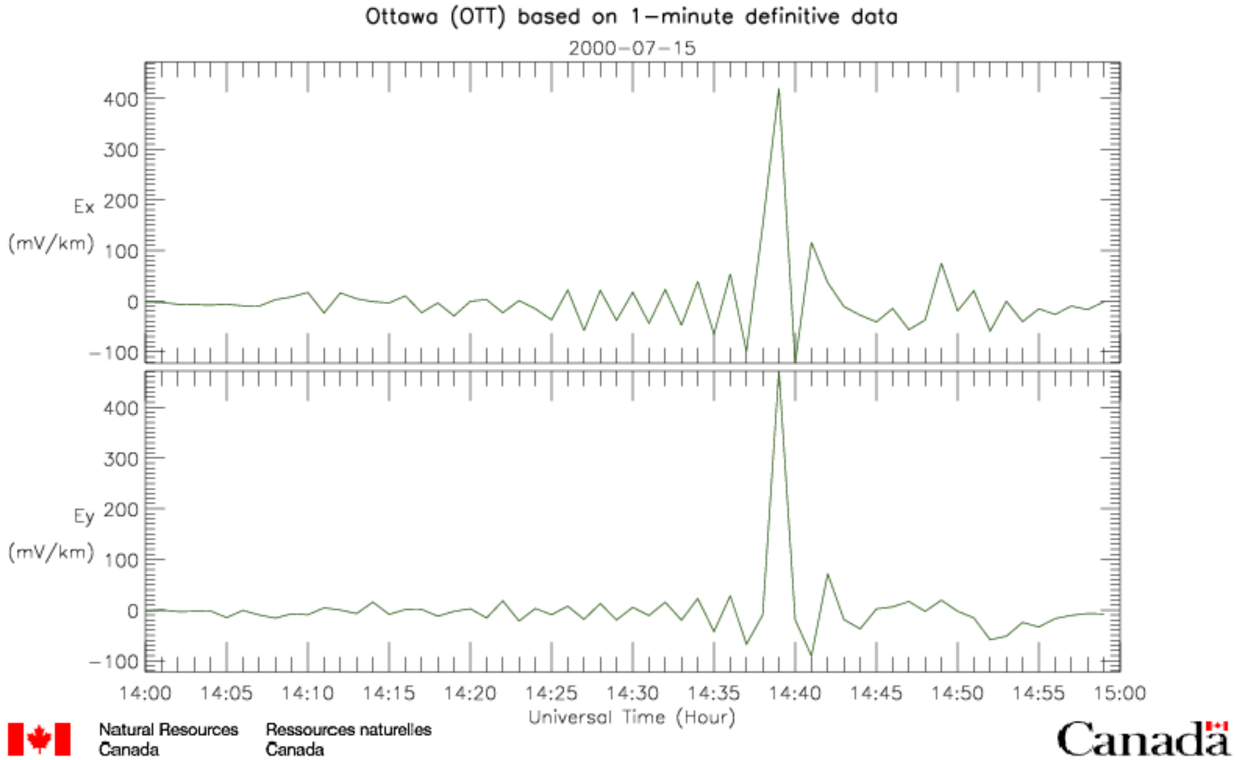
Natural Resources Canada has a plotting service on their website where geoelectric fields for past storms are estimated at Ottawa and St. John observatories using dB/dt readings. Even cursory examinations of past solar storms show that peaks in estimated geoelectric field occur simultaneously at these two observatories 1,760 kilometers apart. Examples are presented below for three significant storms.

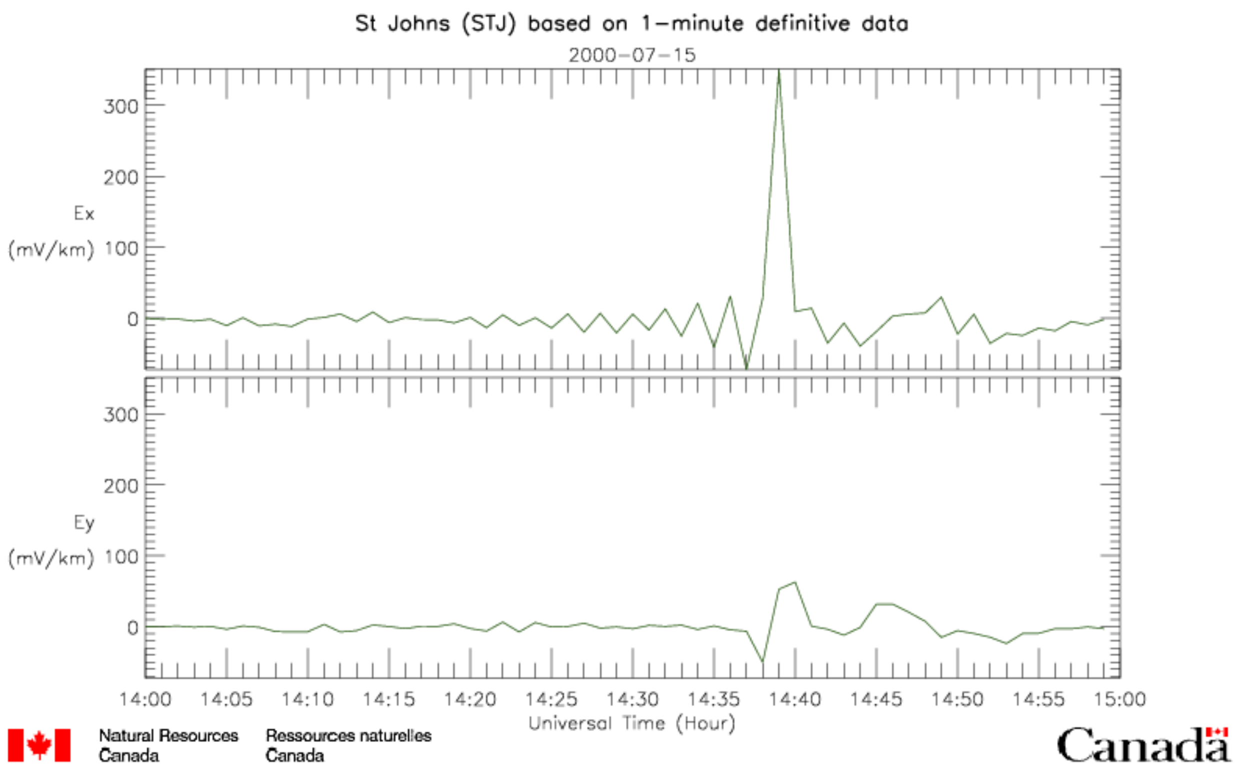
Simultaneous Geoelectric Field Troughs at 03:42 UT on 1991-03-24



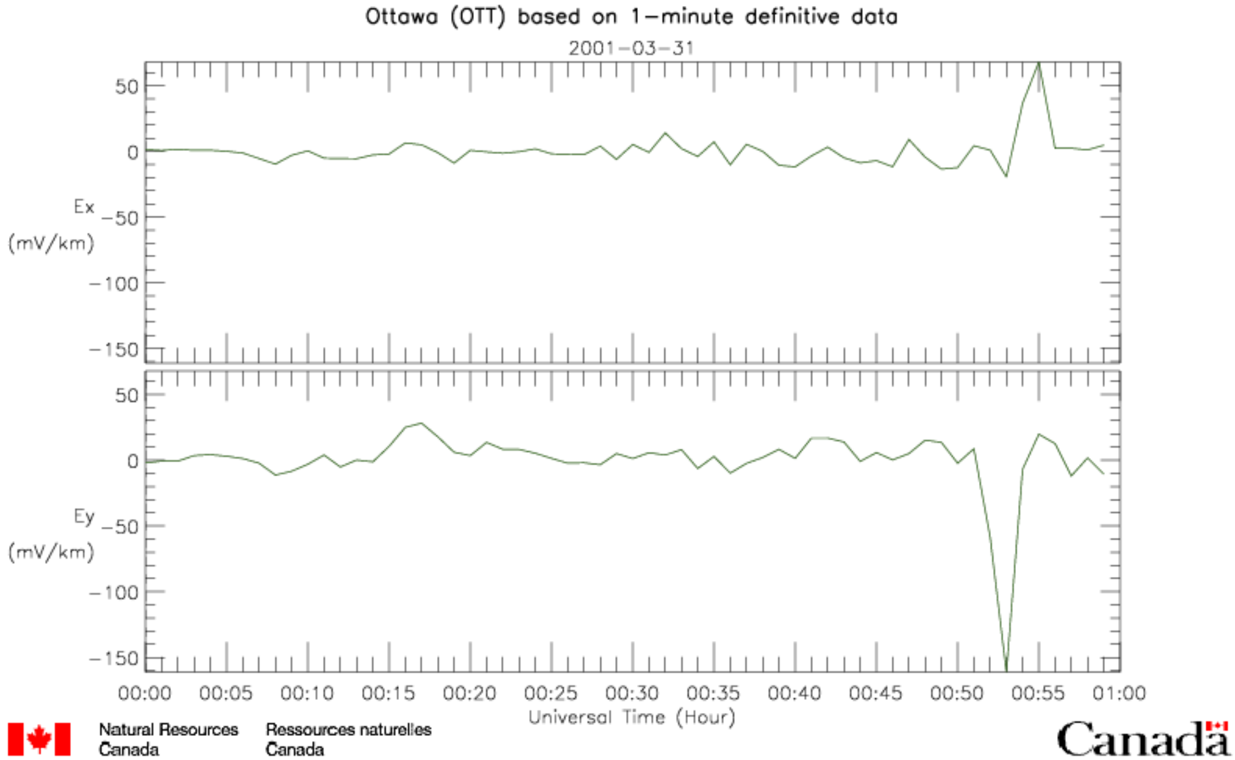


Simultaneous Geoelectric Field Peaks at 14:39 UT on 2000-07-15





Simultaneous Geoelectric Field Troughs at 00:53 UT on 2001-03-31



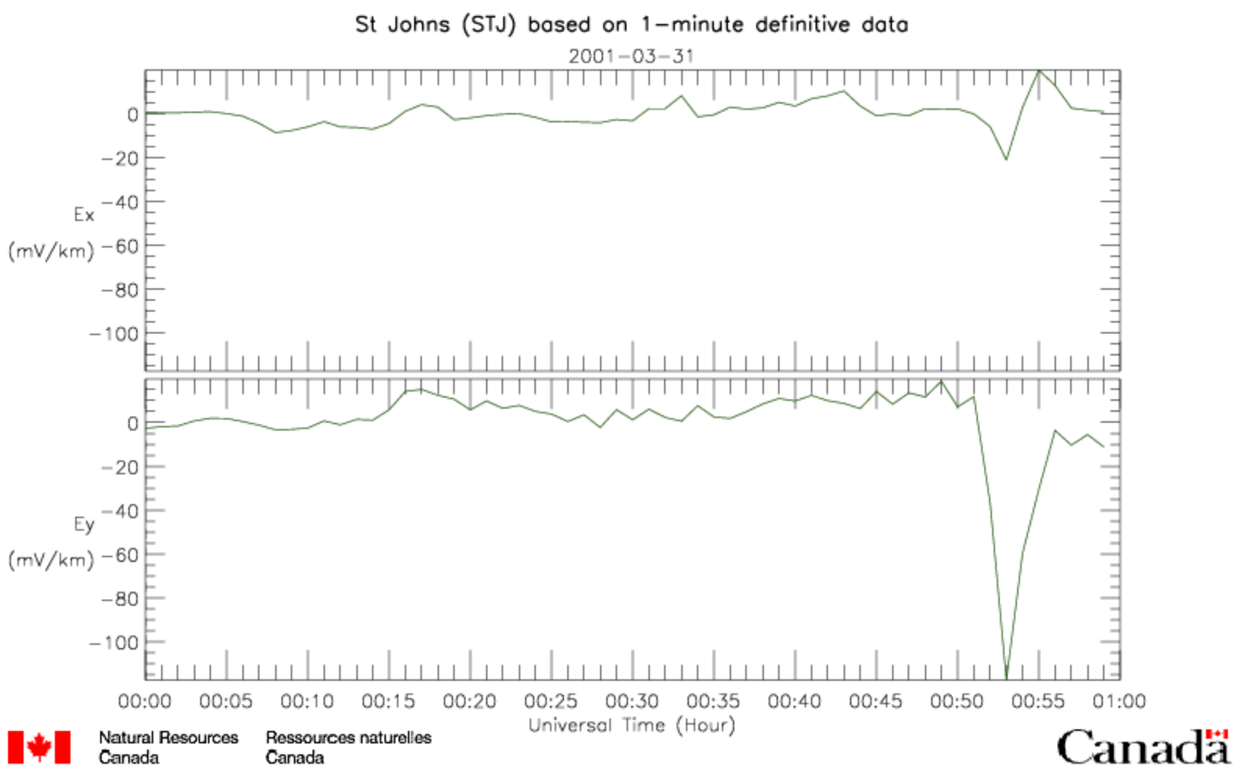


Figure 8: Synchronous Geoelectric field peaks and troughs in distant magnetometers

The weight of real-world evidence even now available shows the NERC "hotspot" conjecture to be erroneous.[28] Simultaneous GMD impacts can and do occur over wide areas. Greater collection and availability of GIC data at a variety of dispersed locations is likely to further confirm the NERC Benchmark GMD Event is technically unjustified and without "strong technical basis."

GMD Intensity and Variance with Geomagnetic Latitude

In the GMD NOPR (p. 23), the Commission appropriately recognized studies indicating that GMD events could have impacts on lower latitudes:

> "37. The Commission also seeks comment from NERC and other interested entities regarding the scaling factor used in the benchmark GMD event definition to account for differences in geomagnetic latitude. Specifically, the Commission seeks comment on whether, in light of studies indicating that GMD events could have pronounced effect on lower geomagnetic latitudes, a modification is warranted to reduce the impact of the scaling factors."

On FERC's own docket for the Stage 1 GMD Standard, there is a description of a transformer failure at a low-latitude location in Contra Costa, California due to GIC:

> It is widely known that the Salem Nuclear plant GSU transformer failure (due to winding heating) was caused by a combination of design of the transformer and its vulnerability to GIC-exposure. This was a Westinghouse manufactured single phase shell-form transformer. However, within the IEEE Survey, one other transformer failure during the March 1989 storm was also declared as being due to GIC. This had not been widely known and was overlooked until a careful review of the data in this survey was assembled in this report. This particular transformer failure was reported as being at the Contra Costa Bank 6 GSU transformer by Pacific Gas and Electric.[29]

Multiple published studies have demonstrated GMD impacts at low latitudes and levels of GIC below the thermal assessment threshold of 75 amps in the standard, including "Transformer failures in regions incorrectly considered to have low GIC-risk," "Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at

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[28] Resilient Societies had not as yet had time to analyze the Kappenman (Storm Analysis Consultants) and Birnbach (Advanced Fusion Systems) forensic review of how the GIC "hotspot" conjecture appeared, was then reformulated, and later surfaced with diminished justification for a new GMD Benchmark Event. The NERC ballot body may not have been fully informed and not enabled to understand before voting upon a standard for hardware protection lacking scientific consensus.

[29] "Comments of the John G. Kappenman, Storm Analysis Consultants," FERC Docket No. RM14-1-000, March 24, 2014.

low-latitude and mid-latitude locations," and "Geomagnetically induced currents in the Southern African electricity transmission network."[30,31,32] In light of this experience and published work, it would be imprudent and without "strong technical basis" for FERC to allow the aggressive geomagnetic latitude scaling factors of the Benchmark GMD Event.

Electric System Boundaries and Coastal Effects

Why does the model for the NERC Benchmark GMD Event systematically under-estimate geoelectric fields (volts per kilometer), or amps per phase, compared to empirical measurements? If a standard-seeking goal is to minimize the facilities and regions of the Bulk Power System that would be responsible to install hardware mitigation, then one tactic would be to eliminate entire classes of risks from benchmark modeling.

A candidate for NERC benchmark modeling that is conspicuously absent in the NERC standard is the coastal effect. The overall result of this purposeful exclusion is to down-rate modeled risks of solar storms in coastal regions of the Continental United States (CONUS) and Canada. Excluding the State of Alaska, fully 39 percent of the U.S. population resides in coastal counties that comprise just 10 percent of the landmass of the CONUS. These coastal counties with extended coastlines account for 48% of the Gross National Product of the United States. So the "coastal zone" is economically important.[33]

And the "coastal effect" or "coastal effects" play a significant risk-elevating role in scientific assessment of GMD vulnerabilities of the Bulk Power System, which has significant numbers of nuclear power plants and large load centers in the coastal zone.

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[30] "Transformer failures in regions incorrectly considered to have low GIC-risk," Gaunt, C.T., and G. Coetzee, Proceedings of Power Tech, July 15, 2007, Lausanne, Switzerland.

[31] "Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at low-latitude and midlatitude locations," John G. Kappenman, Space Weather, Volume 1, Issue 3, December 2003.

[32] "Geomagnetically induced currents in the Southern African electricity transmission network," Koen, J. and Gaunt, T., Power Tech Conference Proceedings, 2003 IEEE Bologna , vol.1, no., pp.7 pp. Vol.1, 23-26 June 2003.

[33] For an overview of the coastal economy, see the NOAA State of the Coast website, found at www.stateofthecoast.noaa.gov/coastal_economy/welcome.html.

Three sets of modeling considerations are intertwined when modeling the "coast effect." These are:

- **Edge effects of electric transmission systems**. Network modeling indicates that GIC tends to enter transmission systems from the edges; hence neutral ground blocking devices can be effective at these locations.
- **Boundary conditions associated with oceanic and land mass interactions**.
- **Higher conductivity of salt water adjacent to electric grid facilities**

The physical principles underlying these three interacting effects are described in published literature but not fully confirmed by empirical measurements. The so-called "coastal effect" was first identified as affecting electric grids nearly ninety years ago in Australia. Four geomagnetic storms recorded at seven separate observatories led to postulation of a "coastal effect" by the year 1926-27.[34] Albert Price advanced physics modeling of geomagnetic induction in 1973.[35] Thereafter, J. L. Gilbert of Metatech published in 1975 a model of interactions of geomagnetic storms at boundaries between oceans and landmasses. Gilbert estimated a coastal effect of about 2X compared to inland geoelectric fields.[36] Boteler and Prijola also published work on oceanic geoelectric fields.[37] Research on transoceanic cable systems modeled the so-called Dirichlet boundary condition, which has the effect of increasing GIC on the land side of various ocean-land boundaries. Some literature indicates that the "coastal effect" differs along different coasts and may relate to deeper subsurface magnetotelluric anomalies.[38]

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[34] Baird, H. F. "A preliminary investigation of some features of four magnetic storms recorded at seven observatories," M. Sc. Thesis, University of New Zealand, Canterbury College, Christchurch, 1927.
[35] Price, A.T., "The Theory of Geomagnetic Induction," T., "The Theory of Geomagnetic Induction," Physics of the earth and Planetary Interiors 7:227-233 (1973).
[36] Gilbert, J.L., "Modeling the effect of the ocean-land interface on induced electric fields during geomagnetic storms," Space Weather 3: S04A03 (1975).
[37] "Magnetic and electric fields produced in the sea during geomagnetic disturbances," Pure Appl. Geophys. 160: 1695-1716. (2003).
[38] See references 3, 4, and 5 in the U.S. Geological Survey submission of July 24, 2015 for additional references on the "coastal effect."

In the past two decades, measurement and modeling of the coastal effect that is also interrelated with end-of-line conditions has led to a broad range of estimates of impact upon the vulnerability of critical electric grid equipment.

At the high end of the range for "coastal effect" is the Atmospheric Environmental Research (AER) modeling performed for Lloyd's, in the context of an extensive electrical equipment claims database for North America that is not publicly accessible. The AER study asserts that the coastal effect increases exponentially near the coast.[39] Since claims data is likely to reflect the interactions of three variables (end of line effects; and ocean-land boundary effects, and ground conductivity), any model developed with the purpose of explaining empirical claims data may overstate the actual "coast effect" component.

More recently, Dr. David Boteler of Natural Resources Canada has participated in two reviews of the "coastal effect." One is a Chapter in a book (2014) under the editorship of Carol Schrijver on geomagnetic effects on the electric grid. This chapter cites a year 1987 study (Wannamaker) that estimates the coastal effect as being about a factor of 7.3X.[40]

In a study commissioned by the Electric Power Research Institute (EPRI), Dr. Boteler concluded in year 2013 that the best estimate for the "coastal effect" was a factor of 4X. Overall, we see estimates for the "coastal effect" and associated end-of-line and electric boundary effects between the range of 2X (Gilbert, 1975) and 7X (Wanamaker, 1987).

Finally, we should bring to the Commission's attention the significance of a careful statistical analysis of the Zurich Re claims database relating to the electric utility industry. This study does not specifically estimate a "coastal effect" but it may help to explain a key finding: unlike the NERC GMD Task Force and Standard Drafting Team, analysts of the Zurich Re insurance claims

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[39] See the Lloyd's-AER Report of June 2013, included as Reference Document No. 11. Sec. 5.3 at p. 10 states: "Coastal regions experience an enhancement in the surface electric field due to the high conductivity of seawater. This can be thought of as the seawater carrying extra charge, and the nearby, grounded, transformers provide a path for the current to flow. The enhancement from the coast effect increases exponentially towards the coast." Some "coastal counties" are shown on Fig. 4, indicating a relative risk factor for high risk counties as more than 1000X times low risk counties. "The regions with the highest risk are along the corridor between Washington, D.C. and New York City. Other high-risk regions are the Midwest and regions along the Gulf Coast." Lloyd's-AER Report at p. 10.

[40] See Reference Document No. No. 9, Dr. Boteler's chapter 4, cites Wannamaker (1987).

database which covers about 8 percent of electric utility insurance in the U.S. find no statistically significant relationship between geographic or geomagnetic latitude and the frequency and amount of insurance claims.[41] This one study casts serious doubt upon the validity of the so-called *Alpha factor* in the NERC Benchmark GMD Event model. Why is there no statistically significant correlation with geomagnetic latitude for the claims database? With a possible coastal effect of 2X to 7X, insurance claims along the Southeast Coast, the Florida Coast, and the Gulf of Mexico could counter or mask a smaller but valid *Alpha Factor.*

For public policy purposes, and for deciding whether to require hardware protective equipment for critical transformers in coastal zones, does it matter if there are three sets of physical principles that are difficult to untangle? If a NERC Benchmark Model exempts most every coastal zone facility, when empirical claims evidence indicates these facilities are at particularly aggravated risk of loss or damage, there may be reasons to require hardware protection, perhaps decades before physicists are able to sort out all the interactions of electric grid behavior in the coastal zone. [42]

Finally, it is notable that most of the transformer failures during moderate solar geomagnetic storms are within the "coastal zone" including: Maine Yankee in Wiscasset, Maine; Seabrook Station along the New Hampshire coast; and Salem-1 and Salem-2 nuclear power plants adjacent to Delaware Bay.

From the evidence adduced, it is apparent that it would be arbitrary and capricious for the Commission to approve the NERC Benchmark GMD Event model and associated standard elements without the consideration of a "coastal effect." Parties located near high-latitude coastal regions, such as Resilient Societies headquartered in New Hampshire and dependent on the Seabrook Station nuclear power plant, would be directly and materially affected by

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[41] See Schrijver, Dobbins, Murtagh, and Petrinec, in Space Weather (2014), Reference Document No. 13.

[42] A complication in this effort relates to the unavailability of some assessments of the "coastal effect" upon the transmission of electric currents from subsurface telecommunications cables that serve national security missions. Some of the best-instrumented ocean-to-land systems are telecommunication systems; these can show the attenuation in volts per kilometer as a cable extended from the near-coast to the interior, away from the coast. It is possible that FERC could seek technical assessment support from NSTAC, a National Telecommunications Advisory system that advises the President on national telecommunications requirements. An NSTAC Report on Telecommunications and Electric Power (2006) is included in Reference Document No. 14 in our filings.

omission of consideration of a coastal effect in the NERC standard and associated Benchmark GMD Event.

Vibration Effects at Lower GIC Thresholds than Thermal Effects

Another category of hazards to critical grid equipment is the effect of vibrations upon high voltage transformers. One aspect of vibration is known as *magnetostriction;* this effect can cause shaking and noise within high voltage transformers. Importantly, the vibrations occur at relatively lower magnitude geomagnetic storms than the magnitudes required to overheat high voltage transformers. Hence, in a severe solar geomagnetic storm, if vibrational effects are not modeled, the model may under-predict the percentage of critical equipment that is damaged or destroyed.

We first discovered an event that involved vibration effects and transformer damage by comparing a database of solar geomagnetic storms with Nuclear Regulatory Commission reports on transformer fires or losses. At Seabrook Station on November 8-9, 1998, there was a solar geomagnetic storm with a North-to-South storm overtaken by a South-to-North storm. These storm interactions can cause a “sudden impulse” even in a storm of moderate magnitude. A stainless steel bolt shook loose into the low voltage winding; and on Nov. 10, 1998, the low voltage windings melted; the transformer was shut down; and Seabrook Station had a 12.2-day outage.

First, Seabrook engineers claimed the damage could not have been caused by a solar storm, because the damage was at the low voltage winding, not the high voltage winding. Pictures of a Salem-1 transformer on March 13, 1989 also indicated the melted windings were at the low voltage end of the transformer. Next, Seabrook engineers claimed the loss was due to a mis-manufactured 4-inch stainless steel bolt. But why did the bolt stay in place for about 3000 days of transformer operation, and only fail during a sudden impulse GMD event?[43] Finally, the NERC

[43] See Harris, “W.R. Seabrook Station Unit 1: Damage to Generator Step-Up Transformer Identified 10 November 1998 Immediately Following Geomagnetic Storm Shocks of November 7-9, 1998,“January 19, 2012, provided to NERC GMD Task Force January 2012, available at http://www.resilientsocieties.org/images/AD12-13-000_Resilient_Societies_Seabrook_Station_GMD_April_25_2012.pdf, last accessed July 27, 2015.

GMD Standard Drafting Team proclaimed this event was merely “anecdotal” as a basis to exclude the entire category of vibration hazards from the NERC Benchmark Model.

Where might non-anecdotal data be found to confirm that vibrational hazards are systematic and widespread during GMD events? The answer: NERC’s own website, where the “March 13, 1989 Geomagnetic Disturbance” report published in 1990 identifies noise or vibration in at least seven separate locations during the 13 March 1989 solar storm.[44] Did NERC ‘s Standard Drafting Team cite their own report in considering vibrational impacts? They did not.

For references to an extensive theoretical and acoustical modeling literature on vibrational impacts on critical equipment, see Resilient Societies Level 1 Appeal documents of Jan 4-5, 2015.[45]

Finally, the GMD Task Force leadership attended experiments at Idaho National Laboratory (INL) in year 2013, together with officials from DTRA DOD and a member of the Resilient Societies’ Board. For a science experiment that was purposeful and non-anecdotal, an INL Team supervised by Scott McBride injected DC power into a 138 kV transformer, and observed the vibration of the transformer; when power was off, the vibrations ceased. Then INL staff attached a neutral ground blocker. When the blocker was turned on, the vibrations ceased; when the neutral ground blocker was turned off, the vibrations returned.

In December 2013, Mr. McBride commented on the recent experiment showing vibration effects on an unprotected transformer, and the protections afforded by neutral blocking devices. Mr. McBride remarked: “Watching a 150,000-pound transformer visibly vibrating and

[44] See 1990 NERC Compilation on March 13, 1989 Geomagnetic Disturbance at p. 57ff: Event 5 Noise SC Edison, Bishop, CA; Event 19, Noise, PJM Calvert Cliffs; Event 66, Noise PJM Calvert Cliffs; Event 77, Noise Portland GE, Oregon; Event 84, Noise PJM Calvert Cliffs; Event 90, Noise SC Edison Mira Loma; Event 105, Noise BPA Rose substation; Event 114, Nose WEP Point Beach, WI.

[45] For multiple references on vibrational models and vibrational impacts, readers should utilize click-through to the NERC Level 1 and Level 2 Appeals files, in Reference Document No. 5, submitted with this Comment filing.

moving along the ground during a simulated solar event (ground-induced current) is a sobering sight."[46]

Altogether, vibrational impacts are important components of GMD hazards to high voltage transformers. The Commission should remand the NERC standard to include, among other considerations, vibrational impacts and options for protective equipment against vibration.

Geomagnetic Field Orientation

The Commission sought comment from NERC in the GMD NOPR on geomagnetic field orientation (p. 27):

> The Commission seeks comment from NERC as to why qualifying transformers are not assessed for thermal impacts using the maximum GIC-producing orientation. NERC should address whether, by not using the maximum GIC-producing orientation, the required thermal impact assessments could underestimate the impact of a benchmark GMD event on a qualifying transformer.

We also wish to comment that GMD Vulnerability Assessments should contain a case for "maximum geomagnetic field orientation" and that any studies of transformer vulnerability, harmonic production, reactive power consumption, voltage collapse, equipment tripping, vibration impact, and other Bulk Power System vulnerabilities should be conducted using amperage from the maximum orientation.

Technically Unjustified Transformer Assessments

Screening Criterion for Transformer Thermal Impact Assessments

The GMD NOPR (p. 25) recites Reliability Standard TPL-007-1, Requirement R6, which proposes that transformers with an effective GIC of less than 75 A per phase during the Benchmark GMD Event would be exempt from thermal screening:

> Proposed Reliability Standard TPL-007-1, Requirement R6 requires owners of transformers that are subject to the proposed Reliability Standard to conduct thermal analyses to determine if the transformers would be able to withstand the thermal effects associated with a benchmark GMD event. NERC states that transformers are exempt

[46] See Keith Arterburn, "Advancing a National Electric Grid Reliability Test Bed," Idaho National Laboratory, at https://inlportal.inl.gov/portal/server.pt/community/newsroom/257/feature_story_deetails/1269?featurestory=DA_607328.

> from the thermal impact assessment requirement if the maximum effective GIC in the transformer is less than 75 A/phase during the benchmark GMD event as determined by an analysis of the system. NERC explains that "based on available power transformer measurement data, transformers with an effective GIC of less than 75 A per phase during the Benchmark GMD Event are unlikely to exceed known temperature limits established by technical organizations.

The 75 amp per phase Screening Criterion for transformer thermal impact assessment is perhaps the most egregious defect in all of Standard TPL-007-1, as this important limit is almost entirely without technical basis. We took the time to carefully review the NERC whitepaper "Screening Criterion for Transformer Thermal Impact Assessment," as well as the key references, and we trust that FERC technical staff will re-review these documents after reading our comment. Here is a partial list of major defects in the Screening Criterion:

1. The Screening Criterion is a mathematically modeled construct without actual testing of any transformers under full load at 75 amps injected direct current.
2. The NERC whitepaper makes the claim near the top of page 4 "The 75 A per phase screening threshold was determined using single-phase transformers, but is applicable to all types of transformer construction." This claim is absurd on its face, even to nontechnical laypeople—it is like an automobile manufacturer conducting crash tests on three models of sedans and then claiming the results can be used to exempt all makes and models from further crash testing.
3. The NERC whitepaper makes the disclosure on the top of page 5 "The screening thermal model is based on laboratory measurements carried out on 500/16.5 kV 400 MVA single-phase Static Var Compensator (SVC) coupling transformer." A "coupling transformer" is used to support reactive power rather than transmit real power and therefore its test results are not applicable, except as a hypothetical construct.
4. On the top of page 5, the NERC whitepaper discloses that "Temperature measurements were carried out at relatively small values of GIC (see Figure 2)." In fact, when the whitepaper references with the more detailed test procedures were checked, we found that the test in Reference 2 was conducted under "no-load conditions" at 5 amps for 2 hours, followed by a maximum of 16.7 amps for only one minute. This unrealistic test

was conducted far below the 75 amp Screening Criterion the standard proposes.[47] Reference 2 for the NERC Screening Criterion whitepaper helpfully discloses the reason more rigorous transformer tests under injected direct current conditions are not performed—"***for fear of damaging the transformer***" (emphasis added).[48]

5. On the top of page 4, the NERC Screening Criterion whitepaper discloses that "Winding hot spots are not the limiting factor in terms of hot spots due to half-cycle saturation, therefore the screening criterion is focused on metallic part hot spots only." In fact, winding hot spots have been the failure mode in several major incidents of transformer GIC damage, the most notable example being the Salem 1 nuclear plant Phase "A" and Phase "C" transformers during the March 1989 solar storm.
6. The NERC Screening Criterion whitepaper does not disclose that second transformer test was conducted essentially under 20% or less load conditions, but this is disclosed in Reference 3.[49]
7. Reference 4 of the NERC Screening Criterion whitepaper is apparently a workshop presentation and is therefore unpublished.[50]

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[47] Reference 2 for the NERC Screening Criterion whitepaper is "Marti, L., Rezaei-Zare, A., Narang, A., "Simulation of Transformer Hotspot Heating due to Geomagnetically Induced Currents," IEEE Transactions on Power Delivery, vol.28, no.1, pp.320-327, Jan. 2013. On page 322 the test procedures are described:
"As another illustration, Fig. 5 shows the measured response obtained during acceptance tests on a single-phase 500/16.5-kV, 400-MVA transformer, which we will call "Transformer B." These measurements were made under no-load conditions at Fig. 4. Asymptotic values of flitch plate hotspot temperature rise versus GIC (Transformer A).Fig. 5. Measured temperature rise in Transformer B (500/16.5 kV, 400 MVA) during dc injection tests. 26 C ambient using sensors placed at several parts of the assembly, including points in the tie plate and at suspected winding hotspots. A dc current of 5 A was injected into the winding for 2 h, followed by a further step increase to 16.7 A for 1 min. The fitted function for the tie-plate hotspot is shown in Fig. 6 for a 5-A step change in current. Since measurement of the response at the 16.7-A level was terminated after just 1min, as required by the specified acceptance tests, no further fitted parameters are available for this unit. In the absence of additional asymptotic temperature information, a simplified straight-line asymptotic behavior with a slope of 15.6/5.0 C/A, has been used for the purpose of illustrating results predicted with our formulation. Unfortunately, there are no winding hotspot measurements available for this unit."

[48] Reference 2 for the NERC Screening Criterion whitepaper helpfully discloses the reason more rigorous transformer tests under injected direct current conditions are not performed (emphasis added): Reference 2, page 325 reads:
"A more difficult issue is that most transformer manufacturers do not routinely perform dc current injection tests; some manufacturers are unable to perform the tests, and asset owners would be reluctant to carry out such tests for the current values needed to fully characterize the asymptotic temperature behavior such as the one shown in Fig. 4 *for fear of damaging the transformer*."

[49] See Lahtinen, Matti. Jarmo Elovaara. "GIC occurrences and GIC test for 400 kV system transformer". IEEE Transactions on Power Delivery, Vol. 17, No. 2. April 2002. Page 560 discloses:
"During the test, the winding temperature did not rise because the phase currents were rather low and were less than 20% of the rated ones."

Given the egregious defect of the 75 amp per phase Screening Criterion for transformer thermal impact assessments, it is helpful for the Commissioners to understand its history. Originally, the Standard Drafting Team set the Screening Criterion at 15 Amps, where it persisted at this level through Draft 1, Draft 2, Draft 3, and Draft 4 used as the basis for three separate ballots. When the standard failed on Ballot 3, the 15 amp Screening Criterion was upwardly reset by a *factor of five* to 75 amps, whereupon the standard handily passed on the next ballot.

The requirements of FERC Order 779 allowed for uniform assessment measures, not uniform measures to exempt transformers from assessment. The Commissioners should remand the 75 amp Screening Criterion for transformer thermal impact assessment.

Transformer Thermal Impact Assessments

With the average age of the extra high voltage transformers in the fleet up to 40 years old, it is not practical or reliable for utilities to perform transformer thermal impact assessments in most cases. Through the GMD Task Force, we have heard that some transformer manufacturers are providing "GIC withstand" warranties for new transformers. The Commission should remand the standard to require "GIC withstand" as a potential mitigation measure only for newly purchased transformers where the transformer manufacturer will warranty the transformer for a specified level of GIC withstand. The allowed GIC withstand amperage in a utility's transformer thermal impact assessment should never exceed the manufacturer's warranty; if the manufacturer will not provide a GIC withstand warranty, no hardware mitigation exception for transformer thermal impact assessment should be permitted under the standard.

Inadequate Protection of BPS Equipment and System Stability

In the GMD NOPR, FERC sought comment from NERC on conditions that could cause load loss due to system instability:

> 56. NERC maintains that Table 1 sets forth requirements for system steady state performance. NERC explains that Requirement R4 and Table 1 "address assessments of

[50] Reference 4 is: "J. Raith, S. Ausserhofer: "GIC Strength verification of Power Transformers in a High Voltage Laboratory", GIC Workshop, Cape Town, April 2014."

> the effects of GICs on other Bulk-Power System equipment, system operations, and system stability, including the loss of devices due to GIC impacts."
>
> Table 1 provides, in relevant part, that load loss and/or curtailment are permissible elements of the steady state:
>
> Load loss as a result of manual or automatic Load shedding (e.g. UVLS) and/or curtailment of Firm Transmission Service may be used to meet BES performance requirements during studied GMD conditions. The likelihood and magnitude of Load loss or curtailment of Firm Transmission Service should be minimized.
>
> **Discussion**
>
> 57. The Commission seeks comment from NERC regarding the provision in Table 1 that "Load loss or curtailment of Firm Transmission Service should be minimized."

FERC was right to solicit comments from NERC, because defects in the standard could cause voltage collapse, High Voltage Direct Current (HVDC) link tripping, protective device tripping, and harmonic production.

Voltage Collapse and Reactive Power Modeling

In FERC Order 779 (p. 11), the Commission recognized that voltage instability and subsequent voltage collapse is one of several GMD scenarios:

> 16. We issue this directive recognizing, as we did in the NOPR, that there is an ongoing debate as to the likely effect of GMDs on the reliable operation of the Bulk Power System. As discussed below, the NOPR comments reflect these differing views, with some comments supporting the *NERC Interim GMD Report's conclusion that the worst-case GMD scenario is "voltage instability and subsequent voltage collapse,"* while other comments endorse the Oak Ridge Study's conclusion that a severe GMD event could put Bulk-Power System transformers at risk for failure or permanent damage.

Ironically, the standard does not require modeling of reactive power consumption and potential voltage collapse. Nonetheless, some network operators have begun to model for this scenario. For example, Bonneville Power Administration (BPA) modeled their network using PowerWorld™ and we were able to obtain the results through a Freedom of Information Act request.[51]

[51] See BPA GMD Impact Assessment, TIP 264 GIC R&D," by Scott Dahman of PowerWorld Corporation for Bonneville Power Administration, September 30, 2013, filed as Resilient Societies' reference document 15 on FERC Docket No. RM15-11-000.

The BPA network model shows that voltage collapse occurs at a geoelectric field of 3.85 V/km:

BPA GMD Impact Assessment
Revised September 30, 2013

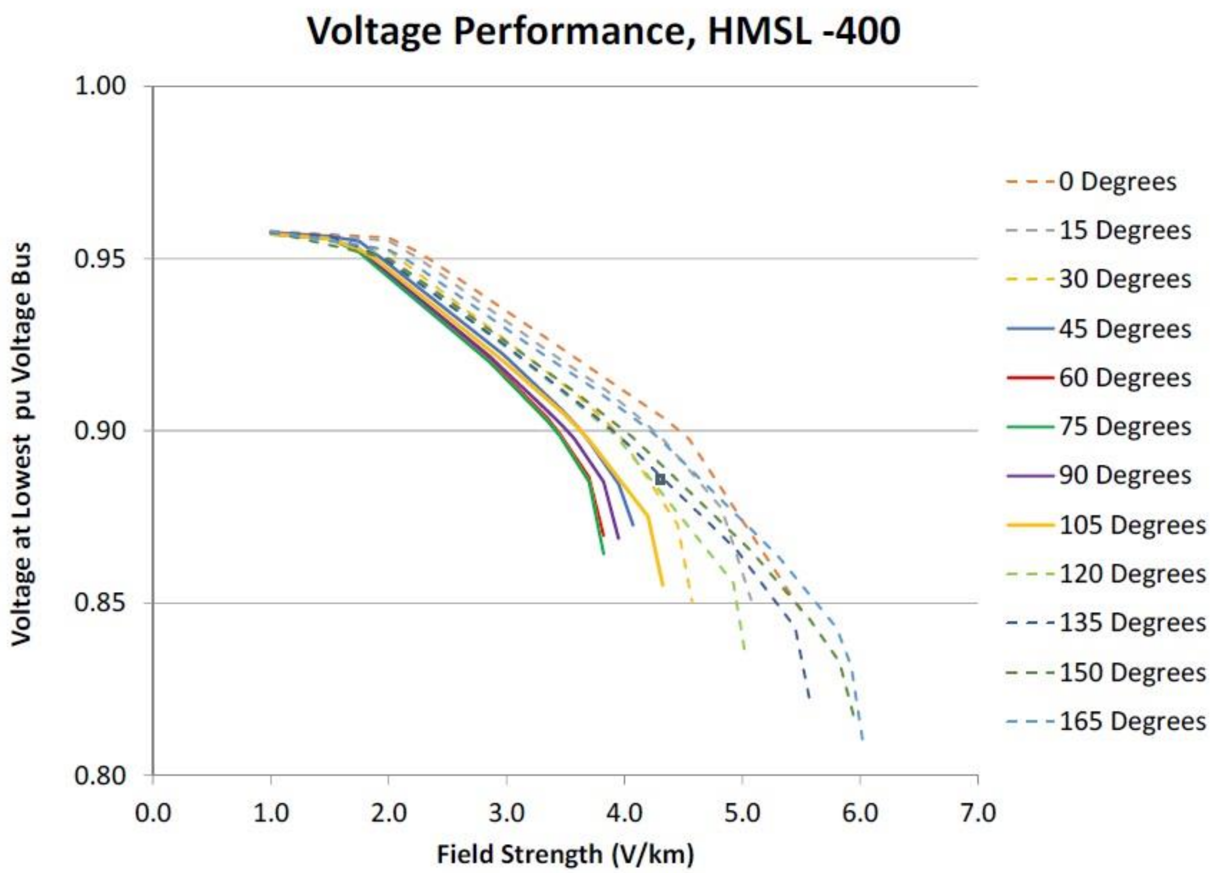

Figure 6

Figure 9: Voltage performance as a function of field strength and latitude

The BPA network is predominantly in the “PB-1 - Pacific Border (Willamette Valley)” physiographic region, with a scaling factor of 0.62 according to the NERC standard. The geomagnetic latitude of Portland, Oregon within the BPA network is 50.98 degrees, with a scaling factor of 0.35. The combined scaling factor is 0.22, resulting in a Benchmark GMD Event of 8 V/km in Quebec scaled down to 1.74 V/km at Portland. According to the BPA model, system voltage would be at approximately 95% at this field strength, within system stability limits.

However, this example also shows the importance of a technically justified Benchmark GMD Event, combined with required modeling for voltage collapse. If the Benchmark GMD Event were set at 20 V/km in Quebec, the scaled geoelectric field at Portland would be 4.36 V/km; voltage collapse would occur under the Benchmark GMD Event.

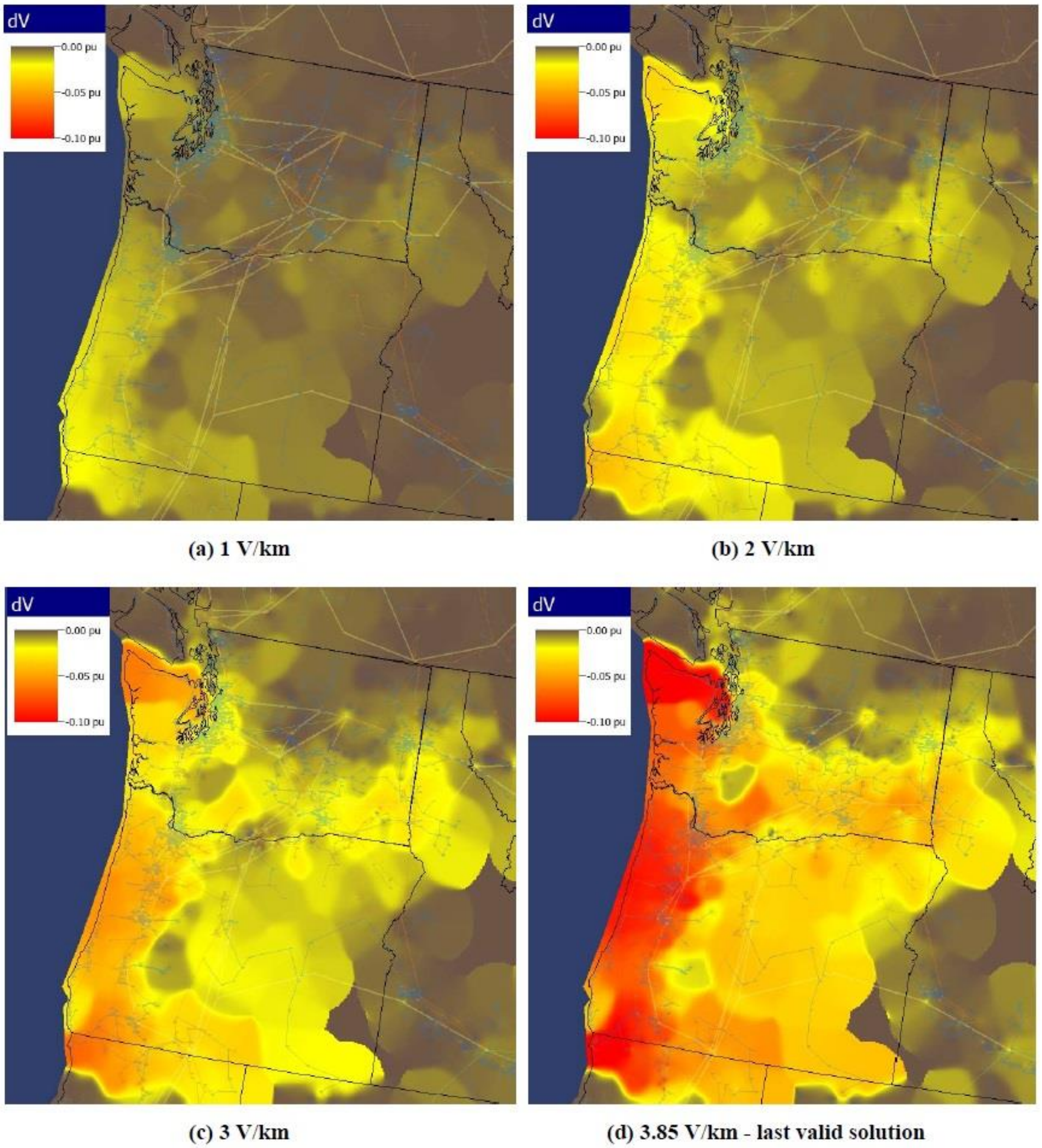

Figure 8 - Voltage Change Contours, HMSL -400, 75 degrees Electric Field Orientation

Figure 10: Voltage Change Contours

HVDC Tripping

Increasingly, High Voltage Direct Current (HVDC) links are transferring both power and potential outage contingencies over long distances and across the boundaries of Reliability Coordinators. Below is a table of HVDC links of capacity 250 MW and above within the United States, both operational and planned:

Major High Voltage Direct Current Ties
250MW and Above within United States

HVDC Link	End 1	Reliability Coordinator End 1	End 2	Reliability Coordinator End 2	Total Length (km)	DC Voltage (kV)	Power (MW)	First Year of Service
Tres Amigas Superstation	Clovis, New Mexico	SPP/ERCOT/Peak	Clovis, New Mexico	SPP/ERCOT/Peak	B-to-B	765	5,000*	2016
Pacific DC Intertie	Celilo, OR	Peak Reliability	Sylmar, CA	Peak Reliability	1,362	500	3,800	1970
Plains & Eastern Clean Line	Texas County, OK	SPP	Shelby County, TN	TVA	1,207	600	3,500	2018
Rock Island Clean Line	O'Brien County, IA	MISO	Grundy County, IL	PJM	805	600	3,500	2017
TransWest Express	Rawlins, WY	Peak Reliability	Las Vegas, NV	Peak Reliability	1,167	600	3,000	2015
Intermountain Power Project	Intermountain, UT	Peak Reliability	Adelanto, CA	Peak Reliability	785	500	2,400	1986
Phase II	Radisson, QC	Hydro Quebec, TE	Ayer, MA	ISO New England	1,480	450	2,000	1991
CU (Great River Energy HVDC)	Underwood, ND	MISO	Rockford, MN	MISO	687	400	1,000	1979
Neptune Cable (Long Island)	Hicksville NY	NY ISO	Sayreville, NJ	PJM	105	500	660	2007
Hudson Tranmission Project	Bergen County, NJ	PJM	New York City	NY ISO	10	180	660	2013
Welch HVDC	Titus County, TX	ERCOT	Mount Pleasant, TX	SPP	10	170	600	1995
Square Butte	Center, ND (Young)	MISO	Adolph, MN	MISO	749	250	500	1977
Trans Bay Cable	Pittsburg, CA	Peak Reliability	San Francisco, CA	Peak Reliability	85	200	400	2010
Cross Sound Cable	New Haven, CT	ISO New England	Shoreham, NY	NY ISO	40	150	330	2002

*Tres Amigas is planned for eventual 30 GW capacity.

Sources: IEEE, ABB, Siemens, Tres Amigas LLC, Wikipedia

Table 5: HVDC Ties

The trend of high capacity, long distance HVDC links is accelerating as more renewable generation is transported long distances for compliance with environmental regulations.

Real-world experience has shown that HVDC links are highly vulnerable to GMD events, because harmonics affect the firing angle of commutators.[52] As the above table shows, HVDC links present large contingencies up to 5,000 MW. It is a fallacy to assume that failures of bi-pole HVDC links will occur independently at different times, allowing contingency planning for

[52] N. Mohan, V. D. Albertson, T. J. Speak, J. G. Kappenman, M. P. Bahrman, "Effects of Geomagnetically-Induced Currents on HVDC Converter Operations," N. Bahrman, IEEE PAS Transactions, Vol. PAS-101, November 1982, pp. 4413-4418.

only half of the capacity. Experience with the Phase II link running from Radisson, Quebec to Sandy Pond, Massachusetts shows that both poles can fail during the same solar storm.

The Phase II link tripped during solar storms on 03/24/91, 05/28/91, 10/27/91, and 10/28/91. According to our calculations using the Standard TPL-007-1 geomagnetic scaling factors and ground model scaling factors, all of these trips occurred during solar storms at 21% or less of the NERC Benchmark GMD Event.

The FERC Commissioners should remand Standard TPL-007-1 for lack of a mandatory requirement for protection of HVDC links against GMD.

Disruptive Harmonic Production

FERC Order 779 (p. 5) recognized disruptive harmonics that can cause sudden collapse of the Bulk Power System.

> GICs can cause “half-cycle saturation” of high-voltage Bulk-Power System transformers, which can lead to increased consumption of reactive power and creation of disruptive harmonics that can cause the sudden collapse of the Bulk-Power System.

NERC’s own report GMD Interim Report in 2012 described the impacts of harmonic production, including tripping of protective devices.[53]

FERC has a legislative mandate in Section 215 of the Federal Power Act to prevent system instability, including sudden collapse. The Commission should remand Standard TPL-007-1 because it does not contain any requirement for mitigation of harmonics that can cause system instability and unanticipated failure of system elements, including HVDC links, as we have shown in this comment.

Exemptions of Networks Operating Below 200 kV

The GMD NOPR (p. 10) recited the exemption of networks with high-side voltages below 200 kV:

[53] 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System,” NERC, February 2012, available at http://www.nerc.com/files/2012GMD.pdf, last accessed on July 26, 2015.

> 13. NERC states that proposed Reliability Standard TPL-007-1 applies to planning coordinators, transmission planners, transmission owners and generation owners who own or whose planning coordinator area or transmission planning area includes a power transformer with a high side, wye-grounded winding connected at 200 kV or higher. NERC explains that the applicability criteria for qualifying transformers in the proposed Reliability Standard is the same as that for the First Stage GMD Reliability Standard in EOP-010-1, which the Commission approved in Order No. 797.

While the FERC-approved Bulk Electric System definition includes transmission at voltages at 100kV and above, and while multiple GMD impacts on Static VAR Compensators and other equipment operating between 100kV and 200kV were reported by electric utilities during the March 1989 solar storm, Standard TPL-007-1 would exempt Transmission Operators with equipment operating between 100 kV and 200 kV. Many Transmission Operators operate Static VAR Compensators, capacitors, and other equipment between 100 kV and 200 kV: equipment designed to provide reactive power and to stabilize transmission networks during GMD. Below is a listing of March 13, 1989 storm impacts on critical equipment operating at less than 200 kV, as disclosed by a FERC-sponsored study:

March 13, 1989 Geomagnetic Disturbance

Chronology of Reported North American Power Grid Events

Adapted from Pages A2-2 to A2-8 of "Geomagnetic Storms and Their Impacts on the U.S. Power Grid"
Oak Ridge National Laboratory, January 2010

Event No.	Date	Time (EST) From	To	Area or System	Event	Base kV	Comments
29	3/13/1989	245		Minn. Power	Capacitor	115	Lost capacitor bank at Nashwauk. Neut overcurrent relay
44	3/13/1989	608		Cent. Hud.	Capacitor	69	Pulvers Corners capacitor trip
47	3/13/1989	615		APS	Capacitor	138	7 Capacitors tripped
54	3/13/1989	618		Va. Pwr.	Capacitor	115	Virginia Beach
57	3/13/1989	619		Cent. Hud.	Capacitor	115	Hurley Ave. capacitor trip
94	3/13/1989	1645	2000	WPL	Voltage	138	Various voltage problems. Regulators hunting
100	3/13/1989	1655		Atl. Elec.	Voltage	69	
108	3/13/1989	1658		BPA	Capacitor	115	Tripped by neutral time ground at 4 substations
175	3/13/1989	2017		NEPOOL	Capacitor	115	Orrington capacitors (1, 2, &3) opened and would not close
183	3/13/1989	2020	2030	Atl. Elec.	Voltage	138	
192	3/13/1989	2032		PJM		69	Nazareth Capacitors tripped

Table 6: Impacts on equipment operating below 200kV during 1989 GMD event

These are real-world and non-trivial GMD impacts during a moderate storm with geoelectric fields of only 2 volts/kilometers in high latitude Quebec.

We researched reactive power support equipment installed in the United States and found three sources: lists of reference accounts published by ABB and Siemens, and individual company disclosures. Notably, there was a high degree of overlap between the three sources. It appears ABB produces the vast majority of SVC/STATCOM for the United States. Based on the ABB sample, we estimate that about 25% of SVC/STATCOM units within the bulk electric system of the United States operate between 100 kV and 200 kV. Reactive power is in particularly short supply during GMD events because transformers in half-cycle saturation consume reactive power. Unexpected tripping of reactive power resources can cause both system separation and cascading system collapse. In fact, the proximate cause of the March 1989 Hydro Quebec blackout, occurring in only 93 seconds, was loss of seven SVC's, all tripping within a 59 second interval.[54]

Below is an example list of reactive power resources within the United States operating between 100 kV and 200 kV, the vast majority installed since 1989:

[54] See S. Renaud and S. Guillon, "Hydro-Québec and GIC: Power Network Studies and Simulation Developments," Presentation of HQ to the JRC Workshop, Ispra, Italy, Oct. 29, 2013, at VG 6, 16, 18 and 24 of 56. See http://ipsc.jrc.ec.europa.eu/fileadmin/repository/sta/SpaceWeatherWorkshop/Session-3_Guillon.pdf.

Examples of Reactive Power Resources 100-200 kV within United States						
Equipment	Utility	Location	Voltage (kV)	First Year of Service	Inductive Rating (MW)	Capacitive Rating (MW)
SVC	AEP	Beaver Creek	138	1978	0	0
SVC	Kansas Gas & Electric	Murray Gill, KS	138	1985	25	200
SVC	Kansas Gas & Electric	Gordon Evans, KS	138	1985	0	300
SVC	Alaska Energy Authority	Soldatna, AK	115	1991	40	70
SVC	Alaska Energy Authority	Daves Creek, AK	115	1991	10	25
SVC	Virginia Power	Colington, VA	115	1996	30	167
STATCOM	COM Central and South West Corp	Eagle Pass HVDC	138	1999	72	72
SVC	Connectiv	Nelson	138	1999	100	150
SVC	ISO Ispat	Ispat	138	1999	0	200
STATCOM	Austin Energy	Holly, USA	138	2003	80	110
SVC	Pacific Gas & Electric	Potero, CA	115	2003	100	240
SVC	Golden Valley Electric Association	Jarvis Creek	138	2004	8	45
SVC	Georgia Power Co	Noth Dublin, GA	115	2005	unknown	unknown
SVC	Duke Power	Beckerdite	100	2006	100	300
SVC	Tucson Electric Power	Tucson, AZ	138	2006	75	200
SVC	Dominion Power	Colington, VA	115	2007	0	0
SVC	Nstar	Barnstable, MA	115	2008	113	225
SVC	Oncor	Renner 1	138	2008	265	300
SVC	Oncor	Parkdale 1	138	2008	265	300
SVC	Oncor	Parkdale 2	138	2008	265	300
SVC	Oncor	Renner 2	138	2009	265	300
SVC	AEP	Hamilton 1	138	2011	25	100
SVC	AEP	Hamilton 2	138	2011	25	100
SVC	Pepco (PHI)	Nelson	135	2011	0	0
SVC	Rochester Gas & Electric	Station 124, NY	115	2011	100	200
SVC	Pepco (PHI)	Ocean City, MD	138	2012	75	75
SVC	Entergy	Porter, TX	138	unknown	unknown	unknown
STATCOM	San Diego G&E	Talega, CA	138	unknown	unknown	unknown
STATCOM	Vermont Electric	Burlington, VT	115	unknown	unknown	unknown
Source: ABB, Siemens, Company Disclosures						

Table 7: List of Reactive Power Resources, 100-200 kV, in United States

In 2013 BPA commissioned a PowerWorld study of vulnerability of its network to GMD.[55] Interestingly, the study concluded that coastal 115 kV networks are especially susceptible to voltage drop.

> **Uniform Field Analysis Conclusions**
>
> The uniform field analysis reveals some vulnerability of the Pacific Northwest power grid due to GIC transformer reactive power losses. *The Olympic peninsula and coastal 115 kV networks are especially susceptible to voltage drop*. The HMSL +550 scenario performs slightly better than the HMSL -400 scenario, likely a result of it having more spinning generator reactive power reserves. GMD electric field orientations of 60-90 degrees pose the greatest threat in both scenarios. The next phase of analysis will examine methods to increase the ability of the network to withstand GMD events.

The arbitrary exemption of networks operating between 100 kV and 200 kV, without any specific study by owners and operators, is technically unreasonable, discriminatory, preferential, and inconsistent with real-world scientific evidence. Critical equipment can operate between these voltages, as the examples for SVCs, STATCOMs, and HVDC links show. Modeling within the BPA system shows that 115 kV networks are vulnerable to GMD. The Commission should remand to eliminate the exemption for networks operating between 100 kV and 200 kV.

Safety Factors and Multiplicative Impacts of Defective Assumptions

FERC Order 779 (p. 43) recited the position of the Electric Infrastructure Security (EIS) Council on safety factors:

> "EIS states that, because the science of GMDs is inexact, an event twice as large as the largest expected GMD should be used as a safety margin."

The Commission was right to recite this comment, because safety factors are commonly used in a variety of engineered structures and products. For example, a safety factor of 2 is commonly used in built structures. Automobiles commonly have a safety factor of 3.[56]

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[55] See "BPA GMD Impact Assessment, TIP 264 GIC R&D," by Scott Dahman of PowerWorld Corporation for Bonneville Power Administration, September 30, 2013, filed as Resilient Societies' reference document 15 on FERC Docket No. RM15-11-000.

[56] See "Factor of Safety," Wikipedia, available at https://en.wikipedia.org/wiki/Factor_of_safety, last accessed 7/25/2015.

However, the “Implicit Safety Margin” in Standard TPL-007-1 is only 1.4 (8 V/km over 5.77 V/km.)

The Commission should recognize that several of the potential defects in Standard TPL-007-1 have multiplicative impact—in other words, biases in the NERC Benchmark GMD Event and transformer thermal Screening Criterion multiply among themselves, producing a level of required protection that may be many times below a prudent and technically justified level.

In the below table, we show a “NERC Scenario” consistent with Standard TPL-007-1 and other reasonable scenarios designated “Middle” and “Conservative,” along with the multiplicative impact of alternative assumptions. Notably, key elements of the other reasonable scenarios are based on preliminary results by scientists on the NERC GMD Task Force or, alternatively, were part of draft versions of Standard TPL-007-1. For example, the GMD Task Force proposed 1-in-100 Year Reference Storm peak geoelectric fields of 20 V/km and 40 V/km in July and February 2013, respectively. As another example, a threshold of 15 amps for the transformer thermal Screening Criterion was embedded in Standard TPL-007-1 for Drafts, 1, 2, 3, and 4.

Multiplicative Impacts of Geomagnetic Disturbance Scenario Assumptions			
NERC Standard vs. Other Reasonable Scenarios at Specific Locations			
Values from References	Scenario		
	NERC Standard	Middle	Conservative
Benchmark GMD Event			
1-in-100 Year Reference Storm	5.77 V/km	20 V/km	40 V/km
NERC "Implicit Safety Margin"	1.4	n/a	n/a
1-in-100 Year Reference Storm with "Safety Margin"	8 V/km	20 V/km	40 V/km
Geomagnetic Latitude Scaling Factor within U.S.	0.1 to 0.5	0.30	0.50
Ground Model Scaling Factor within U.S.	0.22 to 1.17	0.70	1.17
Transformer Assessment			
Thermal Impact Screening Criterion	75 Amps	45 Amps	15 Amps
Multiplicative Impact Ratios	Scenario		
(Ratios: Middle & Conservative to NERC Standard)	NERC Standard	Middle	Conservative
Benchmark GMD Event			
1-in-100 Year Reference Storm (V/km)	1.0	2.5	5.0
Geomagnetic Latitude Scaling within U.S.	1.0	3.0	5.0
Ground Model Scaling Factor within U.S.	1.0	3.2	5.3
Multiplicative Product for Benchmark GMD Event	1.0	23.9	133.0
Transformer Thermal Assessment			
Thermal Impact Screening Criterion (amps)	1.0	3.0	5.0
Overall Safety Factor	1.0	2.0	3.0
Total Multiplicative Products for All Assumptions	1	143	2,000
Notes:			
1. "Middle" and "Conservative" 1-in-100 Year Reference Storm scenarios from work of NERC GMD Task Force.			
2. "Middle" Geomagnetic Scaling Factor is midpoint of NERC Standard's range within U.S. latitudes.			
3. "Conservative" Geomagnetic Scaling Factor is high-point of NERC Standard's range within U.S. latitudes.			
4. "Middle" Ground Model Scaling Factor is midpoint of NERC Standard's range within U.S. latitudes.			
5. "Conservative" Ground Model Scaling Factor is high-point of NERC Standard's range within U.S. latitudes.			
6. "Middle" Thermal Impact Screening Criterion is midpoint of 75 and 15 amps.			
7. "Conservative" Thermal Impact Screening Criterion at 15 amps is NERC Standard value for Ballots 1 and 2.			
8. "Middle" Safety Factor is standard value for built structures.			
9. "Conservative" Safety Factor is standard value for automobiles.			

Table 8: Multiplicative Impacts of GMD Scenario Assumptions

We urge the Commission to understand that fixing just one factor in Standard TPL-007-1, such as the 1-in-100 Year Reference Storm, will not fix all the other defective standards. Importantly, because the various component factors are multiplicative, the overall impact of hazard-reducing sub-models is to drastically reduce the prudence and the realism of the resulting Benchmark GMD Event design and benchmark standard.

We further urge the Commission to add a requirement that utilities annually disclose the number of extra high voltage transformers in their fleet, the number undergoing thermal assessment, the number of transformers determined to need mitigative measures, and the number and categories of mitigative measures among hardware protection, spare units, isolation from service, or other mitigative strategy. If the disclosed number of transformers needing thermal assessment and/or the number of transformers with installed hardware protection or other mitigative measures is trivial, then the Commission will know that the intent of FERC Order 779 for hardware protection is being evaded.

Responses to FERC Solicitation of Comments

GIC Monitoring Devices

GMD NOPR, p. 28:

> 46. The Commission proposes to direct NERC to develop revisions to Reliability Standard TPL-007-1 requiring installation of monitoring equipment (i.e., GIC monitors and magnetometers) to the extent there are any gaps in existing GIC monitoring and magnetometer networks, which will ensure a more complete set of data for planning and operational needs. Alternatively, we seek comment on whether NERC itself should be responsible for installation of any additional, necessary magnetometers while affected entities would be responsible for installation of additional, necessary GIC monitors. As part of NERC's work plan, we propose to direct that NERC identify the number and location of current GIC monitors and magnetometers in the United States to assess whether there are any gaps.

GMD NOPR, p. 29:

> 47. NERC maintains that the installation of monitoring devices could be part of a mitigation strategy. We agree with NERC regarding the importance of GIC and magnetometer data. As the Commission stated in Order No. 779, the tools for assessing GMD vulnerabilities are not fully mature. Data from monitors are needed to validate the

analyses underlying NERC's proposed Reliability Standard and the analyses to be performed by affected entities.

NOPR, p. 30:

> 48. Accordingly, rather than wait to install necessary monitoring devices as part of a corrective action plan, GIC and magnetometer data should be collected by applicable entities at the outset to validate and improve system models and GIC system models, as well as improve situational awareness. To be clear, we are not proposing that every transformer would need its own GIC monitor or that every entity would need its own magnetometer. Instead, we are proposing the installation and collection of data from GIC monitors and magnetometers in enough locations to provide adequate analytical validation and situational awareness. We propose that NERC's work plan use this criterion in assessing the need and locations for GIC monitors and magnetometers.

Geomagnetically-Induced Current (GIC) monitors are commercially available and can be purchased for as little as $10,000 to $15,000 each.[57] Nonetheless, Standard TPL-007-1 has no requirement for GIC monitoring or mandatory sharing of GIC data for scientific study. We agree with the Commission that Standard TPL-007-1 should be remanded for mandatory installation of GIC monitors and magnetometers. Moreover, data from these GIC monitors and magnetometers should be made available to the public to better scientific understanding of GMD effects on the electric grid.

Public Dissemination of GIC Data

In the GMD NOPR (p. 24), the Commission sought comment on barriers to public dissemination of GIC and magnetometer readings:

> The Commission seeks comment on the barriers, if any, to public dissemination of GIC and magnetometer readings, including if the dissemination of such data poses a security risk and if any such data should be treated as Critical Energy Infrastructure Information or otherwise restricted to authorized users.

Resilient Societies supports making GMD data (e.g., GIC monitoring and magnetometer data) available to researchers for study and for publication, peer review, and professional workshop

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[57] See Resilient Societies Findings and Recommendations to the Maine Public Utilities Commission in Maine PUC Docket 2013-00415, October 15, 2013 and December 18, 2013. Costs of commercially available GIC monitoring and automated remote readout have declined from $200,000 per unit to $10,000 to $15,000 per monitoring unit over the past two years. See http://resilientsocieties.org/docketfilings.html, last accessed March 23, 2014.

critique. The Commission should order applicable entities to establish regular procedures for public dissemination of GIC and magnetometer readings. Without disclosure and dissemination of GIC and magnetometer readings, FERC will be enabling an industry-controlled machinery—the NERC reliability-standard-setting process—to generate and perpetuate liability protections without strong technical basis. Concurrently, FERC will aid and abet the protection of electric utility investors while shifting economic losses and societal disruptions from prolonged blackout caused by GMD to all other groups in our society.

The risk of blackout from GMD has been well known since the Hydro Quebec outage in March 1989. However, GIC data has been held as confidential and proprietary by the EPRI SUNBURST consortium and also by individual utilities. This practice has greatly impeded independent scientific study of GMD effects and caused inadequate technical understanding. Non-disclosure of GIC data and GMD impacts further impeded the setting of a technically justified Benchmark GMD Event, a Screening Criterion for transformer thermal assessment, and other necessary requirements and measures in the standard.

There is no security risk to releasing GIC and magnetometer readings. These are indicators of naturally occurring phenomena and their non-disclosure will have absolutely no preventative effect on whether GMD disasters occur or not. Already, GIC data is made available in real time by BPA on their website. TVA has released GIC data under the Freedom of Information Act. On a selected basis, individual private utilities have also released GIC data at the GMD Task Force and other venues. Utilities have disclosed the locations of over 100 GIC monitoring sites.

In order for GIC data to be relevant and actionable for scientific study, it must necessarily include the location of the monitor. Some monitors are located at critical substations and some are located at non-critical substations. As the number of monitors increases and ultimately will number several hundred, the colocation of a GIC monitor will be a very poor indicator of whether a substation is critical or not. Already, there are over 100 GIC monitors installed. Moreover, the location of electric grid substations is not protected information—substation locations are freely available via commercially available databases, including the ubiquitous Google Earth online mapping service.

FERC Order No. 683 clarified the definition of Critical Energy Infrastructure Information (CEII) (pp. 4-5):

> CEII is clarified as specific engineering, vulnerability, or detailed design information about proposed or existing critical infrastructure that: (1) relates details about the production, generation, transportation, transmission, or distribution of energy; (2) could be useful to a person in planning an attack on critical infrastructure; (3) is exempt from mandatory disclosure under the Freedom of Information Act, 5 U.S.C. 552 (2000); and (4) does not simply give the general location of the critical infrastructure. The particular clarifications consist of adding the words “specific engineering, vulnerability, or detailed design” at the Docket No. RM06- 24-000 - 5 - beginning of § 388.113(c)(1) and adding the words “details about” at the beginning of § 388.113(c)(1)(i).
>
> 7. The Commission further clarifies that narratives such as the descriptions of facilities and processes are generally not CEII unless they describe specific engineering and design details of critical infrastructure.

In order for GIC and magnetometer readings to be considered CEII, they must meet all four conditions specified in FERC Order 683. These readings fail on all four conditions:

1. GIC and atmospheric magnetic fields are not usable “energy.”
2. GIC and magnetometer readings would not be useful to persons planning a terrorist attack, because that person could not use real-time or delayed readings to predict GMD events in the future. In fact, public forecasts by the NOAA Space Weather Prediction Center would have more utility for terrorists, but because these forecasts are not restricted as CEII, neither should real-time readings be restricted for security reasons.
3. By releasing GIC readings under the Freedom of Information Act multiple times, the U.S. Government has established that this information is not exempt from mandatory disclosure.
4. Any locational data with GIC and magnetometer readings could simply give the location of the monitor, i.e., latitude and longitude, and need not give any other information about critical infrastructure. FERC Order 683 specifically states that general location is not CEII.

Lastly, it would be unprecedented for a federal agency to restrict public use of information on naturally occurring hazards. There would be public outrage if readings on earthquakes, floods, hurricanes, and the like were restricted and there will be similar outrage if information on solar storm hazards is concealed from the public. Restriction of public dissemination of GIC and magnetometer readings may be in the interest of electric utilities seeking to avoid the installation of hardware protective devices, but it is not in the public interest.

Lowest Common Denominator Standard

FERC Order 672[58] established that a mandatory Reliability Standard should not reflect "the lowest common denominator," and should have no undue effect on competition. Moreover, the Commission established that it will not defer to the ERO with respect to a Reliability Standard's effect on competition. The Commission rejected the notion that an ANSI-certified process automatically satisfies the statutory standard of review for discriminatory impact or negative effect on competition. The relevant paragraphs from Order 672 are quoted below:

> 29. A mandatory Reliability Standard should not reflect the "lowest common denominator" in order to achieve a consensus among participants in the ERO's Reliability Standard development process. Thus, the Commission will carefully review each Reliability Standard submitted and, where appropriate, *remand an inadequate Reliability Standard to ensure that it protects reliability, has no undue adverse effect on competition*, and can be enforced in a clear and even-handed manner. Further, the Final Rule allows the Commission to set a deadline for the ERO to submit a proposed Reliability Standard to the Commission to ensure that the ERO will revise in a timely manner a proposed Reliability Standard that is not acceptable to the Commission. These provisions, as well, will strengthen the ERO and Regional Entities by providing mechanisms to achieve effective and fair Reliability Standards.
>
> 40. The Commission may approve a proposed Reliability Standard (or modification to a Reliability Standard) if it determines that it is just, reasonable, not unduly discriminatory or preferential, and in the public interest. In its review, the Commission will give due weight to the technical expertise of the ERO or a Regional Entity organized on an Interconnection-wide basis with respect to a proposed Reliability Standard to be applicable within that Interconnection. *However, the Commission will not defer to the ERO or a Regional Entity with respect to a Reliability Standard's effect on competition*.

[58] FERC Statutes and Regulations, Rules Concerning Certification of the Electric Reliability Organization; and Procedures for the Establishment, Approval, and Enforcement of Electric Reliability Standards, Order No. 672, February 17, 2006, Docket No. RM05-30-000.

332. *As directed by Section 215 of the FPA, the Commission itself will give special attention to the effect of a proposed Reliability Standard on competition*. The ERO should attempt to develop a proposed Reliability Standard that has no undue negative effect on competition. Among other possible considerations, a proposed Reliability Standard should not unreasonably restrict available transmission capability on the Bulk-Power System.

338. We reject the notion that we should presume that a proposed Reliability Standard developed through an ANSI-certified process automatically satisfies the statutory standard of review. In this regard, *we agree with EEI and others that the development of a Reliability Standard through the ERO's stakeholder process is no guarantee that a proposed Reliability Standard does not have a discriminatory impact or negative effect on competition* even if the proposal meets its technical or operational objective beyond any restriction necessary for reliability and should not limit use of the Bulk-Power System in an unduly preferential manner. It should not create an undue advantage for one competitor over another.

(Italics added.)

Standard TPL-007-1 is a "lowest common denominator" that allows a protection level below the true threat or "technically justified" Benchmark GMD Event. Competitors that contemplate "best practices" above the deficient Benchmark GMD Event may not achieve cost-recovery and will be competitively disadvantaged, therefore establishing an undue effect on competition. The reality is that the "floor" of minimal reliability standards when combined with the promise of liability protection drives out "best practices" in the marketplace for reliability.[59]

The Commission Lacks Authority to Grant Liability Shielding

In FERC Order No. 779, para. 84, the Commission addressed the fears of some industry commentators that the FERC-regulated utilities might be subject to "strict liability" for "failure

[59] On July 21, 2015 at the Electric Infrastructure Security Council Summit VI, FERC Commissioner LaFleur indicated that the minimal standards for "electric reliability" should not preclude both the adoption of "best practices" and eligibility for cost recovery for providing protections above the minimal level required by reliability standards.

To the contrary, at the state level we have witnessed both Public Utility Commission staff in Maine and state legislators question why protective devices should be allowed if they exceed minimal NERC-FERC standards. Moreover, we have witnessed Central Maine Power identify appropriate protective equipment (such as 8 neutral blocking devices), then decline to budget for such equipment upon balloting of the proposed NERC-FERC standard. Further, NextEra Energy subsidiaries at both Point Beach, Wisconsin and Seabrook, New Hampshire have opted not to provide hardware protection for large transformers at high-vulnerability locations: for both the recently installed Point Beach GSU transformer and the soon-to-be installed Seabrook GSU transformer.

to ensure the reliable operation of the Bulk-Power System in the face of a GMD event of unforeseen severity…."

The Commission observes in FERC Order 779 (p. 55):

> 84. The Second Stage GMD Reliability Standards should not impose "strict liability" on responsible entities for failure to ensure the reliable operation of the Bulk-Power System in the face of a GMD event of unforeseen severity, as some commenters fear. The NOPR proposed to require owners and operators to develop and implement a plan so that instability, uncontrolled separation, or cascading failures of the Bulk-Power System, caused by damage to critical or vulnerable Bulk-Power System equipment, or otherwise, will not occur as a result of a GMD. While this language is taken directly from the definition of "reliable operation" in FPA section 215(a)(4), and similar language is found in the Requirements of other Reliability Standards, we clarify that owners and operators should be required to develop and implement a plan to protect against instability, uncontrolled separation, or cascading failures of the Bulk-Power System, caused by damage to critical or vulnerable Bulk-Power System equipment, or otherwise, as a result of a benchmark GMD event. The goal of the NERC standards development process should be to propose Reliability Standards that ensure the reliable operation of the Bulk-Power System in response to identified benchmark GMD events.

FERC Order 779, Para. 85 continues:

> "… Identifying robust and technically justified benchmark GMD events in the Reliability Standards, that the Bulk-Power System is required to withstand (i.e., continue "reliable operation"), addresses the concern that responsible entities might otherwise be required to prevent instability, uncontrolled separation, or cascading failures of the Bulk-Power System when confronted with GMD events of unforeseen severity. In addition, the Reliability Standards should include Requirements whose goal is to prevent instability, uncontrolled separation, or cascading failures of the Bulk-Power System when confronted with a benchmark GMD event. *Given that the scientific understanding of GMDs is still evolving, we recognize that Reliability Standards cannot be expected to protect against all GMD-induced outages*. (Emphasis added.)

Resilient Societies is troubled by FERC's delegation to NERC for selection of the Benchmark GMD Event, combined with the potential for liability relief if that solar storm intensity or duration is exceeded. Resilient Societies agrees that strict liability may not be imposed by courts of competent jurisdiction for unforeseen events. However, multiple blackouts due to GMD events have already occurred, both in North American and Europe, so utilities should be liable for failure to cost-effectively protect against severe GMD. We do not ask for strict liability, but we ask the Commission to clarify its expectation that the FERC jurisdictional entities will be held to account, and be subject to liability in the event of gross negligence or willful misconduct in planning for and mitigating solar geomagnetic storms.

It is troubling that NERC has selected a Benchmark GMD Event that appears to be a roughly one in 20 year or 1 in 25 year moderate level solar storm rather than the 1-in-100 year solar storm that NERC claims to have modeled. Various filings by John Kappenman, a recognized expert in solar storm phenomena, assert that the intensity of the so-called 1 in 100 GMD event in the NERC benchmark model has been exceeded in intensity by several lower intensity GMD events in the past forty years.

The GMD Benchmark Event is apparently designed to exclude the most severe solar storms that would cause prolonged blackouts. What will the Commission do to hold electric utilities financially responsible for potential manipulation of the Benchmark GMD Event? We ask the Commission to recognize that the primary purpose of the Reliability Standard functions of the Commission, established in the aftermath of the U.S.-Canadian Blackout of 2003, was to enhance bulk power system reliability and reduce the likelihood and consequences of large-scale electric blackouts.

The traditional view of the authority of the Commission preceding the Energy Policy Act of 2005 was that the Commission lacked legal authority to grant immunity from liability by setting reliability standards. "Prior to unbundling, retail tariffs were primarily a matter for state regulation, and most states had approved tariff provisions permitting utilities to limit their liability for service interruptions to instances of gross negligence or willful misconduct."[60]

Hence FERC acted as if it "lacks authority to approve liability limitations in RTO [Regional Transmission Organization] tariffs."[61]

It is within the power of the U.S. Congress to set limits on liability by statute. We assert that it would be beyond the power of the Commission to grant a liability shield for the failure, by gross

[60] Quoting Transmission Access Policy Study Group, 225 F.3d 667 at 727-728 (D.C. Cir. 2000).
[61] Ibid., at pp. 728-729.

negligence or willful misconduct, for electric utilities to invest in cost-effective measures to protect the bulk power system from geomagnetic storms that have geoelectric fields in excess of the NERC Benchmark GMD Event, or more extensive duration, or that involve the entirely foreseeable "cannibalizing" or overtaking of one solar storm by another.[62]

We ask the Commission to recognize that arbitrary liability limits above a GMD Benchmark Event, a Screening Criterion for transformer thermal impact, and other exemption avenues may be unsupported by independent scientific investigation. Unwarranted "escape hatches" in the standard that were not developed in conformity with the normal scientific methods cause economic externalities and market failures to invest in greater electric grid reliability.

To offer blanket liability limits does not align with market incentives to prevent harm if liability and accountability persist. In the realm of cybersecurity, there is an important distinction between liability shielding for voluntary reporting of cyber attacks and liability protection for underlying malfeasance in preventing cyber attacks.

As former U.S. Senator Jay Rockefeller observed in a letter on general liability protection for cyber security failures, liability protection "would turn existing market incentives for implementing best practices on their head."[63]

In the market for cyber protection and cyber insurance, the existence of cyber damage liability provides market opportunities for cyber insurance. Thus, the cyber insurance industry has incentives to assist insureds in adopting best practices, and in awarding insurance premium discounts to those entities that adopt best practices. [64]

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[62] FERC has refrained from extending liability protections in Orders No. 693 and No. 890. See also the consideration of liability exclusions, but their ultimate rejection following the "Policy Statement on Matters Related to Bulk Power System Reliability," 69 FR 22502 at 22507 (April 26, 2004).

[63] Letter from Senator Jay Rockefeller, June 3, 2013, cited by U.S. Department of Commerce.

[64] In a recent July 2015 report by Lloyds, the Business Blackout Report, provided as Reference Document No. 12 in Resilient Societies' filing in Docket RM15-11-000, the financial consequences of an extended power outage may exceed $1 trillion dollars for a 30 day blackout in the United States. A solar geomagnetic storm can have comparable economic damage and loss of life. See ongoing economic modeling by Jon D. Bate, a Resilient Societies' Intern in Appendix 1.

Some have proposed that the Commission limit the liability of Regional Transmission Organizations.[65] We strongly disagree. In particular, Resilient Societies finds it particularly troubling that the PJM Interconnection, Inc. (an RTO with sophisticated market mechanisms and planning capabilities) has, via its participation in the NERC Standard Drafting Team, promoted a Benchmark GMD Event and Screening Criterion for transformer thermal assessment that exempts consideration of hardware protection for transformers at nuclear power plants that have already failed during GMD events far smaller than the benchmark event. Of particular concern are nuclear power plants built upon the artificial island adjacent to coastal waters of Delaware Bay: Salem-1, Salem-2, and Hope Creek; and the nuclear power plants at Limerick (1 and 2) that experience saline boundary conditions during high tides, and that have apparently required down-rating of power generation during solar GMD events.[66]

If the NERC Benchmark GMD Event and Screening Criterion for transformer thermal assessment are suspect, or unscientific, or anti-scientific, at least the continuation of liability exposure can be a counterforce for prudence over the long run.

Were the Commission to assert that it has authority, without a future Act of Congress, to grant liability shielding for foreseeable harm from GMD events above the NERC GMD Benchmark Event, Resilient Societies would oppose such Commission action. We would claim that the Commission would be assuming *ultra* vires authority, and in the process placing the security of critical infrastructures at risk.

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[65] See e.g., Pierce, "Regional Transmission Organizations: Federal Limitations Needed for Tort Liability," 23 Energy L. J. 63-80 (2002).

[66] In a presentation at a GMD Workshop at Idaho National Laboratory on April 7-8, 2015, the Chairman of the Standard Drafting Team of NERC, Mr. Frank Koza, presented an ordered list of extra high voltage transformers that would require hardware protection assessment (2 EHV transformers in the AEP system above 75 amps per phase); and a ranked list of others that do not require assessment. Exempted from these dubious screening criteria for transformer thermal assessment are the transformers at the PSEG Salem nuclear plants that have already failed during solar storms. The Koza presentation on April 8, 2015 is included in Resilient Societies' Reference Documents as Ref Doc. No. 4 in this Docket.

Economic Externalities in Solar Storm Protective Measures

A 2012 study by the North American Electric Reliability Corporation (NERC) hypothesized that the most likely severe GMD scenario would be system collapse due to voltage instability, with restoration times “a matter of hours to days,” if replacement transformers were readily available or unnecessary in most cases.[67] An alternative report commissioned by Oak Ridge National Laboratory and sponsored by the U.S. Department of Energy, U.S. Department of Homeland Security, and Federal Energy Regulatory Commission concluded the most likely scenario is long-term outage due to extra high voltage transformer damage, with outage periods of months to years.

Since private utility companies do not bear the full risk-adjusted societal cost of an outage, but only their own risk-adjusted costs, utilities have lower economic incentive to protect against GMD events—absent subsidy in the form of cost recovery for protective devices, strict regulatory standards, and/or legal liability via negligence claims. In contrast, society as a whole has significant economic incentive to protect against even short-term blackouts of “hours or days.”

Protecting the bulk power grid against a severe GMD event creates a positive externality that benefits our electricity-dependent society in the form of avoided power outage costs. Since private utilities do not currently have sufficient incentive to invest in the socially optimal level of grid protection, the gap in protection requires government action in the form of subsidy (cost recovery for protective equipment), regulation, and/or establishment of legal liability for negligence. For more details, including summary results of an economic model confirming these conclusions, please see the draft paper, “Preliminary Economic Analysis of Electric Grid Protection Against Geomagnetic Disturbance (GMD) Events” in Appendix 1 of this comment.

[67] 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System,” NERC, February 2012, available at https://www.frcc.com/Public%20Awareness/Lists/Announcements/Attachments/105/GMD%20Interim%20Report.pdf, last accessed on July 27, 2015.

Unperformed "Initial Actions" Assessments

In FERC Order 779, the Commission ordered "Initial Actions" assessments to be performed by NERC, at NERC's own suggestion. These assessments are to be completed by the effective date of the standard. To the best of our knowledge, none of these assessments has been initiated at this late date. We encourage the Commission to remind NERC of its obligations under FERC Order 779 (p. 36):

> **Commission Determination**
>
> 51. The Commission accepts the proposal in NERC's May 21, 2012 post-Technical Conference comments and directs NERC to "identify facilities most at-risk from severe geomagnetic disturbance" and "conduct wide-area geomagnetic disturbance vulnerability assessment" as well as give special attention to those Bulk-Power System facilities that provide service to critical and priority loads. As noted in NERC's comments, owners and operators of the Bulk-Power System, as opposed to NERC, will perform the assessments and special attention will be given to evaluating critical transformers (e.g., step-up transformers at large generating facilities).82 We agree with the Trade Associations that system-wide assessments could be conducted by planning authorities, or another functional entity with a wide-area perspective, in coordination with owners and operators of the Bulk-Power System. 83 NERC should oversee these efforts and provide responsible entities with a methodology for identifying "at-risk" Bulk-Power System components and "critical and priority loads" that need to be analyzed in the "Initial Actions.

FERC Order 779, p. 37:

> 52. Some commenters state that tools do not exist for conducting the "Initial Actions" assessments. As a result, the commenters assert that the schedule for completing the "Initial Actions" assessments is unrealistic because the commenters believe that the NOPR proposed to require the completion of such assessments by the filing date or implementation date of the First Stage GMD Reliability Standards. We clarify that the "Initial Actions" assessments do no need to be completed by the filing date or implementation date of the First Stage GMD Reliability Standards. The NOPR only proposed that the "Initial Actions" assessments should begin immediately (i.e., simultaneous with the development of the First Stage GMD Reliability Standards). Thus, the "Initial Actions" assessments provide a head start for analyzing the most at-risk and critical facilities before the Second Stage GMD Reliability Standards become effective and could be used to assist in performing the GMD vulnerability assessments required in the Second Stage GMD Reliability Standards. Further, to the extent that owners and operators of the Bulk-Power System have already begun to identify facilities most at-risk

> from severe GMD events, those assessments should help to inform the "Initial Actions" assessments required by this final rule.

FERC Order 779, p. 38:

> 53. In NERC's May 21, 2012 post Technical Conference comments, NERC stated that all of its proposed "Initial Actions" would take 18-24 months to complete.84 The June 2012 GMD Task Force Phase 2 Scope and Project Plan estimated that "improve[d] tools for industry planners to develop GMD mitigation strategies" would be completed within 12-36 months, depending on the task, and "improve[d] tools for system operators to manage GMD impacts" would be completed within 12-24 months. Adjusting the deadline for submission of the Second Stage GMD Reliability Standards to 18 months allows time to identify facilities most at-risk from severe geomagnetic disturbance and to conduct wide-area geomagnetic disturbance vulnerability assessment, with special attention being given to those Bulk-Power System facilities that provide service to critical and priority loads, before the effective date of the Second Stage GMD Reliability Standards.

Lack of Due Process in NERC Standard-Setting

Oak Ridge National Laboratory estimates that a severe solar storm would interrupt power to as many as 130 million Americans. Accordingly, a reliability standard to prevent a blackout from GMD should deserve the highest level of procedural attention from NERC staff and its independent trustees.

The Foundation for Resilient Societies diligently objected to the TPL-007-1 in the NERC standard-setting process, bringing forth a Level 1 Appeal to NERC staff and a Level 2 Appeal to a subcommittee of the NERC Board of Trustees. The independent trustees of NERC should have a fiduciary duty to hear Level 2 Appeals on a timely basis and render decisions in time for the public to comment in federal rulemaking. However, as of the date we submit our comments on this docket, we have yet to learn of the disposition of our appeal, nor will we or other commentators have a citable record of our Level 2 Appeal. This is a gross violation of due process that has caused us irreparable harm in the preparation of our comments and in the federal rulemaking process.

Summary of Rationale for Remand

NERC was once a voluntary standard-setting organization, but as designated Electric Reliability Organization, it has a duty to propose standards that are technically justified. Unfortunately, with Standard TPL-007-1, NERC has failed in its duty to the Commission and to the public. Both NERC and FERC will defeat the purpose of the Energy Policy Act of 2005 if they combine a standard with barriers to hardware protection against GMD, and liability protection against negligence that diminishes a robust marketplace for higher reliability of electric service.

The substantive facts illuminated in this comment show that Standard TPL-007-1 is defectively drafted and will not protect the safety of the public, except by voluntary action outside of the requirements of the standard.

Importantly, implementation of "best practices" above minimums set in the standard may not be eligible for cost recovery and therefore are likely to be put aside. Further, by proposing liability protection in FERC Order No. 779, FERC is effectively disabling prudent underwriting by the insurance and reinsurance industries and implementation of "best practices." Instead of inspecting utility operators and rewarding through reduced insurance premiums "best practices," insurers may watch from the sidelines, constrict the scope of their underwriting, or both.

Reliability Standard TPL-007-1 is a "paper compliance" standard that establishes a Benchmark GMD Event so low, and a transformer thermal assessment Screening Criterion so high, that essentially no hardware protection will be required for nearly all power transformers exposed to GMD impacts. In return for GMD Vulnerability Assessments that will determine in most cases that no tangible action is necessary, electric utilities would claim to receive liability protection for following a federally approved reliability standard.[68]

We ask the Commission to reject this fundamentally flawed and imprudent framework for Standard TPL-007-1 that has allowed NERC and the electric utility industry to pile imprudent

[68] Resilient Societies challenges any FERC claim of authority to grant liability protection by issuance of one or more reliability standards.

assumption on top of imprudent assumption. The result is a miasma of exemptions and inaction. The Commission should remand the entire standard TPL-007-1 to NERC for fundamental reassessment and improvements.

We also urge the Commission to seek assistance from all sources of expertise, including the Department of Defense (DOD) Defense Threat Reduction Agency (DTRA) and from the U.S. Department of Energy (DOE) National Laboratories, with the support of DOE on issues including: vibration effects (Idaho National Laboratory [INL] and DoD DTRA); interactions between installation of E1 and E2 protective hardware upon vulnerability to E3 (INL and DTRA); installation of E3 protective hardware upon E1 reduced vulnerability and mitigation cost impacts (INL and DTRA); coastal effects modeling ; GMD modeling (Los Alamos National Laboratory); and magnetotelluric modeling (USGS).

A better framework would be to require utilities to protect up to a 1-in-100 Year Reference Storm and make utilities liable for any negligence setting in geomagnetic latitude scaling factors, ground model scaling factors, transformer screening criteria, transformer thermal assessments, and other factors that could justify not installing automated and near-real-time equipment protection.

It would be far better for FERC to remand Standard TPL-007-1 than to saddle the public with a reliability standard that would grant liability protection to utilities while blocking the electric grid protection that a 21st century society requires.

Respectfully submitted by:

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for the

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Appendix 1

Preliminary Economic Analysis of Electric Grid Protection Against Geomagnetic Disturbance (GMD) Events

by
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Summary:

The financial impact of a severe “1-in-100 year” geomagnetic disturbance (GMD, known commonly as a “solar storm”) can be estimated using a parameterized economic model. The economic model assumes that economic activity, as measured by local Gross Domestic Product (GDP) will be seriously degraded in geographic areas that experience a blackout due to GMD effects. GDP will also be affected, but much less significantly, in geographic areas usually engaged in day-to-day commerce with the “blackout region.” The model additionally assumes increases in premature mortality (“loss of life”) due to blackout conditions and calculates the social cost of deaths using metrics employed by the U.S. government in other cost-benefit analyses.

The economic model indicates that a severe GMD event and resulting wide-area blackout would be extremely costly, both in terms of direct economic losses and also in social cost of lives lost due to increased mortality rates. Economic losses for electric utilities are modeled separately from society as a whole. For utilities, the model assumes financial impacts are principally lost revenue during the blackout duration, as well as grid equipment damaged from GMD and/or associated system collapse.

[69] Jon Bate, a captain in the U.S. Army, is an unpaid summer intern with the Foundation for Resilient Societies, Inc. He is a second year Master’s in Public Policy candidate at the Harvard Kennedy School of Government. The analysis and views expressed do not reflect the position of the U.S. Army, any other federal department or agency, or Harvard University. The author credits the assistance of Resilient Societies staff in developing and refining the economic model.

A 2012 study by the North American Electric Reliability Corporation (NERC) hypothesized that the most likely severe GMD scenario would be system collapse due to voltage instability, with restoration times “a matter of hours to days,” if replacement transformers were readily available or unnecessary in most cases.[70] An alternative report commissioned by Oak Ridge National Laboratory and sponsored by the U.S. Department of Energy, U.S. Department of Homeland Security, and Federal Energy Regulatory Commission concluded the most likely scenario is a long-term outage due to extra high voltage transformer damage, with outage periods of months or years.[71] Instead of assuming a single “correct” scenario, the economic model takes the approach of making “duration of outage” a parameter that can be adjusted to reflect the different risk perspectives and economic incentives of utilities and the general public.

Significantly, the economic model is risk-adjusted for the small probability—about 1%-- of a blackout from severe GMD in any single year; therefore, the significant cost of transformer damage for electric utilities is risk-adjusted by a factor of 0.01. However, hardware-based protective cost for transformers, assumed to be the cost of neutral ground blocking devices on a ten-year amortized basis, is modeled as a certainty, without risk adjustment.

Since private utility companies do not bear the full risk-adjusted societal cost of an outage, but only their own risk-adjusted costs, the modeling results (see Figures 1 and 2) show that they have lower economic incentive to protect against GMD events, absent subsidy, strict regulatory standards, and/or legal liability from negligence claims. In contrast, society as a whole has significant economic incentive to protect against even short-term blackouts of one day.

[70] 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System,” NERC, February 2012, available at https://www.frcc.com/Public%20Awareness/Lists/Announcements/Attachments/105/GMD%20Interim%20Report.pdf

[71] John Kappenman. “Geomagnetic Storms and Their Impacts on the U.S. Power Grid (Meta-R-319).” Metatech. January 2010. Available from http://web.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-319.pdf.

Key Findings:

- A one-day solar storm could cause 163 million people in 25 states and Washington, D.C. to lose power (based on a 50 degree latitude, 4,800 nanoTesla/minute GMD scenario described in Metatech-R-319 report).[72]
- Societal cost of a one-day solar storm power outage is estimated at $35.7 billion (primarily due to lost GDP and loss of life), compared to $3.0 billion for first day losses for private utility companies (the first-day losses for electric utilities result primarily from transformer damage while subsequent losses would be primarily due to lost electricity revenue).[73]
- Power outage scenario results in 574 deaths per day in affected states due to a degraded healthcare system and increase in accidental deaths.
- Investing in protective equipment for at-risk transformers to avoid a one-day outage has a highly favorable benefit-cost ratio (greater than 10) from an overall social perspective.
- Private utility companies are not currently incentivized to protect against a severe GMD event unless it causes a two day outage or greater. A two-day outage would cause an estimated societal cost of $65.5 billion, including 1,147 deaths.

Modeling Assumptions:

- 25 states (and Washington, D.C.) lose power due to voltage collapse and/or permanent transformer damage: Connecticut, Delaware, Georgia, Idaho, Illinois, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, Washington, West Virginia.
- GDP loss: 90% in outage states; 10% loss in non-outage states due to economic interconnectedness.
- At-risk transformer loss: 50% destruction; $5 million cost per transformer.[74]
- Loss per household due to food spoilage and other one-time costs: $48.60.[75]

[72] Ibid.
[73] Transformer damage of $2.5 billion and residential loss of $3.4 billion are assumed to be one-time costs.
[74] Foundation for Resilient Societies estimate, based on average transformer cost

- Increase in daily mortality rate in outage states is 15%.[76] Cost per life lost: $9.1 million.[77]
- Cost of lost electric utility revenue in affected states: $519 million per day.[78]

Cost-Benefit Analysis of Protection:

Figure 1: Societal Cost-Benefit Analysis

	1 Day Outage	2 Day Outage
GDP Loss	$24.6 billion	$49.2 billion
Transformer Damage	$2.5 billion	$2.5 billion
Residential Losses	$3.4 billion	$3.4 billion
Number of Lives Lost	574	1,147
Social Cost of Lives Lost	$5.2 billion	$26.1 billion
Total Societal Cost	**$35.7 billion**	**$65.5 billion**
Risk-Adjusted Societal Cost	$0.36 billion	$0.66 billion
Total Protective Cost	$0.35 billion	$0.35 billion
Amortized Annual Protective Cost	$0.035 billion	$0.035 billion
Societal Benefit-Cost Ratio	**10.3**	**18.9**

[75] Sullivan, et. al. "Estimated Value of Service Reliability for Electric Utility Customers in the United States." January 2015. http://www.osti.gov/scitech/servlets/purl/1172643. Extrapolated cost of 16 hour outage to a 24 hour period. This is a one-time loss due to loss of perishable goods and increased consumption of stored nonperishable items.

[76] Anderson and Bell. "Lights out: Impact of the August 2003 power outage on mortality in New York, NY." *Epidemiology (Cambridge, Mass)*. 2012;23(2):189-193. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3276729/. Researchers use a regression model to estimate increased mortality in the New York City metropolitan area to be 28% for a one day outage. This model uses a more conservative estimate of 15% since rural areas will be less-affected by a blackout.

The percentage of U.S. population residing in coastal counties adjacent to the Atlantic and Pacific Oceans, the Great Lakes, and the Gulf of Mexico has increased to 29 percent of total U.S. population between the period 1960 and 2008. See the year 2010 Census Bureau report, Coastline Population Trends in the United States: 1960 to 2008. Blackout-related mortality in U.S. coastal counties and densely-populated urban areas may be substantially higher than the 15 percent estimated in this paper, while it may be substantially lower in more rural areas.

[77] "Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses." U.S. Department of Transportation. http://www.transportation.gov/sites/dot.dev/files/docs/VSL%20Guidance_2013.pdf

[78] "Retail Electricity Sales Statistics, 2012." Annual Electric Power Industry Report. U.S. Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

Figure 2: Private Utility Cost-Benefit Analysis

	1 Day Outage	**2 Day Outage**
Loss of Electricity Revenue	$0.52 billion	$1.0 billion
Transformer Damage	$2.5 billion	$2.5 billion
Total Private Utility Cost	**$3.0 billion**	**$3.5 billion**
Risk-Adjusted Private Utility Cost	$0.030 billion	$0.035 billion
Total Protective Cost	$0.35 billion	$0.35 billion
Amortized Annual Protective Cost	$0.035 billion	$0.035 billion
Private Utility Benefit-Cost Ratio	**0.9**	**1.0**

Cost-Benefit Analysis Assumptions:

- $350,000 cost to protect each transformer with neutral blocking equipment.[79]
- Protective equipment cost is amortized over a 10 year useful life.[80]
- Probability of severe solar storm: 1% per year (approximately)—12% per decade.[81]

Conclusions:

Due to the high societal costs of a power outage, federal and state governments have an incentive to protect against even a one-day power outage due to a GMD event. However, private utility companies do not have a business case to invest in protective transformer equipment until the projected outage reaches a minimal duration of two days, assuming there is no cost recovery for protective equipment and also assuming utilities have no exposure to losses from negligent liability claims. Utility losses due to transformer damage and lost electricity revenues are projected to be 7% to 8% of aggregate societal costs the first day of an outage.

[79] Foundation for Resilient Societies estimate based on discussions with manufacturers of protective equipment. Only "at-risk" transformers according to Metatech R-319 report would require protection.
[80] Useful life of blocking equipment would likely exceed 10 years.
[81] Pete Riley. "On the Probability of Occurrence of Extreme Space Weather Events." February 2012. Available from http://onlinelibrary.wiley.com/doi/10.1029/2011SW000734/abstract

By the two-day mark, society faces a cost of $65.5 billion, including over 1,100 lost lives. Absent mandatory governmental regulation, the lack of incentive for private utilities to protect the grid creates a classic “market failure” for grid protection. Protecting the bulk power grid against a severe GMD event creates a positive externality that benefits our electricity-dependent society in the form of avoided power outage costs. Since private utilities do not possess sufficient incentive to invest in the socially optimal level of grid protection, the gap in protection requires government action in the form of subsidy (cost recovery for protective equipment), regulation, and/or establishment of legal liability for negligence.

Appendix 2

Reference Documents

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events	**)** **)**	**Docket No. RM15-11-000**

<u>Reference Document No. 1</u>

Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	Foster, John S.; Gjelde, Earl; Graham, William R; Hermann, Robert J.; Kluepfel, Henry M.; Lawson, Richard L.; Soper, Gordon K.; Wood, Lowell L., Jr.; Woodard, Joan B.
Title	Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures
Publication Series	www.empcommission.org/reports.php
Date	April 2008
Web click-through	http://www.empcommission.org/docs/A2473-EMP_Commission.pdf
Key findings	Ch. 2, Electric Power, pp. 17-61; Fig. 2-3, GIC Damage to Transformer During 1989 Geomagnetic Storm, p. 33; EMP Comm'n field tests of electrical system components and subsystems substantially less than projected EMP E3 fields, p. 18; GMD storms have caused both transformer and capacitor damage even on properly protected equipment, p. 33; 1 in 100 year GMD storm will cause "hundreds of high voltage transformers to saturate" leading to "voltage collapse in the affected areas and damage to elements of the transmission system," p. 43; likelihood of a blackout lasting years over large portions of the affected region is substantial with damage to these high-value components. The islanding … may help reduce the E2 and E3 impacts…." p. 59
Together with other relevant materials and references.	

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<u>Reference Document No. 2</u>

Submitted by the Foundation for Resilient Societies
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in FERC Docket No. RM15-11-000
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Author(s)	Stockton, Paul; Beck, Chris; and Schnurr, Avi (eds.)
Title	Electric Infrastructure Protection (E-PRO) Handbook
Publication Series	www.eiscouncil.org
Date	1st ed. Dec. 17, 2014
Web click-through	Not available. Hard copies distributed 7-21-15 to FERC Commissioners and staff.
Key findings	Severe GMD durations, p. 72; ch. 2, Power Grid Protection & Restoration, pp. 89-190; E-threat characteristics, pp. 103-108; Fig. 2.3, p. 118 shows high voltage transmission systems at risk; Fig. 2.4, locations of Top 500 GIC Participation transformers in CONUS, p. 119 is inconsistent with NERC GMD benchmark model; during "very large" GMD events, transformers near coasts and in Southeast, Florida, and Gulf of Mexico are included among transformers "most likely to be at risk of excessive, > 90 Amps per phase GIC flow"; proposed selective load shedding for unprotected transformers, p. 126, may be infeasible in limited warning windows with exclusion of generator operators from EOP-010-1 mitigation duties without mandatory GIC data sharing. See pp. 132-136 on derating or disconnection options for unprotected EHV transformers. E-3 protection for GMD will benefit E3 protection for EMP; assess consequences of mitigation hardware for GMD-EMP interactions and cost impacts.
Together with other relevant materials and references.	

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Reference Document No. 3

Submitted by the Foundation for Resilient Societies
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(filed on July 27, 2015)

Author(s)	John Kappenman for Metatech Corp. Meta R-319
Title	Geomagnetic Storms and Their Impact on the US Power Grid
Publication Series	
Date	January 2010
Web click-through	https://www.ornl.gov/sci/ees/etsd/pes/pubs/ferc_Meta-R-319.pdf
Key findings	GMD threat environment for power grid, pp. 1-1 to 1-31; March 1989 storm impacts, pp. 2-1 to 2-22; sec.2.2.5 increased reactive power demand and concurrent loss of reactive power capacity in solar storms, a missing element of NERC-FERC modeling upon risks of instability, cascading outages and grid separation, pp 2-23 to 2-28; Salem-1 damage, pp. 2-29 to 2-35; threats from extreme geomagnetic storms, pp. 3-1 to 3-30; At-risk extra high voltage transformers, pp. 4-1 to 4-23; instant reactive power demand increases, p. A1-4; App. 2, detailed Summary, Hydro-Quebec Storm, March 13-14, 1989, pp.A2-1 to A2-8; Appendix 3, Benchmarking solar storms, showing broad impacts concurrently, pp. A3-1 to A3-20; App. 4, Validating transformer modeling, pp. A4-1 to A4-23, in contrast with failure of GMD Task Force to validate its model with empirical transformer performance indicators for North America.
Together with other relevant materials and references.	

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<u>Reference Document No. 4</u>

Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	Frank Koza
Title	NERC GMD Reliability Standards
Publication Series	Idaho National Laboratory
Date	April 8, 2015
Web click-through	Frank Koza presentation on GMD standard
Key findings	
Together with other relevant materials and references.	

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Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	Foundation for Resilient Societies & NERC Staff
Title	NERC Level 1 & 2 Appeal Record in TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events (Project 2013-03, Geomagnetic Disturbance Mitigation.
Publication Series	
Date	January/February 2015
Web click-through	http://www.nerc.com/pa/stand/project201303geomagneticdisturbancemitigation/2013-03_gmd_level_2_appeal_foundation_for_resilient_societies_tpl-007-1_05182015.pdf. http://www.resilientsocieties.org/uploads/5/4/0/0/54008795/appeals_20150104_nerc_stage_1_appeal_tpl-007-1.pdf http://www.resilientsocieties.org/uploads/5/4/0/0/54008795/letters_20150226_nerc_stage_2_appeal_tpl-007-1.pdf
Key findings	Resilient Societies cites failures of data collection, data sharing, data validation, model validation with empirical data from North America and not Finland and other IMAGE sites in Northern Europe; and failures of quality control by the NERC Office of Standards. The failure to include model elements for Reactive Power Losses, Increased VAR demand, and potential system imbalance impacts on voltage and frequency swings; the absence of vibration modeling; the absence of a coast effect; and bias in other model components drive Benchmark Model postulates to the point that known transformer losses during solar storms – at Wiscasset, Maine (Maine Yankee); Seabrook, NH; and Salem 1 and 2 in New Jersey) and other locations of prior damaged or destroyed transformers are exempt from even "assessment" duties. Procedural failures drive substantive errors with systematic bias against any assessment duty for hardware protection.
Together with other relevant materials and references.	

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Submitted by the Foundation for Resilient Societies
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in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	Central Maine Power Co., by Justin Michlig, with contributions by Emprimus, Maine Public Utilities Commission, et al.
Title	2014 Maine GMD/EMP Impacts Assessment
Publication Series	Maine Public Utilities Commission Filings in MPUC Docket 2013-00415
Date	December 23, 2014
Web click-through	https://www.mpuc-cms.maine.gov. Lookup Docket 2013-00415. Download item 51.
Key findings	GIC has potential to cause disruption to power system operations, by transformer heating, reduced voltage operations and harmonics. p.6. The NERC Benchmark model adjusted for Northern Maine projects maximum of 4.53 volt/km geoelectric field for NERC's claimed 1 in 100 year benchmark storm. p.7. The CMP Study Team assumed 1 in 50 year storm voltage up to 14 volts/km and 1 in 100 year volts/km up to 23.5 volts, p.7. Using the NERC model, no neutral blocking devices or other mitigation hardware would be required in Maine. The 1 in 50 yr storm per CMP modeling would justify $2.8 M of neutral ground blocking for 7 transformers at $350K per unit; 16 GIC monitors, at per unit installed cost of $36K. Susceptible capacitor replacements would cost $1M for 4 capacitors. p.7. Since publication in Dec. 2014 and NERC proposed GMD Hardware standard in Jan. 2015, Central Maine Power has declined to budget for or order protective equipment including neutral ground blockers, despite CMP finding 7 of its transformers would exceed 75 Amps per Phase for both their 1 in 50 year GMD event, and their 1 in 100 year GMD event. See Table 3 at p. 27. These results do not model a "coastal effect" which would place at risk additional transformers, and which may have caused damage to Maine Yankee's GSU 345 kV transformer in March 1989 GMD, loss of that transformer in April 1991 and potential damage to 2 replacement GSU transformers installed in 1993.
Together with other relevant materials and references.	

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Reference Document No. 7

Submitted by the Foundation for Resilient Societies
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Author(s)	Emprimus
Title	Effects of GMD and EMP on the State of Maine Power Grid
Publication Series	
Date	January 2, 2015
Web click-through	http://www.maine.gov/tools/whatsnew/attach.php?id=639058&an=2
Key findings	
Together with other relevant materials and references.	

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Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	Foundation for Resilient Societies
Title	Economic Model for Mitigation of GMD and EMP
Publication Series	
Date	2015
Web click-through	Resilient Societies EMP GMD Cost Estimate
Key findings	
Together with other relevant materials and references.	

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Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
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(filed on July 27, 2015)

Author(s)	Dr. David Boteler
Title	The impact of space weather on the electric power grid
Publication Series	Heliophysics V. Space Weather and Society
Date	July 7, 2014
Web click-through	http://www.spacewx.net/pdf/HSS5.pdf pp 68-89
Key findings	
Together with other relevant materials and references.	

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Reliability Standard for Transmission System Planned) **Docket No. RM15-11-000**
Performance for Geomagnetic Disturbance Events)

Reference Document No. 10

Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
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(filed on July 27, 2015)

Author(s)	Carolus J. Schrijver & Sarah D. Mitchell
Title	Disturbances in the US electric grid associated with GMD
Publication Series	J. Space Weather Space Climate
Date	April 19, 2013
Web click-through	http://www.swsc-journal.org/articles/swsc/pdf/2013/01/swsc120066.pdf
Key findings	For the period 1992 thru 2010, with more than 3σ **(sigma)** significance, or odds ratio of 32-to-1, approximately 4% of disturbances in the U.S. power grid reported to the US Department of Energy "are attributable to strong geomagnetic activity and associated geomagnetically induced currents." Abstract. GICs induce thermal effects and reactive power consumption that impacts regional reactive power imbalance s with swings in voltage and frequency. A19p1. Mitigation strategies are warranted. A19p7.
Together with other relevant materials and references.	

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Reference Document No. 11

Submitted by the Foundation for Resilient Societies
52 Technology Way, Nashua, NH 03060
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(filed on July 27, 2015)

Author(s)	Lloyd's; Atmospheric & Environmental Research
Title	Solar Storm Risk to the North American Electric Grid
Publication Series	
Date	2013
Web click-through	Lloyds & AER Report
Key findings	
Together with other relevant materials and references.	

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Submitted by the Foundation for Resilient Societies
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Author(s)	Lloyd's
Title	The insurance implications of a cyber attack on the US power grid
Publication Series	Emerging Risk Report – Innovation Series
Date	July 2015
Web click-through	Lloyds Business Blackout Report
Key findings	
Together with other relevant materials and references.	

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Reference Document No. 13

Submitted by the Foundation for Resilient Societies
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in FERC Docket No. RM15-11-000
(filed on July 27, 2015)

Author(s)	C.J. Schrijver, R. Dobbins, W. Murtagh, S.M. Petrinec
Title	Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment
Publication Series	Space Weather Journal
Date	June 21, 2014
Web click-through	http://arxiv.org/pdf/1406.7024v1.pdf
Key findings	
Together with other relevant materials and references.	

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Reference Document No. 14

Submitted by the Foundation for Resilient Societies
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Author(s)	National Security Telecommunications Advisory Committee
Title	NSTAC Issue Review 06-07
Publication Series	
Date	2007
Web click-through	http://www.dhs.gov/sites/default/files/publications/2006-2007%20NSTAC%20Issue%20Review_0.pdf
Key findings	
Together with other relevant materials and references.	

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<u>Reference Document No. 15</u>

Submitted by the Foundation for Resilient Societies
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(filed on July 27, 2015)

Author(s)	Scott Dahman, PowerWorld Corporation
Title	BPA GMD Impact Assessment TIP 264 GIC R&D
Publication Series	
Date	September 30, 2013
Web click-through	http://elibrary.ferc.gov/idmws/common/opennat.asp?fileID=13941706
Key findings	Modeling for voltage collapse.
Together with other relevant materials and references.	