Secure the Grid Coalition

2020 Pennsylvania Avenue, N.W., Suite 189
Washington, D.C. 20006

Dear Secretary Granholm and distinguished members of the Secretary of Energy Advisory Board:

The *Secure the Grid Coalition* greatly appreciates the opportunity to voice recommendations to the SEAB for consideration during its April 9, 2024, virtual meeting.

Our Request: Our Coalition respectfully recommends that the Department of Energy take URGENT ACTION to rapidly protect vital transformers at substations throughout the U.S. Bulk Power System from harmful ground induced currents (GICs) produced by solar weather (and nuclear electromagnetic pulse). If DOE does not intend to protect the grid against GICs, we recommend at least telling state regulators.

The Bad News: **For more than 12 years we have been urging the Department** to address the vulnerability of large power transformers to GICs. **Transformer lead times are now 4-6 years,** so even a small solar storm can cause a long-lasting and devastating blackout in the United States of America.

During the June 13, 2022 SEAB meeting we provided this same urgent request with peer-reviewed scientific evidence demonstrating that GICs will catastrophically harm these transformers if no action is taken. **Our warning nearly two years ago included a visual aid which we include again now, at right, to remind the SEAB that the current protection standard against GICs is transparently defective and dangerously ineffective.** *[Those June 2022 comments are "Enclosure 1" at the end of this document.]*

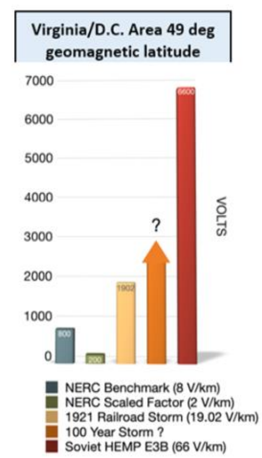
A Visual Aid: The graph on the right shows the comparison between the current GMD protection standard and real-world data by applying the different levels (V/km) of induced currents to a 100km transmission line (average length of U.S. transmission lines).

(Note that the voltage level is proportional to the length of the conductor. Thus induced voltages could be much higher than levels noted here since many transmission lines are longer than 100km)

In this case we use an example utility in the Virginia /Washington D.C. area. (a geomagnetic latitude of 49deg). The utility would take the **"benchmark" of 8 V/km**, and apply the **"scaling factor"** (ref. NERC instruction, page 29, TPL-007-4 – Transmission System Planned Performance for Geomagnetic Disturbance Events) to determine a protection level of **2 V/km.**

Contrast this with **real-world data** collected during the **1921 Railroad Storm** (considered a "40-year" solar storm).

The NERC standard is supposed to bound levels possible for a 100-yr solar storm.



We include an unknown bar for the 100-year solar storm since the last time that occurred (1859 Carrington event) we have no ground voltage or current measurements.

[As will be explained further below, even minor solar activity not immediately resulting in blackouts produces approximately $10b in economic losses annually and can also damage transformers resulting in needed replacements in the months following the event.]

The Good News: As our Coalition announced to the SEAB during your October 25, 2022 meeting, **proven technology exists** to protect against these ground induced currents (GICs) in the form of Neutral Blocking Devices (NBDs). One such NBD, produced by Emprimus, LLC, is known as **"SolidGround"™** and after years of use in the live power grid in multiple locations, this system has emerged as the tested and confirmed solution to mitigate the destructive impact of GICs. **The success of the "SolidGround" system is exemplified by its extensive track record in pilot projects**. [*Important disclaimer: our Coalition and its sponsoring nonprofit receives no funding from Emprimus LLC.]*

Proven Performance in Pilot Project at American Transmission Company (ATC): American Transmission Company (ATC) has operated the "SolidGround" NBD since 2015, reporting flawless performance with 36 successful operations through September 2019, which was the last reported *cumulative* tally from ATC that has been made available to the public.

“SolidGround” protecting 345KV transformer in the ATC grid in Wisconsin (9+ years of testing)

“SolidGround” being installed on DOE’s 345KV transformer in the WAPA grid in South Dakota.

At the Western Area Power Administration (WAPA): Similarly, WAPA has been utilizing the “SolidGround” NBD solution since November 2022, where it has engaged its protection 17 times in the past 12 months alone. Mr. Dan Hamai, Vice President of Engineering and Design at WAPA, attests to the reliability and effectiveness of the "SolidGround" system, stating:

> *"We were pleased to find out that no negative impacts were identified, so WAPA moved into the design and NBD specification phase."*

This endorsement from a key industry figure underscores the confidence in the “SolidGround” NBD system's ability to protect critical infrastructure. Moreover, Mr. Chris Colson, Transmission System Planning Manager at WAPA, shares his experience with the Emprimus “SolidGround” NBD system that was operational at WAPA’s White Substation during a large-scale Geomagnetic Disturbance (GMD) event, stating:

> *"No worries, the White NBD was ready! On four separate occasions, the White NBD operated as expected, sensing the rise in GIC flow and automatically initiating its blocking during the space weather event that lasted about twelve hours."*

His testimony highlights the system's effectiveness in real-world scenarios, providing a reliable defense against electromagnetic threats.[1]

At Tennessee Valley Authority (TVA): Additionally, TVA's implementation of the “SolidGround” NBD system, operational for approximately 8 months, as of this date, has also demonstrated its efficacy during critical events engaging its protection multiple times with no problems.

These pilot projects, spanning several years and encompassing diverse operational environments, serve as a testament to the reliability and durability of the "SolidGround" system. The consistent performance

[1] Closed Circuit, a publication of Western Area Power Administration, “Protecting the Grid from Solar Storms.” https://static1.squarespace.com/static/57bc8a4a414fb50147550a88/t/659d9aaa58360457a8b73076/1704827574210/2023+APRIL+-+WAPA+ARTICLE+on+SolidGround%C2%AE.pdf Accessed April 8, 2024.

across multiple installations underscores its suitability as a scalable solution to fortify our power grid against devastating GICs produced by electromagnetic threats such as solar weather and EMP.

"SolidGround" protecting a 500KV transformer in the TVA grid.

Historical Context:

The concerns regarding the vulnerability of our power grid to solar storms and electromagnetic interference have persisted for many decades. Over the years, numerous reports, petitions, resolutions, and presidential executive orders have sounded the alarm on the catastrophic consequences of EMPs.

Warnings Have Come from Both Government Agencies and Private Entities:

The warnings issued by official governmental bodies over the past several decades have underscored the urgent need to address the vulnerability of our power grid to solar storms and electromagnetic interference. The private sector has also raised alarms regarding the vulnerability of our power grid to solar storms and electromagnetic interference, echoing the concerns voiced by public agencies. The following citations are among the earliest major warnings and are therefore perhaps some of the lesser-known examples to many. More familiar examples are provided as weblinks in the Appendix.

In 1982, there were two Petitions for Rulemaking, docketed as PRM-50-32 and 32B, filed by the Ohio Citizens for Responsible Energy, et al., focused on the impacts of High Altitude Electromagnetic Pulse (HEMP). These petitions emphasized the urgent need for protective measures against electromagnetic threats.

In 1989, NERC (prior to becoming the Electric Reliability Organization for FERC) issued a report titled "March 13, 1989 Geomagnetic Disturbance," which recommended the use of DC-Blocking hardware devices, such as Neutral-Blocking Capacitors, to safeguard against the damaging impacts of solar weather events. This report highlighted the potential for strong auroral currents to disrupt and damage modern electric power grids.

> ***Neutral-Blocking Capacitor***
>
> *Capacitors installed between transformer neutrals and grounds can be very effective in blocking ground-induced currents. Ideally, the capacitor should be very simple, should not increase voltage stress on transformer insulation, should not have to be bypassed during faults (eliminating the necessity for a complex bypass device) and should have a low 60 Hz impedance (to avoid any impact on the system grounding coefficient). The cost of such a device, will of course, have to be weighed against its simplicity, robustness, and reliability. Hydro-Quebec is currently studying a capacitor of this sort and if findings are promising, a prototype will be installed for field testing and evaluation of long-term reliability and performance.*[2]

GICs from Solar Storms Can Create Transformer Failures LATER:

It should be noted that the damaging impacts of Geomagnetic Disturbances do not have to manifest immediately, as the failures often manifest, from cumulative effects, months after an event that caused the damage. For example, there were 12 nuclear power generating stations which suffered transformer failures within 25 months of the 1989 Hydro-Quebec Geomagnetic event. These nuclear plants were:[3]

- WNP 2
- South Texas
- Zion 2
- D.C. Cook 1
- Shearon Harris
- Nine-Mile
- 10 Susquehanna
- Surry 1
- Oyster Creek
- Salem
- Peach Bottom
- Maine Yankee

The 2004 report of the Congressionally mandated **Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack**, titled **Executive Report** describes the Ground Induced Current (GIC) from a solar event Geomagnetic Disturbance (GMD) as less intense than the E3 component of High Altitude Electromagnetic Pulse (HEMP).[4] However, a fast-moving large GMD has proven to have the ability to destroy long lead-time transformers.

The Commission's 2008 Report on Critical National Infrastructures found a valuable yet often overlooked lesson. Namely, that there is less ruggedness to Ground Induced Currents (GIC) in the currently more popular single-phase transformers.

> *"The closer a transformer is operating to its performance limit, the smaller the GIC needed to cause failure. Moreover, newer transmission substations are increasingly using three single-phase transformers to handle higher power transfer, since the equivalently rated three-phase transformers are too large to ship. The three-phase systems are more resistant to GIC, since their design presumes a balanced three-*

[2] North American Electric Reliability Council, "March 13, 1989 Geomagnetic Disturbance" page 46. https://www.nerc.com/pa/Stand/Geomagnetic%20Disturbance%20Resources%20DL/NERC_1989-Quebec-Disturbance_Report.pdf

[3] Page 268, Foundation for Resilient Societies TPL-007-1 Appeal, https://acrobat.adobe.com/id/urn:aaid:sc:VA6C2:8bd5c492-06ae-4959-a449-9a28c49b7606, accessed April 7, 2024

[4] http://www.empcommission.org/docs/empc_exec_rpt.pdf, page 17.

phase operation. Thus the separate single-phase transformers are more susceptible to damage from GIC."[5]

Also in 2008, the Committee on the Societal and Economic Impacts of Severe Space Weather Events Workshop published a report by the National Research Council of the National Academies. This report recognized the disruptive potential of strong auroral currents on modern electric power grids, further emphasizing the need for protective measures.[6]

In 2009, NERC issued an Executive Brief on Electromagnetic Pulse & Geomagnetic Storm Events[7] on August 24, 2009, which warned of the potential impacts of electromagnetic pulses and severe geomagnetic storm events on the power grid. This brief highlighted the susceptibility of the nation's power grid to these events and emphasized the need for proactive measures to mitigate the risks.

In 2010, Oak Ridge National Laboratory on behalf of the Federal Energy Regulatory Commission in joint sponsorship with the Department of Energy and the Department of Homeland Security developed a series of studies[8] that concluded:

• The nation's power grid is vulnerable to the effects of an electromagnetic pulse (EMP), a sudden burst of electromagnetic radiation resulting from a natural or man-made event; and

• EMP events occur with little or no warning and can have catastrophic effects, including causing outages to major portions of the U.S. power grid possibly lasting for months or longer; and

• Naturally occurring EMPs are produced as part of the normal cyclical activity of the sun while man-made EMPs, including Intentional Electromagnetic Interference (IEMI) devices and High Altitude electromagnetic Pulse (HEMP), are produced by devices designed specifically to disrupt or destroy electronic equipment or by the detonation of a nuclear device high above the earth's atmosphere; and

• EMP threats have the potential to cause wide-scale, long-term losses with economic costs to the United States that vary with the magnitude of the event but the cost of damage from the most extreme solar event has been estimated at $1 to $2 trillion with a recovery time of four to 10 years.

On March 15, 2011, based on serious concern about the consequences to nuclear plants – particularly spent nuclear fuel safety systems – during a solar storm-induced long term widespread power outage, the Foundation for Resilient Societies opened a Petition for Rulemaking with the Nuclear Regulatory Commission. This Petition, docketed as PRM-50-96, warned about the potentially catastrophic consequences of inaction. NRC has yet to take action on this petition.

[Of note, our Coalition warned your SEAB during its April 19, 2022, virtual meeting of the potential consequences of nuclear facilities being left without external power for a long term period.] Furthermore, the National Association of Regulatory Utility Commissioners (NARUC) approved a "Resolution Supporting Protection of Utility Infrastructure Against Electromagnetic Pulse Effects" in July of 2011. This resolution highlighted the vulnerability of the nation's power grid to electromagnetic pulse effects and stressed the importance of safeguarding utility infrastructure against such threats.[9]

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[5] http://www.empcommission.org/docs/A2473-EMP_Commission.pdf, page 33.
[6] https://nap.nationalacademies.org/initiative/committee-on-the-societal-and-economic-impacts-of-severe-space-weather-events-a-workshop
[7] http://www.nerc.com/fileUploads/File/CIP/EMP-Geomagnetic-Exec-Brief%281%29.pdf
[8] http://www.ornl.gov/sci/ees/etsd/pes/ferc_emp_gic.shtml
[9] NARUC "Resolution Supporting Protection of Utility Infrastructure Against Electromagnetic Pulse Effects" https://pubs.naruc.org/pub.cfm?id=539863CA-2354-D714-515E-050167AD3FDC

These alerts issued by public agencies and the warnings from the private sector collectively underscore the critical nature of the threat posed by solar storms and electromagnetic interference to our power grid. Despite the clarity of these warnings issued by both sectors and the wealth of scientific evidence supporting them, substantive actions to fortify our infrastructure have been slow to materialize.

The Folly of Calling for Further Studies:

In view of the proven success and extensive operational history of the "SolidGround" system, the notion of conducting additional studies to validate the need for protective measures is both redundant and counterproductive. Concrete examples of its efficacy in real-world scenarios negate the necessity for further delay or deliberation. The time for action is now, and the "SolidGround" system, as the tested and confirmed “Neutral Blocking Device” stands ready to provide the necessary defense against GICs.

Protection is Affordable:

Nearly two years ago when we first recommended this action to the SEAB, it was in the immediate wake of the “Bipartisan Infrastructure Bill” providing over $1 trillion dollars to be allocated toward protecting and restoring our nation’s infrastructure. At the time we explained to the SEAB that the cost for protecting America – nationwide – from harmful GICs was just over $4 billion – one third, of one percent of that Infrastructure Bill. Unfortunately, even after the “Inflation Reduction Act” provided billions more in funding opportunities for action, we have yet to see DOE invest in GIC protection for the electric grid.

The Bottom Line: If DOE Won’t Act, At Least Inform State Regulators

Even if America can deter adversaries from conducting an EMP attack, there is 100% certainty that earth will be struck by a large solar storm sometime in the future. We just don’t know when. Failing to protect our transformers against GICs virtually guarantees a devastating long term blackout in the future. Therefore, if the SEAB and DOE do not plan on utilizing the vast sums of moneys allocated through the Bipartisan Infrastructure Act and the Inflation Reduction Act to invest in protecting the electric grid against GICs, we suggest at least informing state utility commissions (such as NARUC) that they are “on their own.” This admission will at least prompt those regulators to create the type of cost recovery incentives for the utility industry to make the needed investments to protect their transformers, and us.

Respectfully submitted by,

Thomas J. Waller Jr.
Co-Director
Secure-the-Grid Coalition
twaller@centerforsecuritypolicy.org

Douglas. Ellsworth
Co-Director
Secure-the-Grid Coalition
doug.ellsworth@usapact.org

Enclosure 1 - Comments to SEAB during June 13, 2022 Meeting

Secure the Grid Coalition

2020 Pennsylvania Avenue, N.W., Suite 189
Washington, D.C. 20006

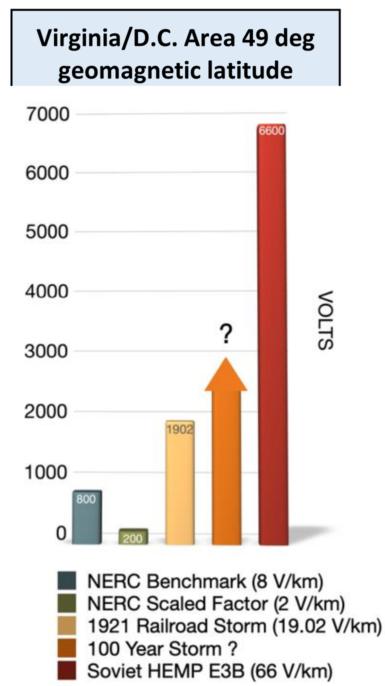
Dear Secretary Granholm and distinguished members of the Secretary of Energy Advisory Board:

The *Secure the Grid Coalition* greatly appreciates the opportunity to voice recommendations to the SEAB for consideration during its June 13, 2022, virtual meeting.

Our Request: We would like to build upon our **previous recommendations, made to DOE for the last 9 years** (and to the SEAB on 25 January) by **urging you to address the vulnerability of large power transformers to ground induced currents** (GICs) produced by solar weather (and nuclear electromagnetic pulse). This urgent recommendation is based on recent peer-reviewed scientific studies that make it clear that the **current protection standards for solar weather are transparently defective and dangerously ineffective** at protecting the electric grid.

A Visual Aid: The graph on the right shows the comparison between the current GMD protection standard and real-world data by applying the different levels (V/km) of induced currents to a 100km transmission line (average length of U.S. transmission lines).

(Note that the voltage level is proportional to the length of the conductor. Thus induced voltages could be much higher than levels noted here since many transmission lines are longer than 100km)



In this case we use an example utility in the Virginia /Washington D.C. area. (a geomagnetic latitude of 49deg). The utility would take the **"benchmark" of 8 V/km**, and apply the **"scaling factor"** (ref. NERC instruction, page 29, TPL-007-4 – Transmission System Planned Performance for Geomagnetic Disturbance Events) to determine a protection level of **2 V/km.**

Contrast this with **real-world data** collected during the **1921 Railroad Storm** (considered a "40-year" solar storm).

The NERC standard is supposed to bound levels possible for a 100-yr solar storm.

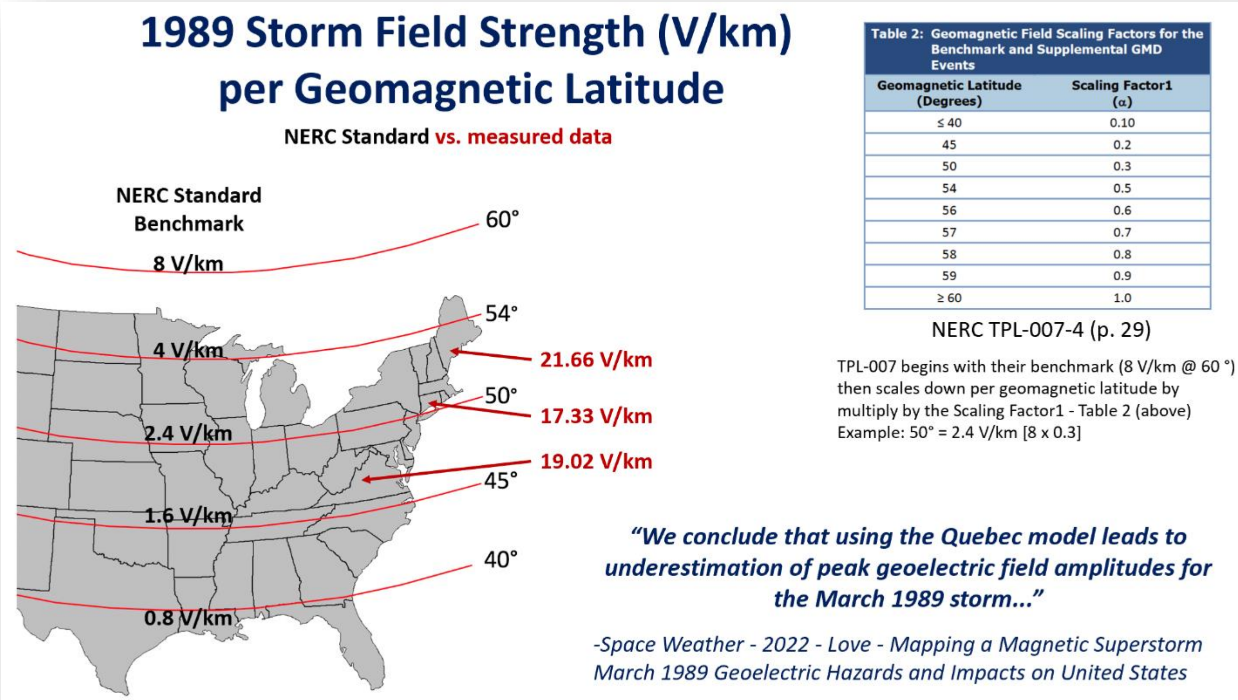
We include an unknown bar for the 100-year solar storm since the last time that occurred (1859 Carrington event) we have no ground voltage or current measurements.

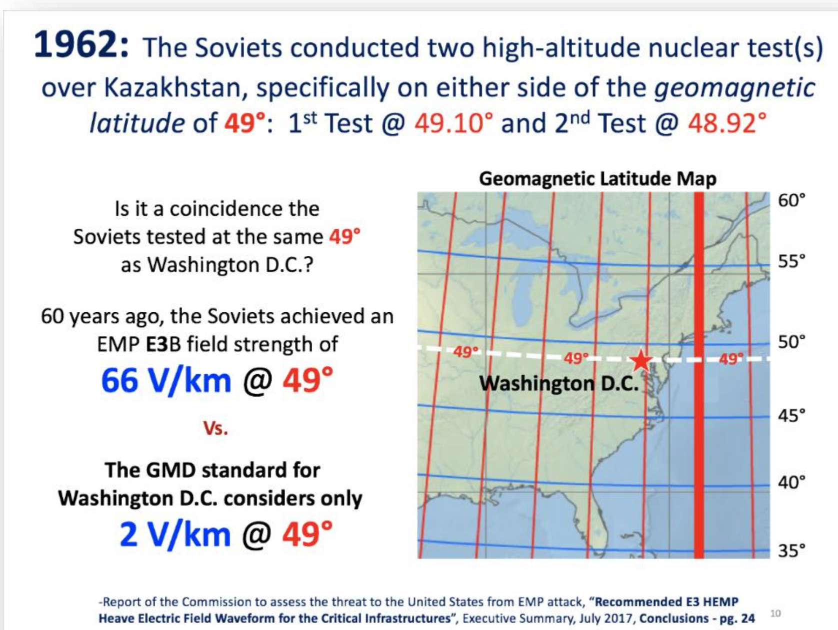
Finally, we provide another example **of real-world data** collected by the Soviets in the 1962 "K-test" of high-altitude electromagnetic pulse (HEMP) effects over what is now considered Kazakhstan. The Soviet tests produced an electric field of **66 V/km** (HEMP E3).

For this reason, the **Congressional EMP Commission recommended protecting the grid to a level of 85 V/km** to guard against both solar weather and HEMP E3. **We concur with that recommendation.**

The pages that follow provide a detailed explanation of the deficiency the current NERC GMD benchmarks. Appendices are also included to provide evidence justifying the need for immediate emergency action to protect the electric grid against GMD and EMP ground induced currents.

Additional Visual Aids: Below are images depicting the differences between the NERC standard "benchmark" and "scaling factor" **(in black)** and actual measured data **(in red)** with an excerpt from page 29 of NERCs TPL-007-4. Also below is a map depicting the specific geomagnetic latitude of the Soviet HEMP test in 1962 over Kazakhstan (which is the same geomagnetic latitude as Washington D.C.)





Background: Since May 2013, the Federal Energy Regulatory Commission (FERC) has required the North American Electric Reliability Corporation (NERC) to set a reliability standard to protect high voltage transformers from the effects of Geomagnetic Disturbances (GMD). For the standard, FERC mandated that NERC set a so-called "Benchmark Geomagnetic Disturbance Event." This benchmark was to establish the maximum 1-in-100-year storm that electric utilities must protect against.

But when the NERC Standard Drafting Team developed the benchmark event, they did not use data on storms impacting North America – but rather used European data on magnetic fields during a 21-year period during which no major storms occurred. Nor did they collect data on past storm effects on critical grid equipment such as high voltage transformers.

Beyond the above manipulation, the Drafting Team spatially averaged their findings which arrived at an insufficient defense-conservative benchmark to protect against only 8 volts per kilometer (8 V/km) beginning at the 60 degree geomagnetic latitude (over parts of Quebec) and then scaled down from there southward into the United States (e.g. only 2.4 V/km for the Washington D.C. area).

This standard, TPL-007, has progressed through four iterations over nearly a decade and its latest version, TPL-007-4, remains critically deficient. This is due to the Drafting Team's spatially averaging their GMD levels to artificially reduce the final "defense-conservative" benchmark to 8 volts per kilometer (8 V/km).

The inadequate benchmark has remained in place despite the science-based criticisms of both the sources and methods employed in its establishment. Specific criticisms that immediately arose upon adoption of this standard follow in **Appendices A and B.**

New Empirical Data from USGS, et.al: In its 2017 report titled "Enhancing the Resilience of the Nation's Electricity System," the National Academies of Sciences pointed out the need for "basic research" and "applied work to develop adequate simulations" to model severe events for the power grid, such as solar weather. **(See Appendix C).**

Two recent research papers published by USGS measuring the most consequential magnetic storms of the past century, the **1921 "Railroad Storm**" and the **1989 "Hydro-Quebec Storm,"** used data collected from magnetometer readings at specified sites.

The first of these is titled, **"Intensity and Impact of the New York Railroad Superstorm of May 1921."** Available at the weblink:
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019SW002250

> This study draws upon magnetometer readings and the failure of telephonic and telegraphic landline systems. This study uses these communications disruptions as a proxy for long-run interconnected conductors, as the electric power delivery topology in 1921 was not interconnected into the bulk power systems we have today. Using the example of the **railroad station that burned down due to overheated telegraph system** in Brewster, Connecticut, the CT160 survey station 27 km north of Brewster reported a geoelectric field of **19.40 V/km**, which is more than 7 times the benchmark of 2.4 V/km per TPL-007-4 for the same geomagnetic latitude.

The most recent of these two studies (May 2022) is titled **"Mapping a Magnetic Superstorm: March 1989 Geoelectric Hazards and Impacts on United States Power Systems."** Available at the weblink:
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW003030

> Geomagnetically Induced Currents (GICs) realized during the magnetic storm of March 1989 caused a blackout in Québec, Canada. Highest measured GICs occurred in the Mid-Atlantic and

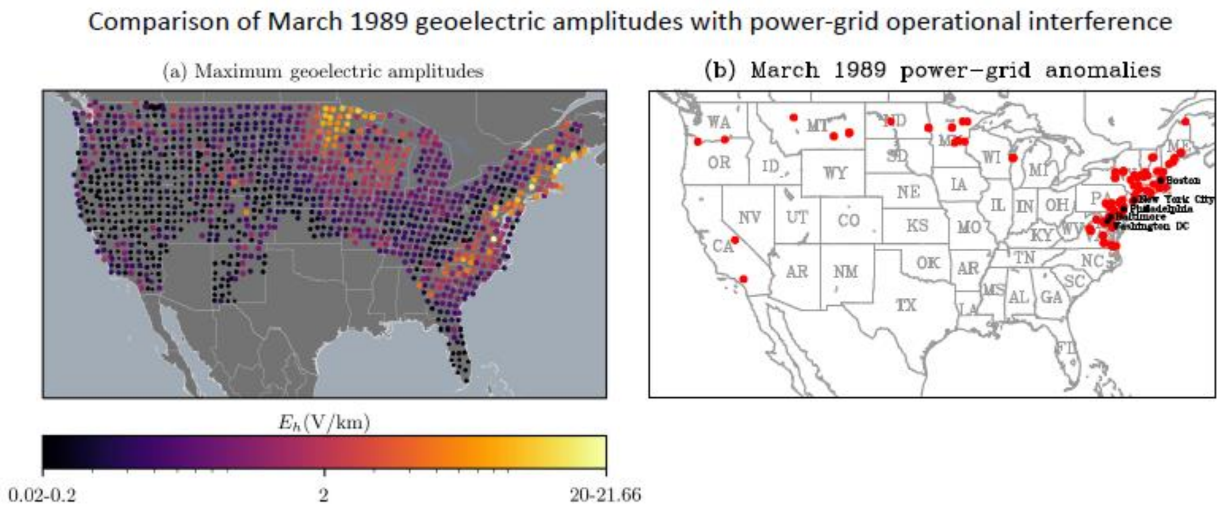
Northeast United States, where they **caused operational interference for electric-power companies and catastrophically damaged a high-voltage transformer.** (See image below)

March 1989 magnetic storm damage to a high-voltage transformer at a nuclear power center in Salem, New Jersey.

This study provides guidance where utility companies might concentrate their efforts to mitigate the impacts of future magnetic superstorms. The 1989 storm had its greatest impacts from Ground Induced Currents (GICs) in those regions of lowest earth crust conductivity. These regions are the highly populated Mid-Atlantic states through New England, and the Upper Midwest region. (See image on next page)

This study of 1989 magnetic storm produced field amplitude peaks 1-minute resolution of **21.66 V/km** in Maine and **19.02 V/km** in Virginia and 17.33 in Connecticut. The Upper Midwest region was measured at **12.28 V/km**, at survey site MNB36 in Minnesota.

These data points far exceed the scaled down V/km benchmarks adopted in TPL-007-4.



<u>GMD/ EMP Impacts Will Be Worse Today than 1989:</u> The March 1989 Solar Storm has been deemed by many in the scientific community, including Dr. Love in the most recent USGS Study, to represent a "1-in-40-year" storm.

In the years after 1989, the electric power grid has operated at higher voltage and current levels. Therefore, a solar storm of the intensity of 1989 with identical geospatial and time dependencies would be expected to debilitate the power grid more severely than the 1989 storm. Again, deemed to be a 1-in-40-year storm.

Since the directive of FERC was to establish a benchmark for a 1-in-100-year magnetic storm the need for a higher benchmark is self-evident.

<u>Protecting Against GMD/HEMP Induced Currents Saves Money Annually</u>: Savings to the general U.S. economy on the order of $10B per year can be realized by the implementation of DC-blocking technologies. This is the conclusion of two independent studies into non-spectacular geomagnetic activity. These studies were conducted by **Lockheed Martin, Zurich Services Corp., and NOAA**. See **Appendix D:** "Assessing the Impact of Space Weather on the Electric Power Grid Based on Insurance Claims for Industrial Electric Equipment." See **Appendix E**: "Electric Claims and Space Weather."

<u>Specific Recommendations:</u>

(1) Establish a Realistic GMD/HEMP E3 Protection Standard: Our Coalition respectfully recommends that the SEAB take immediate action to raise the benchmark above the current inadequate 8 V/km to the 85 V/km recommended by the Congressional EMP Commission. **See Appendices F, G & H.**

(2) Immediately Conduct Transformer Testing: As previously recommended on multiple occasions to DOE and to SEAB, we again recommend the Department of Energy test the multi-million-dollar transformer donated by Duke Energy in South Carolina. Despite numerous requests, we still have no real-world data on the effects of EMP on even one transmission system transformer under load (only modeling from industry-funded studies that are not reliable without threat level test corroboration). The importance of this testing is made clear in the recent Journal of Critical Infrastructure Policy article titled **"Large Transformer Criticality, Threats, and Opportunities"** co-authored by leading engineers from the **Savannah River National Laboratory**. **See Appendix I** (and **previous recommendations to SEAB** on 25 January 2022.)

(3) Immediately Install GMD/HEMP E3 Protection Technology: Implement the use of Direct-Current-Blocking mitigation hardware devices proven and successful in operation on the live transmission grid for seven years. **See Appendix J.**

Our Coalition is ready to assist the SEAB and can make personal introductions to numerous experts throughout the country who can help DOE act on the above recommendations.

Respectfully submitted by,

Thomas J. Waller Jr.
Co-Director
Secure-the-Grid Coalition
twaller@centerforsecuritypolicy.org

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Secure-the-Grid Coalition
doug.ellsworth@usapact.org

Appendix A provides links to the comprehensive history on the shortfalls of this benchmark standard, as articulated to FERC by the **Foundation for Resilient Societies**, (2013-2017).
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-A-Foundation-for-Resilient-Societies-Testimony-on-GMD-Protection-Standards.pdf

Appendix B is the 2019 testimony of **Dr. George Baker** before the **U.S. Senate Committee on Homeland Security and Governmental Affairs**.
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendic-C-2019-George-H-Baker-Written-TestimonyFINAL.pdf

Appendix C is a link to a 2017 study conducted by **The National Academies of Sciences**, titled **"Enhancing the Resilience of the Nation's Electricity System."**
http://nap.naptionalacademies.org/24836

Appendix D: "Assessing the Impact of Space Weather on the Electric Power Grid Based on Insurance Claims for Industrial Electric Equipment."
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-E-Space-Weather-2014-Schrijver-Assessing-the-impact-of-space-weather-based-on-insurance.pdf

Appendix E: **"Electric Claims and Space Weather."**
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-F-2015Zurich-ElectricalClaimsandSpaceWeather.pdf

Appendix F: **Examination of NERC GMD Standards and Validation of Ground Models and Geo-Electric Fields**
http://www.firstempcommission.org/uploads/1/1/9/5/119571849/emp_2017_staff_paper_-_gmd_standards_final.pdf

Appendix G: **Electric Reliability Standards for Solar Geomagnetic Disturbances**
http://www.firstempcommission.org/uploads/1/1/9/5/119571849/emp_2017_staff_paper_-_electric_reliability_standards_for_gmd_final.pdf

Appendix H: **Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures**
http://www.firstempcommission.org/uploads/1/1/9/5/119571849/recommended_e3_waveform_for_critical_infrastructures_-_final_april2018.pdf

Appendix I: "Large Transformer Criticality, Threats, and Opportunities" co-authored by Dr. George Baker and leading engineers from the **Savannah River National Laboratory**
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/LARGE-TRANSFORMER-THREATS-OPPORTUNITIESJCIP-PUBLISHED-VERSION.pdf

Appendix J - Secure the Grid Coalition's Comment Regarding Bulk-Power System EO RFI FR Doc. 2020—14668, pg. 4-6, "**Immediately Protect Large Power Transformers from Direct Current**"
https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-D-2020-08-24-excerpt-from-Secured-the-Grid-Coalition-comments-to-DOE-re-Executive-Order-RFI.pdf