CENTER FOR SECURITY POLICY

**November 2025**

# Speed to Power on a Firm Foundation

## *Overcoming Dangerous Assumptions That Put America's Future at Risk*

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**A Report by the Secure the Grid Coalition • Sponsored by the Center for Security Policy**

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**COVER PHOTO**: A utility manager drove out in the middle of the night to capture this photo of the aurora overhead while the GICs from the May 2024 "Gannon" solar storm were in full force - actively triggering SolidGround® over a dozen times at this substation - protecting a critical transformer behind those walls.

# Executive Summary

Our Secure the Grid Coalition[1] has long worked to improve the security of our nation's most critical infrastructure – the electric grid. Importantly, we receive no funding from governments, foreign sources, the utility industry, or any company that can profit from protecting the grid. We exclusively serve the public interest, recognizing that a prolonged electrical blackout would cripple every one of our nation's 16 critical infrastructures, causing immense harm to our economy, our people, and our national security.

Dangerous assumptions about the invulnerability of our nation's transformers to a known risk – solar weather – make it 100% certain that such a blackout will occur in the future. Solar weather induces low frequency, quasi-DC currents in the Earth's crust that travel the path of least resistance, **entering the power grid from the ground** through transformer ground connected neutrals. These are known as geomagnetically induced currents, also called ground-induced currents (GICs). The E3 component of nuclear High Altitude Electromagnetic Pulse (HEMP) attack also produces GICs that can catastrophically damage the power grid via unprotected transformers.

Today, the United States' power grid is completely vulnerable to these harmful GICs. While the Trump Administration is wisely moving forward with a "Speed to Power" initiative to ramp up U.S. generation, it might be assuming that our current grid is secure and that the Nuclear Regulatory Commission (NRC) is responsibly addressing the GIC threat to current and future nuclear power generation. This report will prove that those assumptions are wrong. Our warning is like one issued by thought leaders for 2500 years, from the ancient Greek Aesop's Fables to Jesus Christ's "Sermon on the Mount":

***Whatever you build will stand or fall depending on the firmness of its foundation.***

Our report will demonstrate that DOE's exciting "Speed to Power" initiative and the future of American energy are at risk of failure due to the lack of a firm foundation protecting our electric grid. Absent protections, the next extreme solar storm could collapse the U.S. electric grid, resulting in millions of deaths—and potential loss of continuity of government. Comprehensive protection against solar storms would also mitigate the GICs generated from the E3 Pulse from a HEMP attack. Thus, nationwide GIC protection will rapidly bolster America's nuclear deterrence against peer adversaries and rogue nations seeking to exploit the asymmetric warfare benefits of HEMP attack.

Fortunately, commercially available, thoroughly validated, and cost-effective technology already exists to protect against both—the capacitive neutral blocking device known as SolidGround®. Deploying SolidGround® to protect America's roughly 6000 vulnerable transformers is a one-time cost of approximately $4 billion. This hardware protection will also save the U.S. approximately $10 billion in annual economic losses from the effects of routine solar weather. This is a commonsense investment.

Our present warning and recommendations are a re-addressal of those we voiced previously to DOE in August 2020[2], and to the previous Secretary of Energy in January 2022[3], June 2022[4] and April 2024[5]. Those leaders failed to act. Addressing the GIC threat today will require bold action from leaders at the federal, state, and local level. ***We just hope these leaders will act in time.***

[1] The Secure the Grid Coalition is a group of policy, energy, and national security experts dedicated to strengthening the resilience of America's electrical grid. It is parented by the Center for Security Policy, a 501(c)(3) nonprofit which receives no funding from governments, foreign sources, the electric industry, or any for-profit corporations involved in protecting the grid.

[2] https://securethegrid.com/wp-content/uploads/2021/02/STG-Coalition-Comments-on-DOE-RFI-24-Aug-2020.pdf

[3] https://securethegrid.com/wp-content/uploads/2025/11/STG-Coalition-Letter_to_DOE_on_Supply_Chain_RFI_Jan_2022.pdf

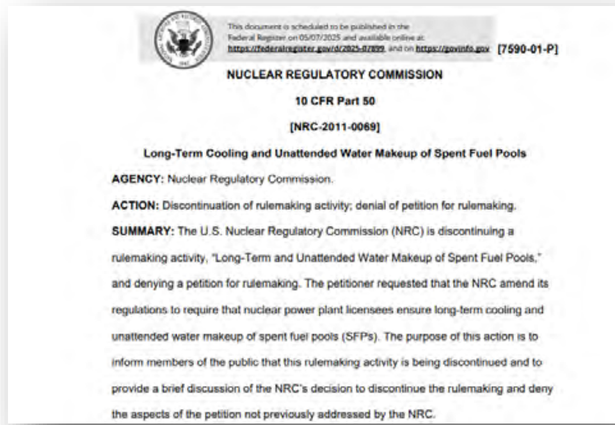
[4] https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/STG-Coalition-Comments-SEAB-13June2022-Final.pdf

[5] https://securethegrid.com/wp-content/uploads/2025/11/STG-Coalition-Comments-SEAB-9April2024-with_Photos_and_Enclosure.pdf

# NRC's Dangerous Decision

On May 7, 2025, the Nuclear Regulatory Commission published in the federal register[6] an extremely consequential decision with respect to the health, safety, and welfare of the American people and the environment of the continental United States. After more than fourteen years of deliberation, NRC denied an important Petition for Rulemaking submitted in February 2011, by the Foundation for Resilient Societies[7]. This Petition, docketed as PRM 50-96,[8] warned of the potentially catastrophic consequences associated with the long-term loss of offsite power for nuclear power plants, a realistic scenario given the vulnerability of America's electric grid to ground induced currents ("GIC") as a result of geomagnetic disturbances (GMDs) produced by the sun and intentional high-altitude electromagnetic pulse (HEMP) attack by enemies of the United States.

PRM-50-96 proposed long-term backup power for spent fuel pools at nuclear power plants because of the potential for human or mechanical error to interrupt power from emergency diesel generators (EDGs) currently employed for back-up power and for which the NRC requires only 7 days of fuel.


This document is scheduled to be published in the Federal Register on 05/07/2025 and available online at https://federalregister.gov/d/2025-07899, and on https://govinfo.gov [7590-01-P]

NUCLEAR REGULATORY COMMISSION

10 CFR Part 50

[NRC-2011-0069]

Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools

**AGENCY:** Nuclear Regulatory Commission.

**ACTION:** Discontinuation of rulemaking activity; denial of petition for rulemaking.

**SUMMARY:** The U.S. Nuclear Regulatory Commission (NRC) is discontinuing a rulemaking activity, "Long-Term and Unattended Water Makeup of Spent Fuel Pools," and denying a petition for rulemaking. The petitioner requested that the NRC amend its regulations to require that nuclear power plant licensees ensure long-term cooling and unattended water makeup of spent fuel pools (SFPs). The purpose of this action is to inform members of the public that this rulemaking activity is being discontinued and to provide a brief discussion of the NRC's decision to discontinue the rulemaking and deny the aspects of the petition not previously addressed by the NRC.

Were these EDGs to fail or run out of fuel during a protracted widespread grid outage, the electric pumps circulating cooling water around the spent nuclear fuel rods could fail, causing the water to boil off.

As the water boils off, the zirconium cladding on the radioactive rods reacts with steam, producing explosive hydrogen gas. At ~1,200–1,800°C, cladding fails, releasing radioactive fission products (cesium-137, iodine-131, etc.) into the "release." At ~2,200°C+, the fuel itself can melt, forming corium and potentially burning through the pool liner. The result could be an airborne radioactive release and possible hydrogen explosion.

Were a major solar storm to blackout the nation's grid for an extended period, numerous nuclear sites could be at risk of this scenario if their EDGs fail or run out of fuel.

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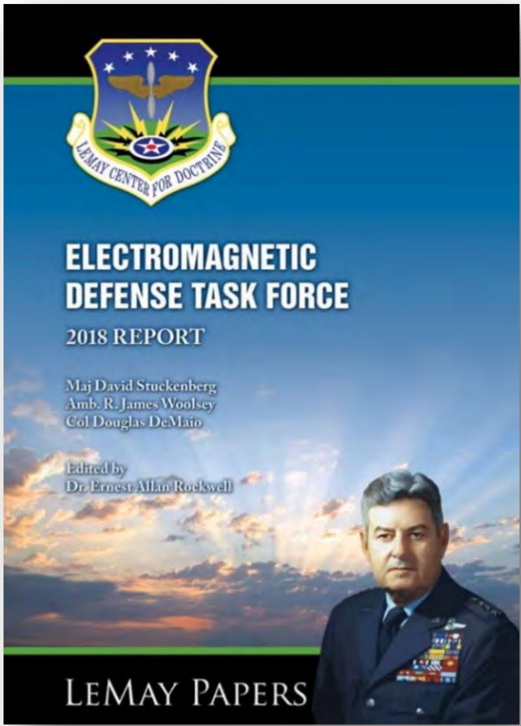
[6] NRC Ruling, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools," https://www.federalregister.gov/documents/2025/05/07/2025-07899/long-term-cooling-and-unattended-water-makeup-of-spent-fuel-pools

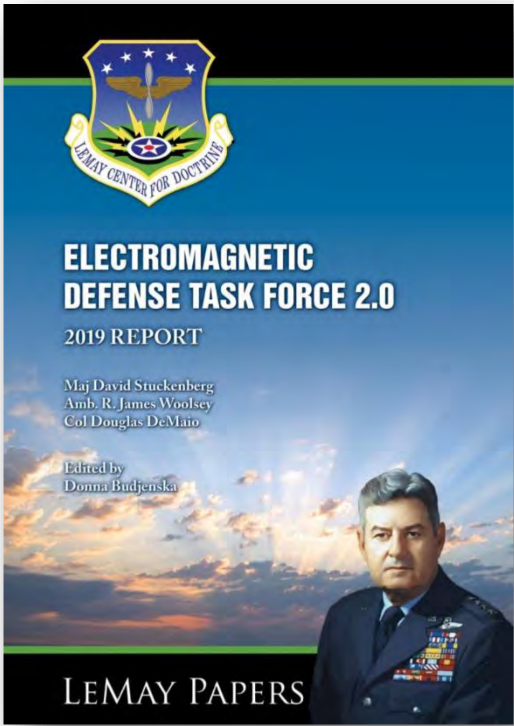
[7] Homepage: Foundation for Resilient Societies, https://www.resilientsocieties.org/

[8] Foundation for Resilient Societies, In the Matter of a Proposed Rulemaking Regarding Amendment of 10 CFR Part 50, "DOMESTIC LICENSING OF PRODUCTION AND UTILIZATION FACILITIES" https://www.resilientsocieties.org/uploads/5/4/0/0/54008795/petition_for_rulemaking_resilient_societies_docketed.pdf

# NRC Disregards USAF EDTF and GAO

Between 2018 and 2020, The White House, Department of Defense (DoD), Department of Energy (DOE), the NRC, and Air University hosted multiple interagency exercises examining the likelihood of prolonged electric power outages and consequent impacts to U.S. nuclear reactors and safety systems – including spent nuclear fuel. The unclassified findings and recommendations were published in Air University's special collection called The LeMay Papers.[9]




These reports[10] [11] and their annexes are the most read documents in Air University history, note the same vulnerabilities associated with previous reports on spent nuclear fuel and promote a series of similar recommendations, including that the NRC mandate the use of existing technologies to ensure long term cooling of spent nuclear fuel. In the EDTF's 2019 report, the NRC staff stated the following (p. 58):

> "*While the NRC expects spent fuel pools would boil off in days or weeks without electrical power for cooling, they do not expect EDG failures. Post-Fukushima safety improvements include instrumentation of spent fuel pools. Potential inability to obtain fuel delivery is a concern. Suggest the Department of Defense (DOD) provide a logistics option/guarantee.*"

There is no such DoD logistics option/guarantee in place to provide fuel to nuclear facilities following a protracted blackout, so NRC's decision to deny PRM-50-96 disregards the USAF EDTF's concerns.

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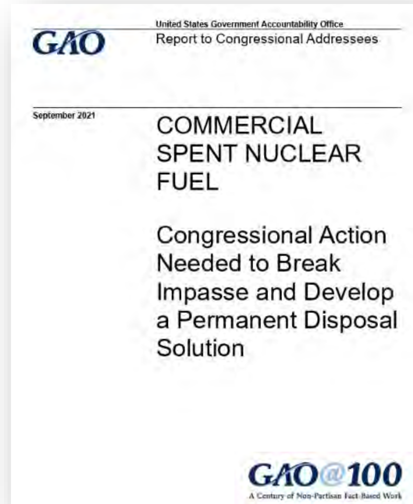
[9] Index: LeMay Papers, https://www.airuniversity.af.edu/AUPress/LeMay-Papers/

[10] Electromagnetic Defense Task Force 2018 Report, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0002_DeMaio_Electromagnetic_Defense_Task_Force.pdf

[11] Electromagnetic Defense Task Force 2019 Report, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0004_ELECTROMAGNETIC_DEFENSE_TASK_FORCE_2_2019.PDF

In September 2021, the Government Accountability Office[12] concurred with the USAF EDTF's concerns that spent fuel "—can pose serious environmental, public health, and security risks if not properly managed," warned that the "amount of spent fuel is growing by about 2,000 metric tons annually," and recommended Congressional action to and "develop a permanent disposal solution."


GAO
United States Government Accountability Office
Report to Congressional Addressees
September 2021
COMMERCIAL SPENT NUCLEAR FUEL
Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution
GAO@100
A Century of Non-Partisan Fact-Based Work

Since there is no permanent disposal solution, the nation must grapple with the fact that thousands of metric tons of this material are located across the country at nuclear sites, and much of it submerged in water that must keep circulating, using power from a grid assumed by the NRC to be invulnerable.

These NRC assumptions are based on major analytical flaws with respect to understanding and analyzing the GIC threat, on a reliance on a defective GIC protection standard, as well as dangerously optimistic assertions about transformer resilience.

# Understanding and Analyzing the GIC Threat

Geomagnetic Disturbances (GMDs) induce a quasi-DC current in the earth that travels the path of least resistance. These "geomagnetically induced currents" – also known as ground induced currents **(GICs) - invade the power grid from the earth** through the neutral to ground connection of high voltage transformers and travel across long transmission lines, causing damage to the largest components on our power grid — transformers, high voltage circuit breakers and large power generators — as well as the electric load.[13] The late-time component (E3) of nuclear high altitude electromagnetic pulse (HEMP) also produces GIC of 100's to 1,000's of Amps/phase.[14]

The field strength generating these GICs is measured in volts per kilometer (V/km) —a measurement that simply describes how strong the electric field is over a given distance—and directly correlates to the GIC magnitude expected to flow into the electric grid.[15] Example: a 2 V/km field strength inducing 100 Amps GIC at a specific location means that a 20 V/km event would generate 1000 Amps GIC at that location.

Thus the "V/km field strength" measurement is a big deal.

In the 1960s both the United States and the Soviet Union performed high-altitude nuclear tests that revealed the destructive power of HEMP. The Soviets chose a test location over an industrialized area

[12] GAO, Report to Congressional Addressees, Commercial Spent Nuclear Fuel, "Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution" https://www.gao.gov/assets/gao-21-603.pdf
[13] "Geomagnetic Disturbances (GMD) Impacts on Protection Systems", https://www.pes-psrc.org/kb/report/022.pdf
[14] Risk-Based National "Infrastructure Protection prioriities for EMP and Solar Storms" by George Baker, July 2017, Report to the EMP Commission & Congressional EMP Commission Report, "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
[15] "The Lehtinen-Pirjola Method Modified for Efficient Modelling of Geomagnetically Induced Currents in Multiple Voltage Levels of a Power Network", https://angeo.copernicus.org/preprints/angeo-2021-63/angeo-2021-63-manuscript-version2.pdf

almost as large as Western Europe —present-day Kazakhstan —and proved that a single HEMP detonation produced strong GICs that severely damaged portions of the Kazakhstan electric grid.[16]

The V/km field strength is also dependent on geomagnetic latitude. GMD events tend to focus at the poles and lose some strength as they head toward the geomagnetic equator.[17] **HEMP E3 works in the opposite direction where the peak V/km field strengths are generated toward the geomagnetic equator** and begin to drop as they head toward the poles.[18] It is notable that the test location the Soviets focused on is at the specific geomagnetic latitude of Washington D.C.

After Congress established the EMP Commission in 2000, the Commission's scientists received important data from Russian scientists on those 1960s HEMP tests, determining that the Soviets achieved a "field strength" of **66 V/km**.[19]

In May 2025, the International Electrotechnical Commission (IEC) — a globally recognized organization that develops and publishes international standards for electrical, electronic, and related technologies, as well as grid operations —updated its recommended HEMP E3 protection standard (IEC 61000-2-9) to **85 V/km.**

Meanwhile, in the United States, there is no enforceable standard to protect our electric grid from the GICs generated by HEMP.

The only protection standard we have is for GMD. This standard, established by the North American Electric Reliability Corporation (NERC) and approved by the Federal Energy Regulatory Commission (FERC) is what NRC assumes is protecting the nation from GIC. This is a major analytical flaw and gravely dangerous assumption.

## NRC Reliance on a Flawed NERC GIC Protection Standard

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

[16] Emanuelson, J., "Soviet Test 184: The 1962 Soviet Nuclear EMP Tests over Kazakhstan" https://www.futurescience.com/emp/test184.html
[17] Popik, T., Baker, G., Harris, G., "Electric Reliability Standards for Solar Geomagnetic Disturbances", Comments submitted to the Federal Energy Regulatory Commission https://securethegrid.com/wp-content/uploads/2018/06/2017-Electric-Reliability-Standards-for-Solar-Geomagnetic-Disturbances.pdf
[18] Congressional EMP Commission, "Recommended E3 Waveform for Critical Infrastructures", https://securethegrid.com/wp-content/uploads/2018/05/2017-Recommended-E3-Waveform-for-Critical-Infrastructures-FINAL-April2018.pdf, 2017.
[19] Congressional EMP Commission, "Executive Report on Assessing the Threat from Electromagnetic Pulse (EMP)", 2017. https://securethegrid.com/wp-content/uploads/2018/05/2017-Executive-Report-on-Assessing-the-Threat-from-EMP-FINAL-April2018.pdf Executive Report on Assessing the Threat from EMP 18April2018

grid equipment such as high voltage transformers.[20] 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[21] (e.g. **only ~ 2 V/km for the Washington D.C. area at 49-degrees** which is the precise geomagnetic latitude as the 66 V/km achieved in 1962 by the Soviet HEMP testing over Kazakhstan).

This standard, TPL-007, has progressed through four iterations over nearly a decade and its latest version, TPL-007-4, established a well-developed set of requirements for GMD vulnerability assessment process, modeling timeframes, required models needed for complete analysis, and violation severity levels but remains critically deficient in TPL-007-1 as shown in "Attachment 1 Calculating Geoelectric Fields for the Benchmark and Supplemental GMD Events.[22]"

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) over Quebec.

The inadequate benchmark has remained in place despite the science-based criticisms of both the sources and methods employed in its establishment. These well-founded and scientifically based criticisms came from both the nonprofit Foundation for Resilient Societies[23] and by the chief physicist for the Congressional EMP Commission, Dr. George Baker[24] before the U.S. Senate Committee on Homeland Security and Governmental Affairs.

In its 2017 report titled "Enhancing the Resilience of the Nation's Electricity System[25]," 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.

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."**[26]

> 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

[20] Popik, T., Testimony of the Foundation for Resilient Societies, March 1, 2016 Technical Conference, Docket No. RM15-11-000. https://www.ferc.gov/sites/default/files/2020-08/Popik-ResilientSocieties.pdf

[21] Waller, T., Ellsworth, D., written comment submitted to the Secretary of Energy Advisory Board, 2022. https://www.energy.gov/sites/default/files/2022-07/STG-Coalition-Comments-SEAB-13June2022-Final.pdf

[22] https://www.nerc.com/pa/Stand/Reliability%20Standards/TPL-007-1.pdf

[23] https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-A-Foundation-for-Resilient-Societies-Testimony-on-GMD-Protection-Standards.pdf

[24] https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendic-C-2019-George-H-Baker-Written-TestimonyFINAL.pdf

[25] http://nap.naptionalacademies.org/24836

[26] Love, J., Hayakawa, H., Cliver, E., "Intensity and Impact of the New York Railroad Superstorm of May 1921", 2019. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019SW002250

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."[27]

Geomagnetically Induced Currents (GICs) realized during the magnetic storm of March 1989 caused a blackout in Québec, Canada. The 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.

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[28] and **17.33 V/km**[29] in Connecticut. The Upper Midwest region was measured at **12.28 V/km**, at survey site MNB36 in Minnesota.[30]

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

**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

[27] Love, J., Lucas, G., Rigler, J., Murphy, B., Kelbert, A., Bedrosian, P., "Mapping a Magnetic Superstorm: March 1989 Geoelectric Hazards and Impacts on United States Power Systems", 2022. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW003030
[28] Ibid., p1 https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW003030
[29] Ibid., p 19 https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW003030
[30] Ibid., p 11 https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021SW003030

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:[31]

- 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

## Transformer Damage from the 2003 South Africa Solar Storm

In 2003, a very-low-level solar event occurred that affected South Africa's grid. Joseph H. McClelland, director of the Federal Energy Regulatory Commission's Office of Energy Infrastructure Security, said it was one-fiftieth the size of the 1921 "Railroad Storm" event, but it lingered on for a period of days. Mr. McClelland continued in his testimony before a 2015 U.S. Senate Committee hearing, that while the grid in South Africa did not collapse immediately, it did damage expensive utility substation equipment that terminally failed over a period of time. Instead of immediate damage, utility equipment saw prolonged exposure to the GIC event and, over a period of months. According to McClelland, "12 transformers were lost due to that event."[32]

## GMD/ EMP Impacts Will Be Worse Today than 1989 and 2003

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 and 2003, the electric power grid continued to expand, becoming more interconnected and operating at higher voltage and current levels. According to a 2013 report from Lloyd's, "The higher voltage lines offer less resistance, and therefore larger [GIC] currents flow relative to lower voltage lines when exposed to the same surface electric fields."[33] 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, it was 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.

## 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. [See images on next page].

[Note: More information on the dangerously lethargic FERC/NERC rulemaking process is provided below in Appendix 1.]

[31] 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

[32] Committee on Homeland Security and Governmental Affairs, United States Senate, "Protecting the Electric Grid from the Potential Threats of Solar Storms and Electromagnetic Pulse", 2015. https://www.govinfo.gov/content/pkg/CHRG-114shrg22225/pdf/CHRG-114shrg22225.pdf

[33] Lloyd's, "Solar storm Risk to the North American Electric Grid", 2013. https://assets.lloyds.com/assets/pdf-solar-storm-risk-to-the-north-american-electric-grid/1/pdf-Solar-Storm-Risk-to-the-North-American-Electric-Grid.pdf

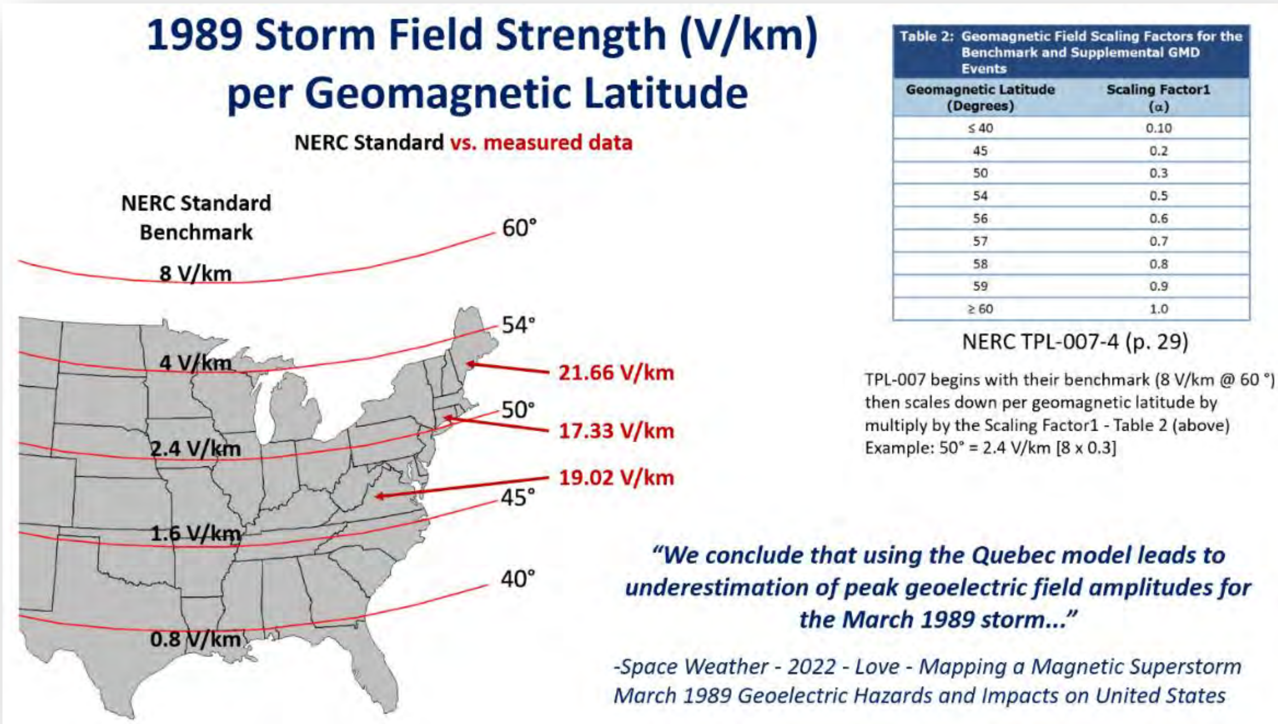
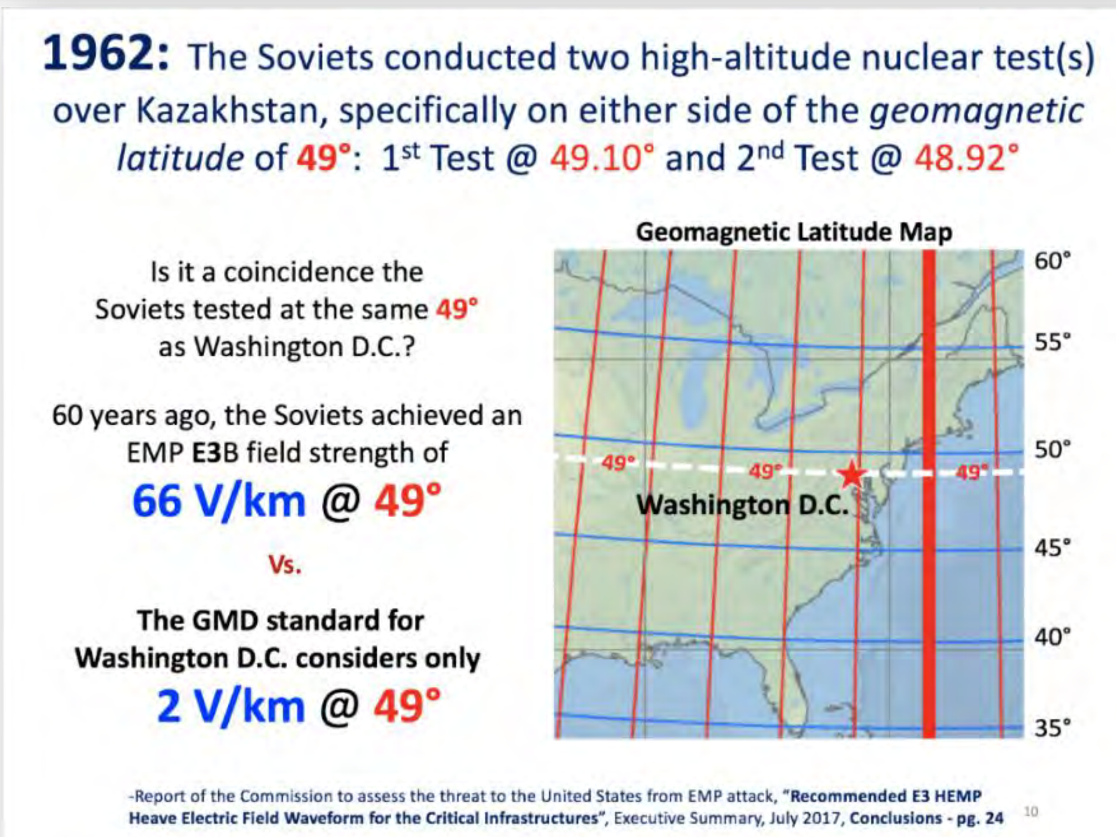


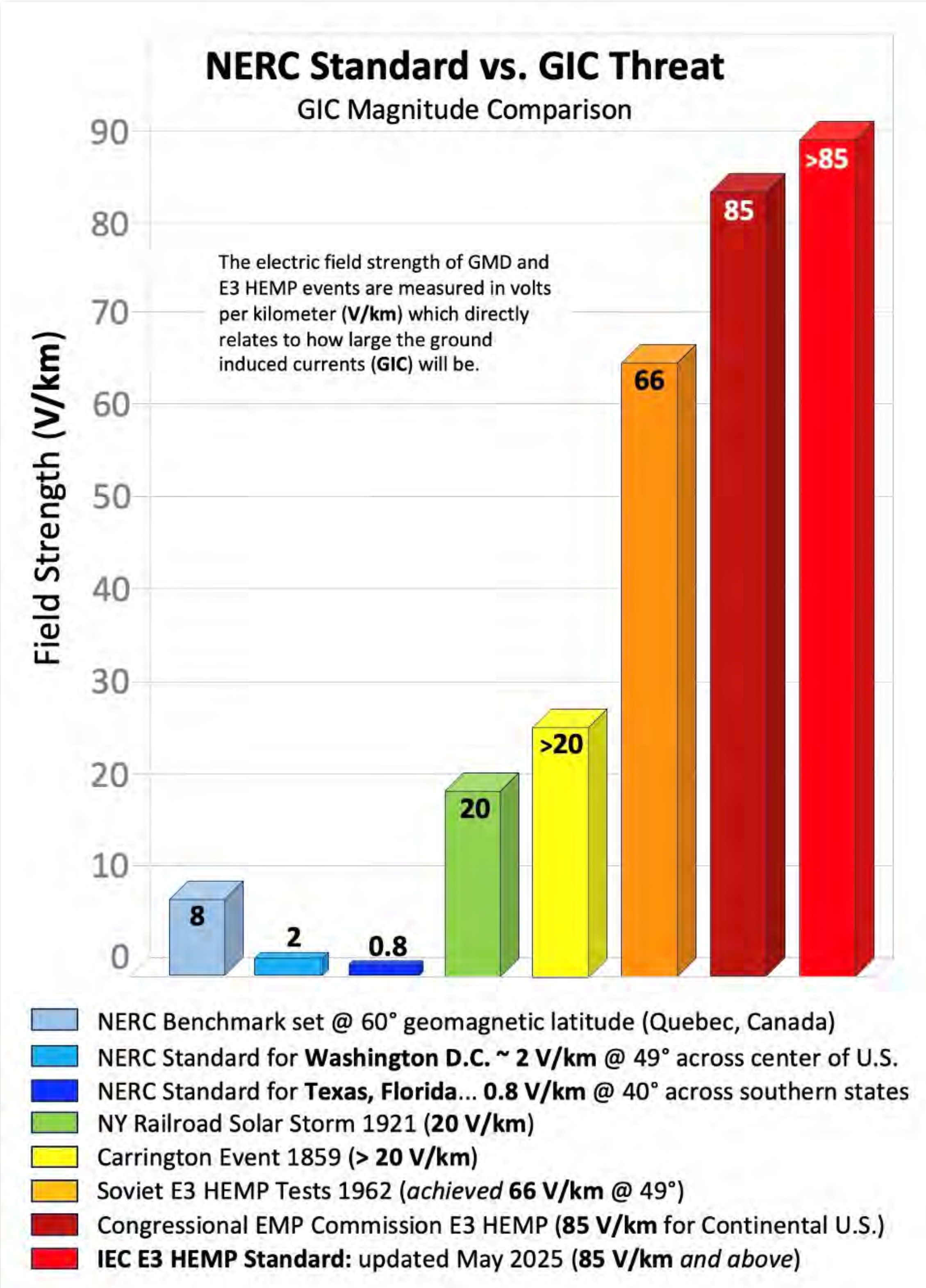


Table 2: Geomagnetic Field Scaling Factors for the Benchmark and Supplemental GMD Events

| Geomagnetic Latitude (Degrees) | Scaling Factor1 (α) |
|---|---|
| ≤ 40 | 0.10 |
| 45 | 0.2 |
| 50 | 0.3 |
| 54 | 0.5 |
| 56 | 0.6 |
| 57 | 0.7 |
| 58 | 0.8 |
| 59 | 0.9 |
| ≥ 60 | 1.0 |



**NERC Standard Vs. the Real Threats**



Moreover, geomagnetic storm intensity as reported by NOAA and others that study the solar phenomena is measured in nanoteslas (nT) for purposes of comparing events. This does not correctly compare, nor is it the function of solar scientists to compare, the extent of damage that a solar event could inflict on the power grid. The correct measurement to compare the intensities of ground induced currents (GIC) from a solar event is nanotesla per minute (nT/min). It is the rate of change that is the determining factor in the magnitude of ground-induced currents. According to Faraday's Law of Induction, a faster rate-of-change in magnetic flux results in a greater induced voltage. The nT comparison of solar storms is inaccurate and misleading when considering the space weather threat to our power grid. Example: it is the nT comparison that leads some to the belief that the 1989 Quebec Storm was 50% the estimated size of the 1859 Carrington Event when in actuality it was less than 10% the size as it relates to GIC magnitude due to the rate of change (nT/min.)

# NRC Dangerous Assumptions on Transformer Resilience to GIC

In 2018, Mr. Scott McBride, Infrastructure Security Manager at the Department of Energy's Idaho National Laboratory (INL), testified[34] before the US Senate, warning that "The Nation's High Voltage (HV) and Extra High Voltage (EHV) power grid contains a few thousand large power transformers which are potentially vulnerable to the threat of GMD events" and that "These transformers are very expensive to build and typically have long lead times of eighteen to twenty-four months."

Since then, production lead times on large power transformers have only grown.

Last year, **Utility Dive**[35] reported that the National Electrical Manufacturers Association (NEMA) warned that "delivery of a new transformer ordered today could take up to three years" and Hitachi Energy specified that, "transmission scale unit lead times are now three years to six years, with specialized transformers taking the longest time."

Those large transmission scale transformers mentioned by Hitachi are custom built, cost tens of millions of dollars, and are the MOST vulnerable to GICs, per their design.

Yet, in **NRC's decision to deny PRM-50-96**,[36] the commission stated the following:

> ***"Currently, more than 80 percent of extra high voltage transformers are resistant against the effects of geomagnetically induced currents."***

This statement by the NRC fails to consider the transformer design and real-world operational conditions of power transformers in the U.S. electric grid. Conditions that need to be considered in the effects of GIC on power transformers are the age of the power transformer, its insulating oil condition, and transformer loading at the time of the GIC. These are all factors in the susceptibility of power transformer damage and failure.

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[34] Statement of Scott A. McBride, Infrastructure Security Manager: National & Homeland Security, Idaho National Laboratory, before the United States Senate Homeland Security & Governmental Affairs Committee, September 13, 2018. https://www.hsgac.senate.gov/wp-content/uploads/imo/media/doc/Testimony-McBride-2018-09-13.pdf

[35] Utility Dive, "Transformer supply bottleneck threatens power system stability as load grows", Feb. 12, 2025. https://www.utilitydive.com/news/electric-transformer-shortage-nrel-niac/738947/

[36] Nuclear Regulatory Commission denial of PRM 50-96, Docket ID NRC-2011-0069, 2025. https://www.nrc.gov/docs/ML2427/ML24275A091.pdf

The **"Large Power Transformer and The U.S. Electric Grid"**[37] publication by the Department of Energy (DOE) Office of Electricity stated:

> "*The average age of installed LPTs in the United States is approximately 38 to 40 years, with 70 percent of LPTs being 25 years or older. While the life expectancy of a power transformer varies depending on how it is used, aging power transformers are potentially subject to an increased risk of failure."* [38]

The aging of power transformers in the U.S. Electric Grid increases their susceptibility to GIC due to insulating oil condition and coil conditions. Older power transformers are subject to mechanical stress of the coil due to inrush currents, system faults, and coil degradation.[39] Additionally, transformer loading at the moment of a GMD event will contribute to the power transformer's susceptibility to GIC.[40] Mechanical stress of the coil in power transformers increases the susceptibility of transformer damage and failure due to GIC.[41]

Extra High Voltage (EHV) power transformers use an insulating medium for the transformer coil. Most large power transformers use mineral oil for the power transformer insulating and cooling medium.[42] A lesser proportion of large power transformers use bio-based oil, such as FR3, which has a higher flashpoint and is considered environmentally better due to its biodegradability.[43] However, this insulation medium is still susceptible to forms of contamination that will make it susceptible to the effects of GIC.[44] Given the age of the majority of the power transformers in the U.S. Electric Grid, it is necessary to question the monitoring, testing and maintenance of power transformers in the U.S. Electric Grid.

Maintenance of power transformers includes insulating oil testing to determine the condition of the insulating oil. Necessary analysis includes Dissolved Gas Analysis (DGA), which detects arcing, overheating and insulation failure, Moisture Analysis, Dielectric Breakdown Voltage, which determines oil insulating capacity, Flash Point, Interfacial Test, which tests oil contamination, and Furan Test, which determines the paper content in the insulating oil to determine coil insulation breakdown.

As power transformers age the condition of the insulating oil becomes a critical factor in enhancing the effect of GIC in damage and power transformer failure. The need to test power transformer insulating oil and replacement is a key factor in the power transformer's susceptibility to the damaging effects of GIC.

In a **Market Reports World**[45] report titled "Transformer Oil Testing Market Size, Share, Growth, and Industry Analysis, By Type (Dissolved Gas Analysis, Moisture Analysis, Dielectric Breakdown Voltage,

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[37] U.S. Department of Energy, Infrastructure Security and Energy Restoration
Office of Electricity Delivery and Energy Reliability, "Large Power Transformers and the U.S. Electric Grid", 2014 Update. https://www.energy.gov/sites/default/files/2014/04/f15/LPTStudyUpdate-040914.pdf

[38] https://www.energy.gov/sites/default/files/2014/04/f15/LPTStudyUpdate-040914.pdf - page vi

[39] Steurer, M., and Frohlich, K., "The impact of inrush currents on the mechanical stress of high voltage power transformer coils," in *IEEE Transactions on Power Delivery*, vol. 17, no. 1, pp. 155-160, Jan. 2002 https://ieeexplore.ieee.org/document/974203

[40] NERC, "2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System", https://www.nerc.com/globalassets/programs/rapa/gmd/reference-documents/nerc_gmd_report_2012.pdf

[41] DOE, "Large Power Transformer Resilience", 2024, https://www.energy.gov/sites/default/files/2024-10/EXEC-2022-001242%20-%20Large%20Power%20Transformer%20Resilience%20Report%20signed%20by%20Secretary%20Granholm%20on%207-10-24.pdf

[42] Ibid.

[43] Cargill, "Dielectric Fluids", https://soltexinc.com/wp-content/uploads/2024/01/FR3-Data-Sheet.pdf

[44] Department of Electrical Engineering, Blekinge Institute of Technology, "Properties of Transformer Oil that Affect Efficiency" https://www.diva-portal.org/smash/get/diva2%3A829952/FULLTEXT01.pdf

[45] Market Reports World, "Transformer Oil Testing Market Size, Share, Growth, and Industry Analysis, By Type: Regional Insights and Forecast to 2033", https://www.marketreportsworld.com/market-reports/transformer-oil-testing-market-14716359#:~:text=Transformer%20Oil%20Testing%20Market%20Overview.%20The%20Transformer,CAGR%20of%205.8%25%20from%202025%20to%202033.

Flash Point, Interfacial Tension, Others), By Application (Mineral Oil, Non Mineral Oil), Regional Insights and Forecast to 2033" (2024) the report found the following concerning utility power transformer insulating oil testing:

> "*In the United States, over 60% of utility companies have integrated transformer oil test data into centralized asset management systems*."

While the percentage is above half of the utilities in the U.S., it still does not indicate the frequency of testing, the test results, or the amount of maintenance done to improve the insulating oil in the large power transformers. If large power transformers insulating oil is not tested on a regular, consistent interval and maintained, then the condition of the large power transformer, its core and coil will degrade. This, combined with the age of the core and coil of the transformer, will increase the susceptibility of the large power transformer to GIC.

Additionally, when the total number of large power transformers is considered, the 40% of utilities that give no indication of power transformer insulating oil testing and maintenance is a cause for grave concern with respect to those large power transformers' susceptibility to GIC.

All these factors taken together, indicate that the susceptibility of large power transformers in the U.S. electric grid is not negligible and that they are not resistant to GIC-induced damage and failure. In review of the real-world operations of the U.S. electric grid by way of its large power transformers, the view taken by the NRC that "*Currently, more than 80 percent of extra high voltage transformers are resistant against the effects of geomagnetically induced currents.*" is misleading and without foundation.

# GICs Could Spell the Death of Our Nation

In the 2008 House Armed Services Committee hearing, Commission Chairman Dr. William R. Graham and Commissioner Dr. Lowell Wood emphasized that the U.S. population is overwhelmingly urbanized and non-agricultural, at approximately 83 percent, meaning only a small fraction has the means to survive without the grid. Dr. Graham noted that a post-EMP society would resemble a pre-industrial, rural economy in which perhaps only 10% of the population could sustain itself, "about 30 million people.[46]"

According to a 2017 report by the **U.S. Senate Committee on Homeland Security**,[47]

> "A successful nuclear electromagnetic pulse (EMP) attack against the United States **could cause the death of approximately 90 percent of the American population**. Similarly, a geomagnetic disturbance (GMD) could have equally devastating effects on the power grid."

This projection that as much as 90% of the U.S. population could perish within a year after a nationwide loss of electricity was not based on the direct physical effects of EMP, but on the cascading collapse of every life-sustaining system in modern society once power is removed.

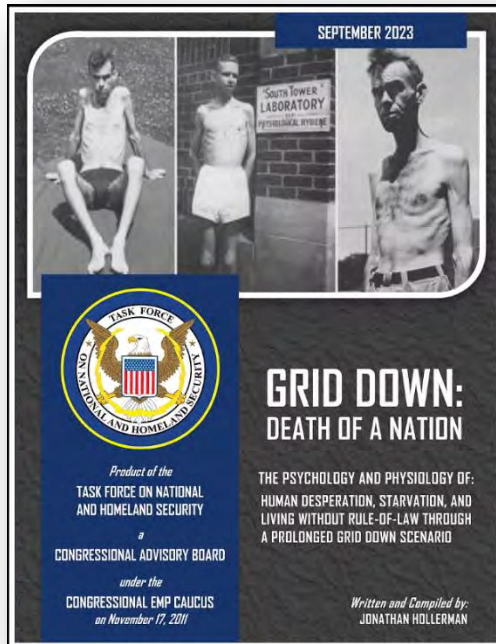
The United States operates on highly interdependent, "just-in-time" supply chains with minimal reserves of food, fuel, medicines, and treated water. Diesel supplies—critical for transportation, generators, water

[46] Source: "Threat Posed by Electromagnetic Pulse (EMP) Attack", Committee on Armed Services, House of Representatives, 2008. https://www.congress.gov/110/chrg/CHRG-110hhrg45133/CHRG-110hhrg45133.pdf ]

[47] Report of the Committee on Homeland Security and Governmental Affairs, United States Senate and its Subcommittees, 2017. https://www.govinfo.gov/content/pkg/CRPT-115srpt12/pdf/CRPT-115srpt12.pdf

treatment, and hospital operations—exist largely at point of sale or in transit and would be rapidly exhausted. Without electricity, water and sanitation systems fail, food distribution halts, hospitals lose backup power without fuel, and fuel production ceases. The resulting shortages, disease, and inability to maintain order and social stability quickly lead to law of the jungle in urban environments.

In an effort to examine the analysis of the Senate and EMP Commission, the U.S. Air Force Electromagnetic Defense Task Force asked for the assistance of Air Force Veteran and Survival Evasion Resistance and Escape (SERE) Instructor Jonathan Hollerman. At the request of EDTF Staff, Hollerman published his findings in an eye-opening report on the psychology and physiology of Human Desperation, Starvation, and living in a world Without-Rule-of-Law.




The report, originally published in 2019 for the USAF EDTF, was updated in 2023, and titled **Grid Down: Death of a Nation**.[48] The report proved analytically that a widespread and protracted blackout would indeed lead to the death of most of America's population – likely more than predicted by the Congressional EMP Commission and the U.S. Senate. This underscores the grave need to protect our grid from the GIC threat ignored by NRC.

# GICs Cost America Billion(s) of Dollars Annually

The fact that a HEMP or large solar storm could devastate these critical assets is only part of the bad news.

The other bad news is that even minor solar storms produce harmful GICs that pass through these "high risk design" large power transformers, causing them to induce harmonics which ruin downstream equipment —producing economic losses in the United States of **approximately $10 billion each year**.

That statistic comes from the rigorous statistical analysis of the highly credible Swiss-based global insurer Zurich, based on insurance claims filed, in its 2015 study titled "Electric Claims and Space Weather",[49] which drew upon previous joint research[50] between Zurich, Lockheed Martin, and the National Oceanic and Atmospheric Administration (NOAA).

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[48] Hollerman, J., GRID DOWN: Death of a Nation, 2023. https://www.griddownconsulting.com/grid-down-report
[49] Zurich, "Electrical Claims and Space Weather: Measuring the visible effects of an invisible force, 2015. https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-F-2015Zurich-ElectricalClaimsandSpaceWeather.pdf
[50] C. J. Schrijver, R. Dobbins2, W. Murtagh, S. M. Petrinec, "Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment", 2014. https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-E-Space-Weather-2014-Schrijver-Assessing-the-impact-of-space-weather-based-on-insurance.pdf

Adjusted for inflation, the Zurich estimates suggest America is now, in 2025 dollars, suffering $15 billion in losses annually because we've gotten it wrong and failed to block these routine GICs from entering the grid.

# "Operating Procedures" Are Not the Answer to GIC Threat

Despite the grave risks to nuclear safety and to the very survival of the American people, the electric power industry claims that "operating procedures" can mitigate the known hazards of GIC. It is important to note that **operating procedures cannot block GIC from entering an operating grid**. Instead, these procedures attempt to mitigate GIC hazards after they have entered and cascaded across the grid. One industry countermeasure is the use of "Static VAR Compensators" or "SVCs" which are traditionally used to help grid operators stabilize the system.[51]

Before explaining how this procedure can actually be counterproductive, it is worth reviewing how GICs from GMD and E3 HEMP damage the grid.

From the perspective of transformer physics, both GMDs and HEMP E3 events induce low-frequency, quasi-direct currents **in the earth** (GIC) which travel the path of least resistance and invade the electric power grid through the ground connected neutrals of transformers and travel across transmission lines. Transformers are designed exclusively for alternating current (AC) operation, with magnetic cores that function optimally under balanced, sinusoidal conditions. When direct current enters the windings, it biases the core toward saturation on one half of the AC waveform. This "half-cycle saturation" produces three major harmful effects: generation of harmonics that disrupt the stability of the wider grid and damage components, intense localized heating of windings and structural components, and reactive power consumption.

Harmful intensities of these harmonics increase as GIC increases and are further enhanced as they travel through transmission into progressively lower voltage distribution paths, causing damage and wear on customers' equipment. The heating effect can damage insulation, accelerate aging, or in extreme cases cause catastrophic transformer failure. The harmonic distortion and reactive power consumption triggered by saturation can depress transmission voltages over large areas.[52] [53] [54]

## Employing SVCs – A Countermeasure That Increases the Damage

As transmission voltages over large areas are depressed, system operators are forced to deploy voltage-supporting capacitors known as "Static VAR Compensators" or "SVCs."

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[51] Midea-Hiconics, "Understanding SVC: The Role of Static Var Compensators in Modern Power Systems", 2024. https://www.hiconics-global.com/understanding-svc-the-role-of-static-var-compensators-in-modern-power-systems.html

[52] Congressional EMP Commission, "Critical National Infrastructures", 2008. https://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf

[53] NERC, 2012 Special Reliability Assessment Interim Report: "Effects of Geomagnetic Disturbances on the Bulk Power System", https://www.nerc.com/globalassets/programs/rapa/gmd/reference-documents/nerc_gmd_report_2012.pdf

[54] Jointly-Commissioned Summary Report of the North American Electric Reliability Corporation and the U.S. Department of Energy's November 2009 Workshop: "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System", 2010. https://www.energy.gov/sites/prod/files/High-Impact%20Low-Frequency%20Event%20Risk%20to%20the%20North%20American%20Bulk%20Power%20System%20-%202010.pdf

This procedure can benefit the operator during small scale solar impacts but are precisely the wrong thing to do during large-scale solar or E3 HEMP.

With SVCs in place, the problems not only remain but are exacerbated as GIC and induced harmonics increase, as does the duration of a continuing event. VAR support is a very dangerous approach for large GIC events.

As grid operators are attempting to solve one issue (VAR loss/voltage drop) they are opening a host of other issues increasing the likelihood of a catastrophic outcome for critical grid assets such as transformers, circuit breakers, power generators and the load.

According to NERC:[55]

> *"Reactive power absorption from saturated transformers would tend to lower system voltages. Tripping of reactive power support from capacitor banks and SVCs due to high harmonic currents at a time when the saturated transformers increase the VAR demand, creates the scenario for voltage collapse."*

This supports the idea that one mechanism (voltage drop due to reactive losses) is being addressed by operators, but **additional stress** (harmonics, saturated transformers, loss of reactive support) appears.

According to EPRI:[56]

> *"The most vulnerable power equipment includes* ***capacitor banks and synchronous generators****.* ***High harmonic current levels can either damage this equipment or force their protective tripping. Capacitor banks and generators*** *supply the majority of a system's* ***reactive power resources****, and* ***their tripping or failure remove reactive sources at a time when the grid is subjected to the significantly increased reactive power demands*** *of the GIC-saturated transformers."*

Thus, **operating procedures to utilize SVC's or turn up generation and provide replacement VARs** to make up for VAR losses (due to transformers half-cycle saturating from GIC) can help prop up the voltage and **prevent grid collapse during small GIC events but puts the power grid at greater risk of catastrophic damage during a large GIC event**.

Moreover, GIC induced harmonics and risk of thermal damage increase as GIC increases and equipment is exposed to GIC for a longer period of time. Relying on VAR support to prop up the voltage during a large GIC event to keep the grid up longer as GIC continues to climb puts components across the grid at greater risk of permanent damage (including at the Distribution level as harmonics generated at the Generation and Transmission level continue to grow as they travel towards load).

From a NERC-hosted EIS Council Summit Transcript:[57]

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[55] Op. Cit.. NERC, 2012, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System" https://www.nerc.com/globalassets/programs/rapa/gmd/reference-documents/nerc_gmd_report_2012.pdf

[56] EPRI, "Analysis of Geomagnetic Disturbance (GMD) Related Harmonics", 2014. https://www.epri.com/research/products/000000003002002985

[57] Transcripts: The Electric Infrastructure Security Summit III, London, 2012 https://www.nerc.com/globalassets/programs/rapa/gmd/reference-documents/london_transcript_112012.pdf

> *"In general while this is defining the envelope here and we can see it goes up in the case of some of the transformers as much as about 60 amps per phase the reality is a severe geomagnetic storm as we know from the simulations done from collected data making intelligent extrapolations from that collected data, we know that there will be transformers which have for some of the most severe and extreme events that we're aware of much higher GIC levels than 50 amps per phase, maybe in some cases approaching nearly 1,000 amps per phase. We begin to remove some doubt about what may happen to these design transformers."*

We can see that it is critical to block GIC and prevent it from entering the power grid. Keeping the grid up by way of VAR supply will lead to the inevitable decision to intentionally open phase breakers (or unintentionally due to harmonics or E1) and will be at the worst possible time with high GIC across those breakers. AC Circuit Breakers require "zero crossings" to break AC. They are not designed to break GIC. Attempting to utilize AC breakers to break GIC is a misapplication and can lead to catastrophic damage.

# "Missile Defense" Is Not the Answer to GIC Threat

While missile defense systems play an important role in protecting the United States from certain classes of strategic attack, they are not, and cannot, be considered a solution to the threat posed by the E3 component of high-altitude electromagnetic pulse (HEMP) weapons. Understanding these limitations is critical for policymakers, because overreliance on missile defense as a singular protective measure risks leaving the nation exposed to catastrophic grid failure.

### Effective Missile Defense is Not the Solution

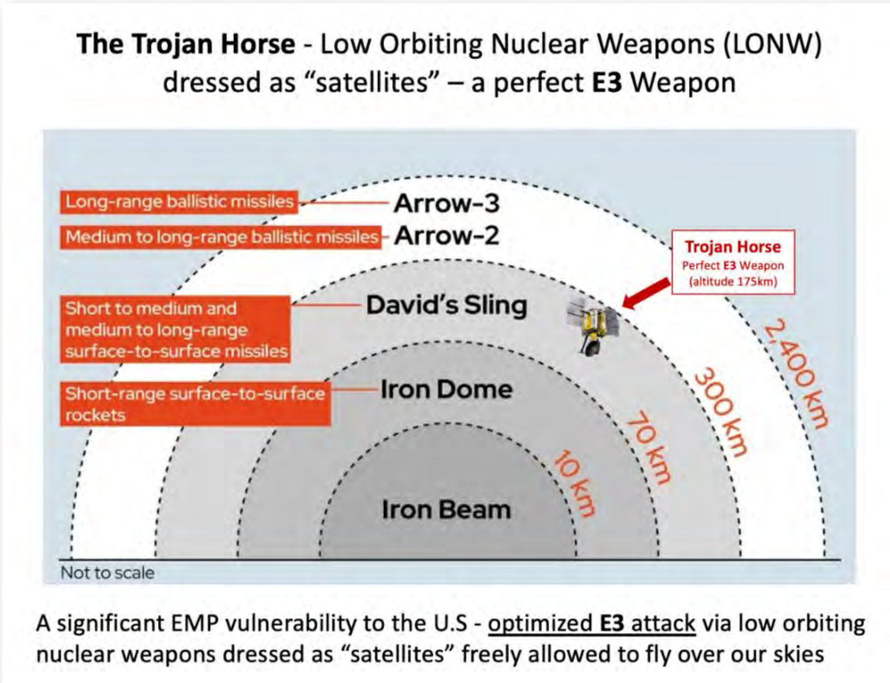
To recap: Unlike lower-altitude nuclear strikes, high-altitude nuclear detonations do not cause blast or thermal effects at ground level but instead induce powerful electromagnetic fields over continental-scale areas. North America is surrounded by oceans making it the perfect EMP target as the enemies of the United States will not impact their own grid or their allies when attacking with high-altitude electromagnetic pulse. The E3 component of this high-altitude electromagnetic pulse which can last for more than 1,000 seconds (IEC 61000-2-9, Edition 2.0 2025-05), mimics the quasi-direct current effects of a severe geomagnetic storm, but with field levels ten times stronger than a severe GMD event. All of this drives extreme ground induced currents (GICs) into the grid and threatens widespread transformer saturation, harmonics, damage and collapse of the bulk power system.

## Payloads in Satellites in Low-Earth Orbit are at a Prime Altitude for E3 HEMP

Peak E3 HEMP field strength (resulting in maximum GIC) only requires a small 100-kiloton nuclear weapon yield, burst at altitudes between 140 and 500 kilometers above the Earth's surface. The required altitude for maximum E3 and the weapon's light weight make low-orbiting satellites an optimal delivery system for this sort of attack. Missile defense systems, such as Israel's Iron Dome or the U.S. Ground-based Midcourse Defense program, are designed primarily to intercept incoming ballistic missiles during the midcourse or terminal phases of ballistic missile flight. While these systems can, in theory, intercept a missile intended for a high-altitude detonation, several factors limit their real-world effectiveness against this type of threat:

First, **a missile successfully intercepting a nuclear weapon at high-altitude can cause an E3 HEMP event** as these E3 weapons can and are designed with special fusing mechanisms[58] to detonate upon interception and/or sensor detection of an approaching missile.

Second, a nuclear weapon disguised as a low orbiting satellite would provide many attack opportunities. Low orbiting satellites are the easiest to launch and there is no effective way to detect a nuclear warhead "dressed" inside of a satellite as many 1,000s cross over the U.S. each day.




Third, trajectory and timing present unique challenges. An adversary could use a **Fractional Orbital Bombardment System (FOBS)**[59] such as the Soviet Union developed during the Cold War, or a similar delivery platform to place a nuclear warhead into low-Earth orbit, then de-orbit it over the continental United States from an unexpected direction, such as from the south. This approach could bypass much of the U.S. early-warning radar coverage, which is optimized for threats approaching from the north, and significantly compress the decision and intercept window.

Fourth, multiple attacks or the use of decoys could overwhelm defensive systems. An adversary need not achieve perfect accuracy with multiple warheads or payloads; a single nuclear weapon detonated at high-altitude over the continental U.S. will have nationwide effects on the grid. If just one of several inbound payloads evades interception, the attack succeeds in its objective of generating E3 ground induced currents in our electric grid.

[58] "Electromagnetic Pulse Threats to U.S. Military and Civilian Infrastructure", Hearing before the Military Research and Development Subcommittee of the Committee on Armed Services, House of Representatives, 1999.
https://commdocs.house.gov/committees/security/has280010.000/has280010_0.htm
https://www.empcommission.org/docs/empc_exec_rpt.pdf
[59] Thomas L. Hughes to the Secretary, "Tests of Soviet Fractional Orbital Bombardment System (FOBS)," Intelligence Note 669, 14 August 1967.
https://nsarchive.gwu.edu/document/21718-document-28-thomas-l-hughes-secretary

Fifth, the geography of missile defense coverage is not uniform. Current U.S. interceptors are concentrated in specific locations, leaving potential gaps in coverage for trajectories that exploit the curvature of the Earth or blind spots in radar networks, or as described, coming from the south with a northern trajectory.

### Missile Intercept Cannot Halt/Deter the Vagaries of the Sun

Finally, even the most effective defense systems cannot address the other origin of GIC threats: our sun. A Carrington-class coronal mass ejection would produce GIC effects over much the same geographic footprint as an E3 HEMP event, but no missile defense system can intercept or deflect a burst of charged particles emitted by the Sun.

This is why a dual-track approach is essential: continued investment in missile defense to intercept certain classes of threats, combined with the deployment of proven, cost-effective GIC-blocking technology across critical grid assets to protect against E3 HEMP and GMD. Without the second component of grid hardening, the United States remains exposed to a scenario in which an E3 HEMP attack, or the occurrence of a severe solar storm, could lead to nationwide power collapse.

# The Validated Solution to GIC Threat is Available

As Mr. Scott McBride of Idaho National Laboratory shared with the Senate in 2018:[60]

> *"**A mature, tested and validated technology** has been developed and represents one potential solution to protect HV and EHV power transformers from the threat of both GMD's and EMP's...the EMP hardened transformer Neutral Blocking Device (NBD)…marketed as **SolidGround®**."*

SolidGround®, produced by **EMPRIMUS**,[61] simply attaches to the neutral ground cable of a transformer, blocking GIC at the point of entry before it enters the grid.

Simple connection to transformers

It is a closed system (no tampering with existing AC controls) and is installed on the neutral ground cable of HV transformers. No customer load flows through the device. When quasi-direct current from a GMD or an E3 HEMP event attempts to enter from the earth through the neutral grounding connection of the transformer, the SolidGround® device automatically interrupts its path, eliminating the DC bias that causes half-cycle core saturation. This prevention of half-cycle saturation **removes the heating, VAR consumption and harmonic effects**

[60] Op. Cit., Statement of Scott A. McBride, U.S. Senate, 2018 https://www.hsgac.senate.gov/wp-content/uploads/imo/media/doc/Testimony-McBride-2018-09-13.pdf
[61] EMPRIMUS, homepage, "About Us" https://www.emprimus.com/

**that otherwise compromise transformer performance and grid stability** during a GIC event. Importantly, the device accomplishes this protection without interfering with the transformer's normal AC ground and performance or its ability to safely handle fault currents.

This device has undergone extensive research and testing by academia through the University of Manitoba[62], by the government through the Department of Defense's (DoDs) Defense Threat Reduction Agency (DTRA), the Idaho National Laboratory (INL),[63] and the Oak Ridge National Laboratory (ORNL).[64]

SolidGround® was also purchased, installed and validated by the Department of Energy (DOE) per President Obama's Executive Order 13744 under Contract no. 89503421PWA001210, through public and privately owned utilities such as American Transmission Company (ATC), the Western Area Power Administration (WAPA), the Tennessee Valley Authority (TVA), and even through the utility industry's Electric Power Research Institute (EPRI), which has studied SolidGround® extensively.[65]

With over 10 years of operation history on the power grid at the 345kV level and above, the technology has demonstrated continuous operational reliability with zero maintenance-intensive failures and a 100% success rate blocking GIC automatically during GMD events. Unfortunately, the artificially low standard set by NERC provides no incentive to block GIC and protect the grid.

Meanwhile, outside of the United States, other countries do not rely on the NERC standard but instead on measured data and have tested SolidGround® and are beginning to install them on their nation's most critical transformers as they prepare for a 1:100-year solar event with a magnetic field strength of 4,000 nT/min.

Additionally, a Chinese entity has infringed upon the patents of the only proven viable neutral blocking device, the EMPRIMUS SolidGround® system, and is in production of these duplicate counterfeits, which are being deployed within China.

[62] University of Manitoba Report: "Grid Impact of Neutral Blocking for GIC Protection" Prepared by Athula Rajapakse, 29 June 2013.
[63] SolidGround®, EMPRIMUS website, https://www.emprimus.com/solidground/
[64] Oak Ridge National Laboratory, Piesciorovsky, E., Tarditi, A., "Modeling the impact of GIC neutral blocking devices on distance protection relay operations for transmission lines", 2020. https://www.sciencedirect.com/science/article/abs/pii/S0378779619304547?via%3Dihub
[65] Research collection EMPRIMUS, https://www.emprimus.com/research

# The Solution to GIC is Both Affordable & Bi-Partisan

The good news is that **protecting America's roughly 6,000 critical large power transformers identified "high-risk design" to GIC (the first to half-cycle saturate)** is affordable. Unlike massive, custom built, multi-million-dollar transformers, SolidGround® is not custom made but a standardized "one size fits all" device able to be produced on an assembly line. It costs about $500,000 and can be licensed to major transformer manufacturers to rapidly scale-up production and deployment across the United States. Nationwide deployment on the estimated 6,000 critical large power transformers would cost ≈ **$3–4 billion (one time cost)**—less than 0.5 percent of the 2021 Infrastructure Investment and Jobs Act

Employing SolidGround® to block GIC not only protects those critical transformers but also protects the rest of the grid *from* those transformers, which, if left vulnerable during extreme GMD or E3 HEMP events, will half-cycle saturate and take down the rest of the grid, damaging components with severe GIC-induced harmonics and VAR losses. This is what collapsed Quebec's electric grid in 1989 during a relatively minor GMD event (~ 2 V/km).

Again, we turn to **Scott McBride of Idaho National Laboratory**, who stated in testimony before the *U.S. Senate Homeland Security & Governmental Affairs Committee*, September 13, 2018:[66]

> *"…there must be a priority to protect the most critical large power transformers in place – my preliminary estimates are that* ***this would cost less than $4 billion*** *if we made it a priority to install NBDs at our most critical EHV substations."*

That cost estimate was validated by the nonprofit Foundation for Resilient Societies[67] and the independent analysis of ABB, Inc., which owns the largest collection of transformer designs in the US fleet.

Investing $4 billion to block GICs nationwide and defend some of the grid's most critical assets from HEMP would help deter our adversaries from using that method of attack. It would also save the American economy $15 billion in annual economic losses (2025 dollars) from routine solar weather. Based on this annual loss figure alone, the benefit-cost ratio of nationwide deployment makes it one of the most cost-effective resilience investments available in the energy sector.

Deploying the solution would also protect against large GMD events, which we cannot deter and are statistically certain to impact Earth in the future. In 2013, Lloyd's of London estimated the economic cost of a large "Carrington-class" solar storm (which occurred in 1859) on the North American grid today at between $0.6 and $2.6 trillion based solely on the value of lost load.[68]

Finally, the bipartisan appeal of this solution is worth emphasizing. The protection of critical grid infrastructure from GIC-induced failure is not a partisan issue; it aligns equally with national security imperatives, economic stability, and public safety. This bipartisan potential is reflected in prior executive actions. As noted previously, President Obama's Executive Order 13744[69] addressed space weather

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[66] Op. Cit., Statement of Scott A. McBride, U.S. Senate, 2018. https://www.hsgac.senate.gov/wp-content/uploads/imo/media/doc/Testimony-McBride-2018-09-13.pdf

[67] "Estimating the Cost of Protecting the U.S. Electric Grid from Electromagnetic Pulse", Foundation for Resilient Societies, 2020. https://www.resilientsocieties.org/uploads/5/4/0/0/54008795/estimating_the_cost_of_protecting_the_u.s._electric_grid_from_electromagnetic_pulse.pdf p. 63.

[68] Op. Cit., Lloyd's, "Solar storm Risk to the North American Electric Grid", 2013. https://assets.lloyds.com/assets/pdf-solar-storm-risk-to-the-north-american-electric-grid/1/pdf-Solar-Storm-Risk-to-the-North-American-Electric-Grid.pdf

[69] "Coordinating Efforts To Prepare the Nation for Space Weather Events", Presidential Executive Order, 2016. https://www.federalregister.gov/documents/2016/10/18/2016-25290/coordinating-efforts-to-prepare-the-nation-for-space-weather-events

preparedness, while President Trump's Executive Order 13865[70] focused on national resilience to EMP threats. Both directives recognized the need to protect infrastructure from GIC effects, implicitly supporting the kind of technology SolidGround® represents.

## Cost Recovery

Moreover, SolidGround® deployment could be authorized and supported under FERC's **"just and reasonable"** standard for cost recovery,[71] allowing regulated utilities to recover investment costs through rate structures. This regulatory pathway removes one of the primary excuses for inaction – that utilities cannot justify the expenditure without guaranteed cost recovery – by giving them a clear and approved mechanism to finance the upgrades.

The conclusion is inescapable: SolidGround® is a mature, tested, and economically viable solution that can be scaled quickly and neutralizes the shared threats from GMD and E3 HEMP scenarios. It does so at a fraction of the potential economic and societal cost of inaction, without introducing operational trade-offs or vulnerabilities. **The barrier is not technical. The barrier is the willingness of policymakers and regulators to mandate widespread adoption of this technology before the next inevitable GMD or HEMP event tests the resilience of the U.S. grid.**

# What America Must Do – Act Now

At present, the most powerful tool to protect our grid is not just a device, or a standard, but leadership.

It is leadership that is needed to overcome the decades of regulatory lethargy and industry lobbying that have slowed, deflected, or diluted serious mitigation measures to protect our grid from the GIC threat.

The responsibility for action now rests squarely on national and state-level leaders who have been elected by the people or appointed by their executives to serve the public interest. Below are steps that these leaders can take to rapidly protect the American people:

## U.S. Federal Government

1. **DOE issues an Emergency Order to Identify GIC-Vulnerable Transformers:** DOE should use the authorities granted it under Section 202(c) of the Federal Power Act (16 U.S.C. § 824a(c)), the energy emergency declared in EO 14156 (January 20, 2025), and the direction to use 202(c) authorities provided in EO 14262 (April 8, 2025) to require all ISOs/RTOs to conduct a thorough survey of all GIC-vulnerable electric transformers.

The survey would identify those that must be protected against GICs from both GMD and E3 HEMP by using credible GIC scenarios for a 100-year solar storm and E3 waveforms associated with the recently updated international IEC standard (IEC 61000-2-9, Edition 2.0 2025-05), using the standard waveform in Figure A.5, modeling a peak magnetic field strength of 20,000 nT and corresponding electric field of 85 V/km. The emergency order should direct the results of the survey to be submitted within 180

[70] "Coordinating National Resilience to Electromagnetic Pulses", Presidential Executive Order, 2019. https://www.federalregister.gov/documents/2019/03/29/2019-06325/coordinating-national-resilience-to-electromagnetic-pulses
[71] The Brattle Group, "The Zone of Reasonableness and Long Term Power Contracts", 2007. https://www.brattle.com/wp-content/uploads/2017/10/6321_zone_of_reasonableness_wp_fox-penner_wharton_mar_14_2007.pdf

days. The order should then be extended in 6-month increments until the nation produces and deploys the sufficient number of SolidGround® Capacitive Neutral-Blocking Devices to protect the electric grid from GIC.

**[See Appendix III – Proposed Secretary of Energy Emergency Order on GIC Protection]**

**2. DOE Deploys SolidGround® Capacitive Neutral-Blocking Devices:** DOE should start with federally owned portions of the U.S. electric grid such as the Tennessee Valley Authority (TVA), Bonneville Power Administration (BPA), Western Area Power Administration (WAPA), Southeastern Power Administration (SEPA), Southwestern Power Administration (SWPA), Alaska Power Administration (APA).

**3. DOE Integrates GIC Mitigation into DOE's Reserve-Margin Methodology:** Section 3(b) of EO 14262 directs DOE to develop a "uniform methodology for analyzing current and anticipated reserve margins." That methodology must consider not only fuel availability and generation dispatch but also the risk of generation loss from geomagnetic disturbances and HEMP E3 events.

Current planning models assume that generation capacity is lost only through mechanical or fuel outages. In reality, a single severe GMD could simultaneously disable hundreds of transformers, erasing gigawatts of reserve margin nationwide within minutes.

Therefore, DOE should:

A. **Mandate GIC-inclusive Reserve-Margin Assessment** for all regions regulated by FERC, using credible GIC scenarios for a 100-year solar storm and E3 waveforms associated with the recently updated international IEC standard (IEC 61000-2-9, Edition 2.0 2025-05)

2. **Identify At-Risk Regions** where modeled reserve margins fall below acceptable thresholds under the same credible GIC scenarios.

3. **Direct Priority Deployment** of SolidGround® capacitive neutral-blocking devices in those regions using TFP/GRIP funding.

4. **Publish a National GIC Hazard Map** analogous to FEMA's flood-risk maps to guide state and utility investment.

Incorporating GIC risk into DOE's reserve-margin model fulfills the Executive Order's mandate to use "all available generation resources" and ensures that the Nation's emergency energy analysis is grounded in physics rather than optimism.

## State Governments

The historical record of federal inaction does not prevent states from leading. Governors, working through their state energy offices and Public Utility Commissions (PUCs), already possess the authority to require investor-owned utilities (IOUs) to submit resilience readiness plans. They can direct infrastructure investment toward prioritized substation upgrades, encourage projects for GIC mitigation within existing rate structures, and support the deployment of SolidGround® in strategic locations.

State regulators can also leverage their rate-setting authority to incentivize prudent protective actions and can coordinate regional procurement of mitigation equipment to achieve economies of scale. Precedent exists: several states have already mandated grid protection measures in response to cybersecurity threats and wildfire risks.

In the wake of Winter Storm Uri, state leaders in Texas rapidly established an effective and enforceable standard for cold-weather protection much faster than FERC/NERC would have ever done – proving that state action can be effective and also supporting the concept that ERCOT should remain independent.[72]

In August 2025, the influential and bipartisan National Conference of State Legislators (NCSL)[73] passed a resolution urging swift action to protect our nation's electrical grid from solar geomagnetic disturbances (GMDs) and high-altitude electromagnetic pulse (HEMP).

New Hampshire State Representative Doug Thomas (R) sponsored the resolution, co-authored by Representatives JD Bernardy (R) and Rita Mattson (R). It passed unanimously after the legislators were informed that both President Obama and President Trump had written executive orders to address these threats, but that little had been done to actually harden the electric grid.

The full text of the resolution reads as follows:[74]

> *"Electromagnetic Pulses and Solar Flares (Resolution)"*
>
> *"NOW, THEREFORE, BE IT RESOLVED, that the National Conference of State Legislatures urges members of Congress and the President of the United States to initiate and coordinate efforts with state governments and the electric power sector to implement plans and preparation for the protection of electric power generation, transmission and distribution assets from EMPs and geomagnetic disturbances (solar flares);* ***first addressing those sectors most vulnerable and with the longest lead times for repair****, and then by using a risk based assessment approach to harden the remainder of nation's electric production, transmission and distribution systems for resilience against, and recovery from, all types of malicious or naturally occurring events that could adversely impact the electric power grid."* [Bold emphasis added.]

The resolution's approach of first addressing sectors that are the "most vulnerable and with the longest lead times for repair" is a wise one. It echoes the recommendations of leading HEMP/GMD experts and their concerns about assets with extremely long lead times, particularly transformers.

Therefore, the next logical step is for Governors, through executive action, or state legislatures through legislative action, to direct their utilities to survey all their transformers to vulnerability to GIC to determine how many need to be protected by SolidGround®.[75]

**[Appendix IV includes robust model language for such legislative action.]**

**[Appendix V includes a condensed form of this model language developed by NH lawmakers.]**

Due to the interconnected nature of the electric grid, these surveys will necessarily be conducted regionally within the Regional Transmission Operators (RTOs) and Independent System Operators (ISOs) that operate the grid. It would therefore be prudent for state leaders to work with the leaders of these RTOs and ISOs and with the leaders of the states they border. Once state leaders understand the scope of protection needed, they can create incentives and penalties for the electric utility industry to protect their assets by installing SolidGround® on vulnerable transformers. History demonstrates that the electric utility industry will lobby heavily in opposition to such requirements. Rate recovery is thus imperative so

72 https://centerforsecuritypolicy.org/5-reasons-why-a-federal-takeover-of-texas-electric-grid-will-hurt-resilience/

73 National Conference of State Legislatures webpage, "About Us". https://www.ncsl.org/about-us

74 https://nationalinterest.org/blog/energy-world/national-conference-of-state-legislators-urges-grid-protection-from-solar-weather-emps

75 For assistance, state legislators should visit: https://centerforsecuritypolicy.org/center-for-security-policy-state-education-and-outreach-initiatives/

that the investments made in protecting the grid are shouldered by the people – who too must understand the criticality in protecting the grid from GICs.

## Local Power: Civil Society and Citizen Pressure

Top-down policy from either the federal or state level will not succeed without bottom-up demand. Citizens, until now, have largely been disengaged from the technical and policy discussions surrounding grid resilience. That will change the moment electricity demand outstrips generation capacity or prolonged outages make the criticality of electricity "real" in daily life. The problem is that at that point, it is too late.

Proactive citizen action is therefore critical. Residential consumers should contact their governors and PUCs to demand protective measures, write directly to their utilities requesting transformer hardening, raise the profile of grid resilience in local media and community forums, and press local political candidates to take clear positions on the issue. The American public is not powerless, it is merely under-informed, and that is a problem that can be fixed.

Our Secure the Grid Coalition is consistently providing resources to educate the public and have been honored to work with documentary film producer David Tice on his production of the award-winning documentary "***Grid Down, Power Up***." Narrated by Hollywood celebrity Dennis Quaid, the film contributed to the success of Texas passing historic grid-protection legislation for its independent ERCOT grid, helping conclude ten-year legislative effort.


***Grid Down, Power Up*** can be immediately viewed at:
https://watch.salemnow.com/searchs?q=grid%2520down

## Building a Network of Resilient Communities

Ultimately, the American people must become much better prepared for blackouts and more resilient at the community level. Our Center for Security Policy has produced a series of reports to encourage community leaders to take measures to increase resilience and bring back civil defense (*pictured and linked on the following page*).

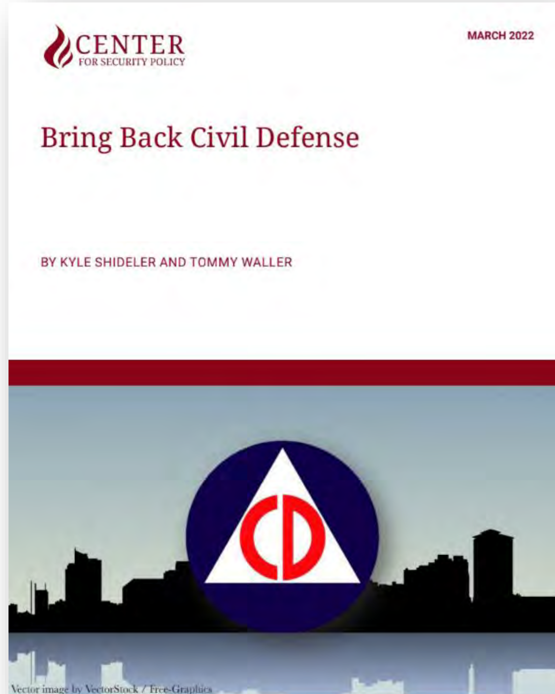
We are also available to provide threat briefings to local elected and appointed officials and invite them to join our "Resilient Communities Network."

More information on the Center for Security Policy's community outreach can be found here:

https://centerforsecuritypolicy.org/elected-officials-emergency-manager-briefings/

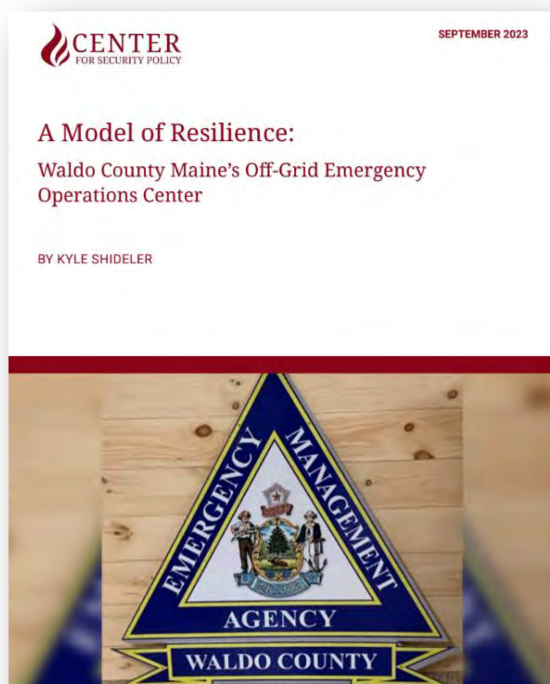
# Center for Security Policy Reports Encouraging Community Resilience


https://centerforsecuritypolicy.org/as-russia-ukraine-situation-raises-specter-of-cyberwar-how-can-we-be-better-prepared-here-at-home/




https://centerforsecuritypolicy.org/report-bring-back-civil-defense/


https://centerforsecuritypolicy.org/report-food-security-is-national-security/




https://centerforsecuritypolicy.org/a-model-of-resilience-waldo-county-maines-off-grid-emergency-operations-center/

# Appendix I – NERC/FERC Rulemaking Puts America – And the World – At Risk

The slow pace of rulemaking within the Federal Energy Regulatory Commission (FERC) and its designated Electric Reliability Organization (ERO), the North American Electric Reliability Corporation (NERC), has repeatedly left the United States vulnerable to known and well-documented threats. While these bodies have statutory authority to address reliability risks to the bulk power system, the historical record shows that the process of developing, approving, and implementing new standards can take years. This is true even when the threat is urgent, the technical solutions are well understood, and the potential consequences of inaction are catastrophic.

Because other modern societies with electric grids look to the United States and NERC for the development of their own reliability and security standards, NERC can either enhance or undermine the resilience of grid infrastructure worldwide. For solar weather, which poses a threat to the entire globe, the lives of more than America's 330 million citizens are at risk if other nations choose not to protect their grids against GIC by following NERC's lead.

Thus, it is worth reflecting on the NERC/FERC rulemaking processes surrounding a few notable past examples:

## The 2003 Northeast Blackout: Congressional Action and Regulatory Bottleneck

The August 14, 2003, Northeast blackout, which left over 50 million people without power across eight U.S. states and Ontario, was triggered in part by overgrown vegetation contacting 345 kV transmission lines.[76] In response, Congress passed the Energy Policy Act of 2005 (EPAct 2005), expanding the Federal Energy Regulatory Commission's (FERC) authority under Section 215 of the Federal Power Act to certify an Electric Reliability Organization (ERO) responsible for developing and enforcing mandatory reliability standards for the bulk power system.[77] On July 20, 2006, FERC designated the pre-existing North American Electric Reliability Corporation (NERC), originally a voluntary trade association formed in 1968, as the ERO.

**Vegetation management emerged as an immediate priority for the new FERC-NERC framework**, given its direct role in the 2003 cascade. **Despite this urgency, it took approximately 9.5 years** from the 2003 blackout—until FERC's approval of Reliability Standard FAC-003-2 in Order No. 777 on March 21, 2013—**for a fully enforceable standard to be finalized**. This standard introduced minimum vegetation clearance distances based on the "Gallet equation", annual inspections, and expanded applicability to critical lower-voltage lines, addressing deficiencies identified in earlier versions.[78]

This protracted timeline reflects the deliberate, industry-driven nature of NERC's ANSI-accredited standards development process, which requires multiple rounds of drafting, public comment, balloting, and FERC review to ensure technical rigor and industry consensus. While it is claimed that voluntary

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[76] U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations", 2004. https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf

[77] FERC Ruling: "Rules Concerning Certification of the Electric Reliability Organization; and Procedures for the Establishment, Approval, and Enforcement of Electric Reliability Standards", 2006. https://www.federalregister.gov/documents/2006/02/17/06-1227/rules-concerning-certification-of-the-electric-reliability-organization-and-procedures-for-the

[78] FERC Ruling: "Revisions to Reliability Standard for Transmission Vegetation Management", 2013. https://www.federalregister.gov/documents/2013/03/28/2013-07113/revisions-to-reliability-standard-for-transmission-vegetation-management

efforts reduced vegetation-related outages by over 50% in the interim, the delay in mandatory enforcement left persistent reliability gaps, contributing to events like the 2011 Southwest blackout.[79]

The vegetation management case exemplifies the trade-offs in our industry-driven regulatory construct which facilitates compliance. Such accommodation hinders rapid response to known vulnerabilities in an aging and stressed grid.

## Regulatory Lethargy Has Costs

Past examples illustrate the danger of these delays. One FERC directive to NERC to develop standards for physical security, Order No. 802, came in the wake of the April 2013 Metcalf substation attack, in which unknown attackers caused over $15 million in damage to a critical transformer yard serving Silicon Valley. Despite the clear demonstration that a small, coordinated team could inflict serious damage on critical grid infrastructure, the resulting NERC standard (CIP-014) took nearly two years to finalize. Moreover, its final form allowed industry discretion in identifying which facilities were "critical" and thus subject to protection, resulting in many vulnerable assets being excluded from any mandated security measures.[80]

The timeline for GMD protection standards is even more troubling. FERC first directed NERC to create geomagnetic disturbance (GMD) reliability standards in 2013 under Order No. 779,[81] which launched a two-stage rulemaking process to address both operational and planning vulnerabilities. The first planning standard, TPL 007-1, was not approved until September 2016 through order number 830,[82] and even that approval included directives for further modification to improve model validation, geomagnetic latitude scaling, and data collection. Implementation was phased over five years under NERC's 2014 implementation plan,[83] meaning protections would come online only gradually. Subsequent revisions - TPL-007-2 (2018),[84] TPL-007-3 (2019),[85] and TPL-007-4 (2020)[86] - each took years to develop and phase in, with new compliance dates extending still further.

Even today, regulators acknowledge that the GMD standard continues to fall short of protecting against historically credible storm intensities, illustrating how a single FERC directive can evolve through nearly a decade of slow, iterative bureaucratic process before delivering a standard that experts have long questioned as inadequate, because its chosen benchmark event, which forms the analytical foundation of the entire GMD standard, is grounded in fallacy. [See above section "NRC Reliance on a Flawed NERC Standard"] Hence, the current version still falls short of providing adequate protection against historically credible events.

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[79] 2018 Conference 2018 IEEE Power & Energy Society General Meeting (PESGM), "Vegetation-Related Outages on Transmission Lines in North America", 2018. https://www.researchgate.net/publication/329898451_Vegetation-Related_Outages_on_Transmission_Lines_in_North_America

[80] NERC, CIP-014 Report – Physical Security Protection for High Impact Control Centers
Docket No. RM15-14, 2017. https://www.balch.com/-/media/erl-blog/cip014-high-impact-control-center-report.pdf

[81] FERC, Reliability Standard for Geomagnetic Disturbance Operations, RM14-1-000, 2014. https://www.ferc.gov/sites/default/files/2020-05/E-3_19.pdf?

[82] FERC, Order No. 830, Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events, RM15-11-000, 2016. https://www.ferc.gov/sites/default/files/2020-04/E-4_2.pdf

[83] NERC, Implementation Plan: Project 2013-03 Geomagnetic Disturbance Mitigation, 2014. https://www.nerc.com/globalassets/standards/projects/2013-03/tpl_007_1_implementation_plan_20141205_clean.pdf

[84] FERC, Geomagnetic Disturbance Reliability Standard, RM18-8-000, 2018. https://www.ferc.gov/sites/default/files/2020-12/RM18-8-000.pdf

[85] NERC, Implementation Plan: Project 2019-01 Modifications to TPL-007-3, 2019. https://www.nerc.com/globalassets/standards/reliability-standards/tpl/draft-tpl-007-4-implementation-plan_final-ballot_qr.pdf

[86] NERC, TPL-007-4 – Transmission System Planned Performance for Geomagnetic Disturbance Events, https://www.nerc.com/globalassets/standards/reliability-standards/tpl/tpl-007-4.pdf

This protracted pace of rulemaking is not simply a function of procedural complexity; it is often the result of deliberate industry lobbying to limit the scope and cost of new requirements. NERC's standards development process is industry-led, with utility representatives holding substantial influence over drafting teams and balloting bodies. When proposed measures threaten to impose significant costs, such as the installation of GIC-blocking devices on critical transformers, industry stakeholders can and do use procedural mechanisms to delay, dilute, or derail the standard.

## The Costs are the Placing of Our Society in Harm's Way

The result is a pattern in which years pass between the identification of a serious vulnerability and the implementation of even partial protection. During this time, the grid remains exposed, and adversaries are given a clear window of opportunity, and they know it. The slow-motion approach to risk mitigation is especially dangerous for high-impact, low-frequency events like severe GMDs and HEMP attacks, where the absence of recent precedents is wrongly interpreted as justification for delay.

This institutional inertia is compounded by the absence of binding statutory deadlines for standard development. While FERC can order NERC to create or revise a standard, it rarely specifies aggressive timelines, and NERC's internal processes default to multi-year development cycles. The end result is that critical protections arrive, if at all, long after the window for timely action has closed.

The consequences of such delays are not theoretical. Had a Carrington-class solar storm struck during the decade-long gap between the 2012 near-miss CME and the present, the grid would have collapsed and – depending on the severity of GIC-induced transformer damages – it may still not have been restored. In national security terms, this is equivalent to acknowledging a known vulnerability in missile defense and then taking a decade to decide whether to employ a countermeasure, all while adversaries actively prepare to exploit the gap.

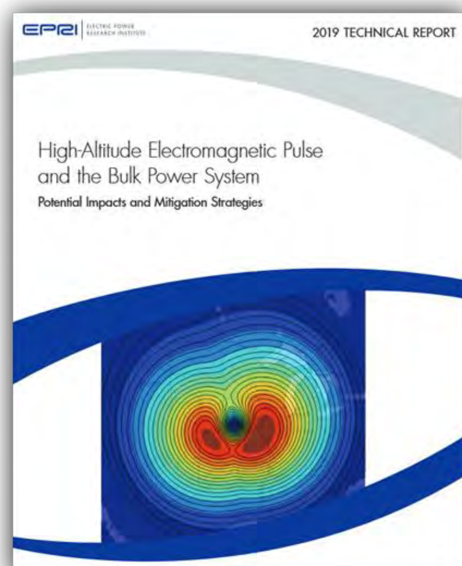
Without reform of the rulemaking process—whether through statutory deadlines, streamlined procedures, or the imposition of interim protective measures—the cycle of delay will continue. And each year that passes without decisive action is another year in which the United States gambles with the survival of its most critical of critical infrastructures.

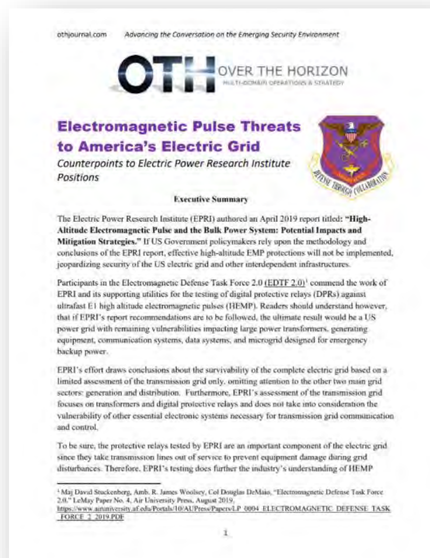
# Appendix II - Myths Vs Facts on GICs from GMD/HEMP

Decades of inaction on GMD/HEMP threat mitigation stem not only from bureaucratic delays and budget constraints, but also from a set of persistent myths that have seeped into policymaking and utility culture. Sometimes the myths are purposely inserted into the policy debate by lobbying organizations seeking to downplay the threats to the grid or to bolster the notion that they are addressing these threats.

An example of this that pertains to GMD/HEMP occurred in February 2015 with the Edison Electric Institute (EEI) publishing a white paper titled "Electromagnetic Pulses: Myths vs. Facts."[87] In May 2015, our Secure the Grid Coalition published a rebuttal[88] to this document, which was subsequently scrubbed from the internet.

Similarly, in April 2019, the industry-funded Electric Power Research Institute (EPRI) published a report titled: "High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies." This report vastly understated the gravity of the EMP threat, to the point that the U.S. Air Force Electromagnetic Defense Task Force (EDTF) was compelled to author a counterpoint paper published by the Air Force's "Over the Horizons" online journal[89].

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**Electromagnetic Pulse Threats to America's Electric Grid**

*Counterpoints to Electric Power Research Institute Positions*

**Executive Summary**

The Electric Power Research Institute (EPRI) authored an April 2019 report titled: **"High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies."** If US Government policymakers rely upon the methodology and conclusions of the EPRI report, effective high-altitude EMP protections will not be implemented, jeopardizing security of the US electric grid and other interdependent infrastructures.

Participants in the Electromagnetic Defense Task Force 2.0 (EDTF 2.0)[1] commend the work of EPRI and its supporting utilities for the testing of digital protective relays (DPRs) against ultrafast E1 high altitude electromagnetic pulses (HEMP). Readers should understand however, that if EPRI's report recommendations are to be followed, the ultimate result would be a US power grid with remaining vulnerabilities impacting large power transformers, generating equipment, communication systems, data systems, and microgrid designed for emergency backup power.

EPRI's effort draws conclusions about the survivability of the complete electric grid based on a limited assessment of the transmission grid only, omitting attention to the other two main grid sectors: generation and distribution. Furthermore, EPRI's assessment of the transmission grid focuses on transformers and digital protective relays and does not take into consideration the vulnerability of other essential electronic systems necessary for transmission grid communication and control.

To be sure, the protective relays tested by EPRI are an important component of the electric grid since they take transmission lines out of service to prevent equipment damage during grid disturbances. Therefore, EPRI's testing does further the industry's understanding of HEMP

[1] Maj David Stuckenberg, Amb. R. James Woolsey, Col Douglas DeMaio, "Electromagnetic Defense Task Force 2.0," LeMay Paper No. 4, Air University Press, August 2019, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0004_ELECTROMAGNETIC_DEFENSE_TASK_FORCE_2_2019.PDF

1

That USAF EDTF article plainly stated the truth:

**"If US Government policymakers rely upon the methodology and conclusions of the EPRI report, effective high-altitude EMP protections will not be implemented, jeopardizing security of the US electric grid and other interdependent infrastructures."**

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[87] https://securethegrid.com/wp-content/uploads/2019/03/EEI-Misinformation-Electromagnetic-Pulses-EMPs-Myths-vs.-Facts.pdf

[88] https://securethegrid.com/wp-content/uploads/2025/11/STG-RebuttalToEEII-Misinformation.pdf

[89] https://othjournal.com/2019/08/27/electromagnetic-pulse-threats-to-americas-electric-grid-counterpoints-to-electric-power-research-institute-positions/

Unfortunately, these myths are repeated in public statements, testimony, and even regulatory filings, often without scrutiny. These myths create a dangerously false sense of security and undermine the urgency for adopting proven protective measures. Confronting these misconceptions directly, with documented facts, is essential to clearing the path for prudent, cost-effective protection of the grid. Below are 14 important myths related to the GIC threat to the grid and the subsequent facts to correct the record.

## Myth #1 — "Transformers are immune to GIC damage."

**Fact.** U.S. large power transformers—whose average age today is roughly **38–40 years**—are **not** immune to geomagnetically induced currents (GICs). This myth is typically based on the assertion, advanced by some in the electricity complex, that 80% of the US high voltage transformer fleet is "resistant" to GIC effects. The physics are straightforward: quasi-DC bias drives half-cycle saturation, which in turn produces harmonics, hot spot overheating, core stress, and progressive insulation damage; in severe cases this cascade ends in catastrophic failure. These effects are not speculative. **National laboratory reports**,[90] **utility testbeds**[91] and **transformer manufacturer disclosures**[92] have documented them for decades. Aging magnifies the risk because cellulose insulation and dielectric oil degrade over time, narrowing the thermal and electrical margins within which a transformer can ride through even moderate GIC exposure.[93] The way you operate a transformer can also increase its aging. Today we are placing higher power demands on our transformers.

## Myth #2 — "NERC's TPL-007 proves the system is secure."

**Fact.** The NERC TPL-007 standard ignores NERC's own committee of 8 respected space weather scientists who estimated a reference storm in February 2013, the "preliminary results" were determined to be a maximum electric field strength of 30-40 V/km.

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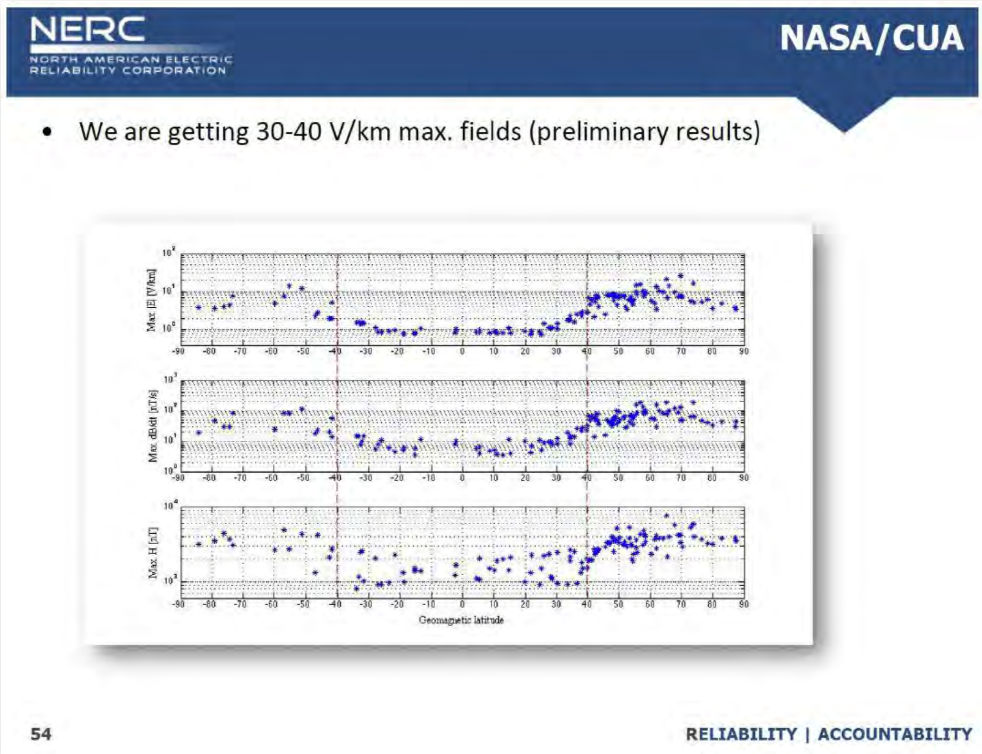
[90] Los Alamos National Laboratory, Review of the GMD Benchmark Event in TPL-007-1, 2015. https://www.energy.gov/oe/articles/review-gmd-benchmark-event-tpl-007-1

[91] Hydro-Québec, Montréal, Québec, "GMD Impacts on Hydro-Québec system", 2023. https://www.ipstconf.org/papers/Proc_IPST2023/23IPST017.pdf

[92] ABB Power Transformers, "Effect of GIC on Power Transformers & Power Systems" https://www.pes-psrc.org/kb/report/1020.pdf

[93] University of Quebec at Chicoutimi and Hydro Quebec Research Institute, "Degradation Mechanisms of Cellulose-Based Transformer Insulation: The Role of Dissolved Gases and Macromolecular Characterisation", 2025. https://www.mdpi.com/2673-6209/5/2/20




Slide 54 from NERC GMD Task Force presentation

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).

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.[94]

Instead the **NERC TPL-007** standard rests on **low historical benchmarks** of a selected period of particularly low solar activity, and the geophysical makeup of Europe which differs markedly from the geophysical characteristics common to most of North America.[95] The standard also excludes the largest known storms, including **1921** and **1859**.[96] It also lets utilities **self-select** key modeling inputs, such as **assumed ground conductivity,** that strongly influence exposure calculations.[97] The combined effect is to weaken the floor that "minimum" reliability thresholds were meant to establish. The chosen benchmark

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[94] http://www.resilientsocieties.org/uploads/5/4/0/0/54008795/comments_20130809_gmd_planning_application_guide.pdf

[95] Op. Cit., Los Alamos National Laboratory, Review of the GMD Benchmark Event in TPL-007-1, 2015. https://www.energy.gov/oe/articles/review-gmd-benchmark-event-tpl-007-1

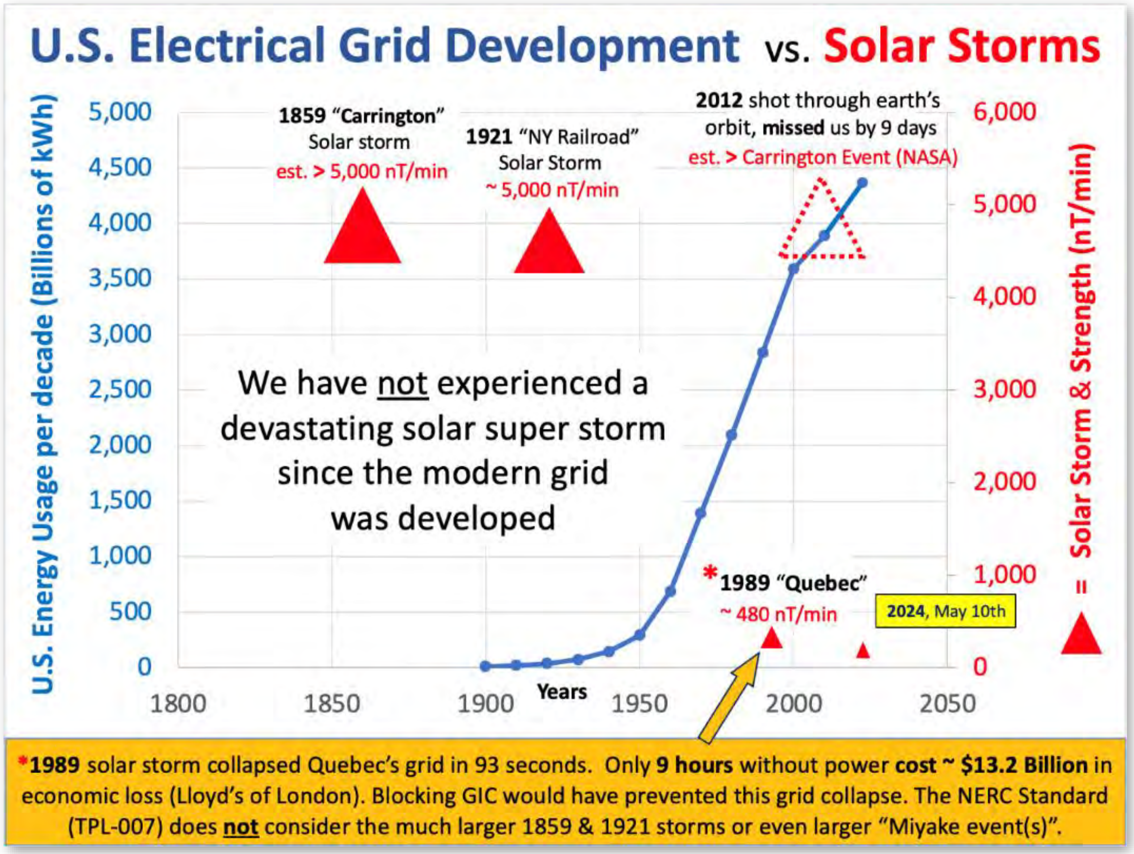
[96] NERC, Level 2 Appeal Foundation for Resilient Societies, Inc. TPL-007-1 - Transmission System Planned Performance for Geomagnetic Disturbance Events https://www.nerc.com/globalassets/standards/projects/2013-03/2013-03_gmd_level_2_appeal_foundation_for_resilient_societies_tpl-007-1_05182015.pdf

[97] Ibid.

event, 8 volts per kilometer (over Quebec) and scaled down to 4 V/km (northern U.S.), 2 V/km (center of the U.S.) and 0.8 V/km (southern U.S.),[98] does not represent a credible worst-case storm for North America. This **standard is set at a level that avoids the need to install hardware to protect the power grid.** A standard built on under-representative data and flexible assumptions **cannot** serve as proof of system security against severe GMDs.

## Myth #3 — "If GICs were a real danger, we'd see more blackouts."

**Fact.** Historical records and modern near misses refute this contention. We have not experienced a large GMD direct hit since the modern grid was developed.




The 1859 "Carrington Event" and the 1921 "NY Railroad" Solar Storm are proof that extreme space weather has occurred in the past (prior to the development of our bulk power grid) and are statistically certain to occur again. NASA cites the estimates of the probability of a Carrington class CME hitting Earth at 12% per decade.[99] The absence of clearly labeled "GIC blackouts" is not evidence of safety; it reflects **misattribution** and **under-monitoring**. In most substations there is **no real-time GIC monitoring**, so operators often assign resulting disturbances to other causes. Moreover, GIC damage can be **cumulative**: thermal stress and insulation degradation may set the stage for failures **years** later, long

[98] NERC, Benchmark Geomagnetic Disturbance Event Description Project 2013-03 GMD Mitigation Standard Drafting Team (corrected)", 2014. https://www.nerc.com/globalassets/standards/projects/2013-03/benchmark_gmd_event_june12_redline_corrected.pdf
[99] Riley, P., "On the probability of occurrence of extreme space weather events", 2012. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2011SW000734

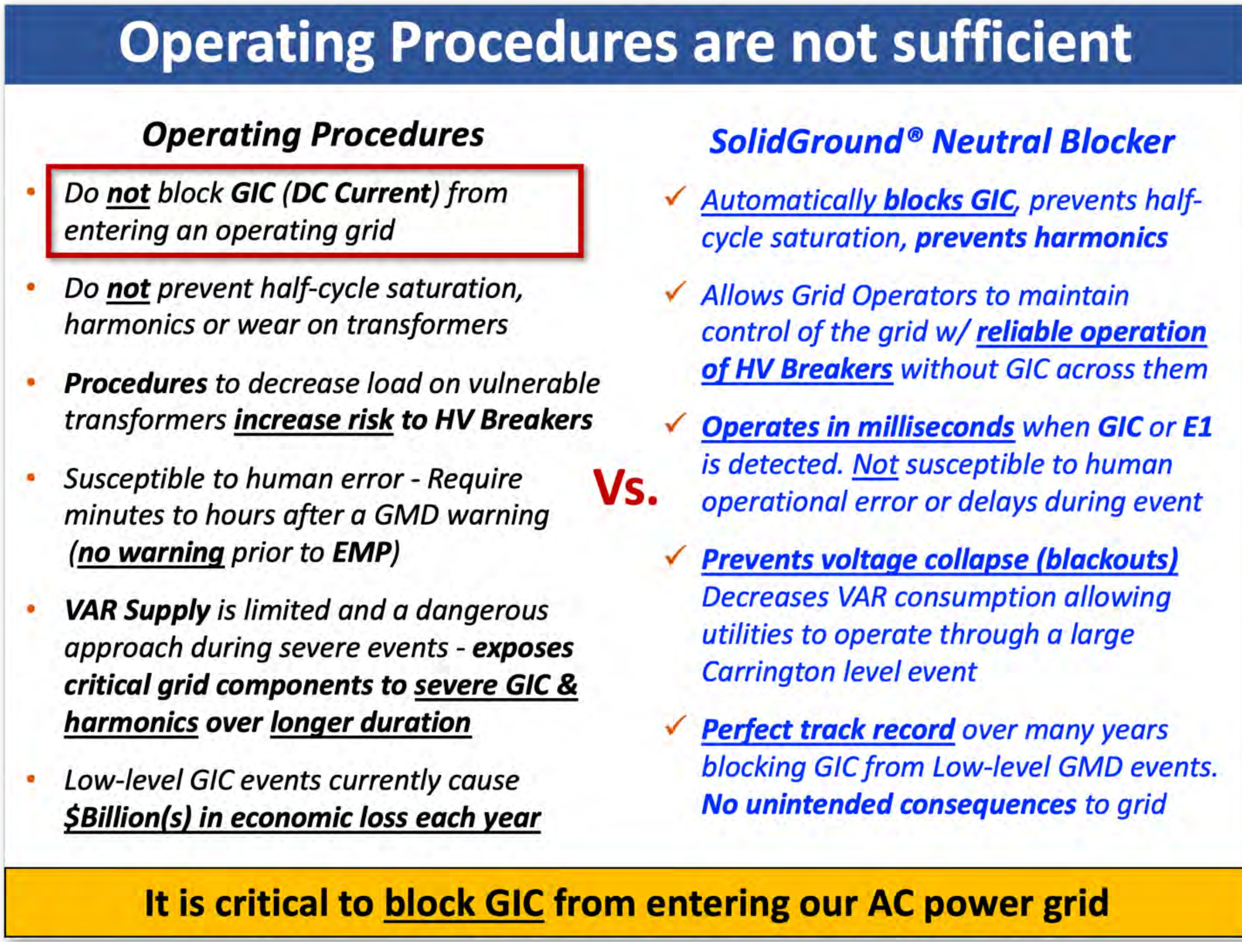
after the initiating events.[100] Moreover, near-misses matter. As the Earth orbits around the sun, the sun rotates on its own axis shooting off large solar flares with coronal mass ejections ("CMEs") through the Earth's orbit. If the Earth happens to be in the line-of-sight of one of these large CMEs, the results will be catastrophic. **We are in essence playing Russian roulette with the sun**. The **2012 solar superstorm** that **missed Earth by nine days** demonstrates how unprepared the grid remains for a Carrington-class strike. Per NASA that 2012 event was "in all respects at least the size of Carrington."[101] Recall that Lloyd's of London estimated in 2013 that if a Carrington sized event were to occur, it would cost the U.S. economy between $0.6 to 2.6 trillion based on value of lost load, not including catastrophic loss of life and equipment damage.

As for HEMP E3 threats, adversary nations already possess both the weapons and delivery systems capable of executing such an attack. As mentioned earlier, **in 1962 the Soviet's achieved 66 V/km (many times larger than the "Carrington" event)**. China's manifesto "How to Defeat a Superior Adversary" was developed following the first Gulf War and cites initiating a "Black Out" war by completely turning off the adversary's power via EMP. Three other nation states have adopted this same plan – Russian, North Korea and Iran. These are not remote possibilities; they are predictable risks within the foreseeable future.

## Myth #4 — "Operational procedures alone can safeguard the grid during GMD or EMP events."

**Fact.** Operating procedures do <u>not</u> block GIC from entering an operating grid. There is **no practical way** to detect and **preemptively** de-energize the grid in time to prevent damage in an **E3 HEMP** event, which unfolds in **seconds**. SolidGround® automatically blocks GIC induced by E3 HEMP or GMD when detected in the neutral of the transformer. Even for GMDs with timely warnings from NOAA's Space Weather Prediction Center, **utilities lack documented policies** to voluntarily take systems offline—contractual obligations and liability concerns make such actions unrealistic. Capacitors installed in the neutral that automatically **block GIC in the Earth from entering into transformers** through the ground connected neutral wires is therefore essential.

[100] Op. Cit., "Geomagnetic Disturbances (GMD) Impacts on Protection Systems", https://www.pes-psrc.org/kb/report/022.pdf
[101] NASA Science Editorial Team, "Near Miss: The Solar Superstorm of July 2012", 2014. https://science.nasa.gov/science-research/planetary-science/23jul_superstorm/




## Myth #5 — "GIC solutions are unproven or prohibitively expensive."

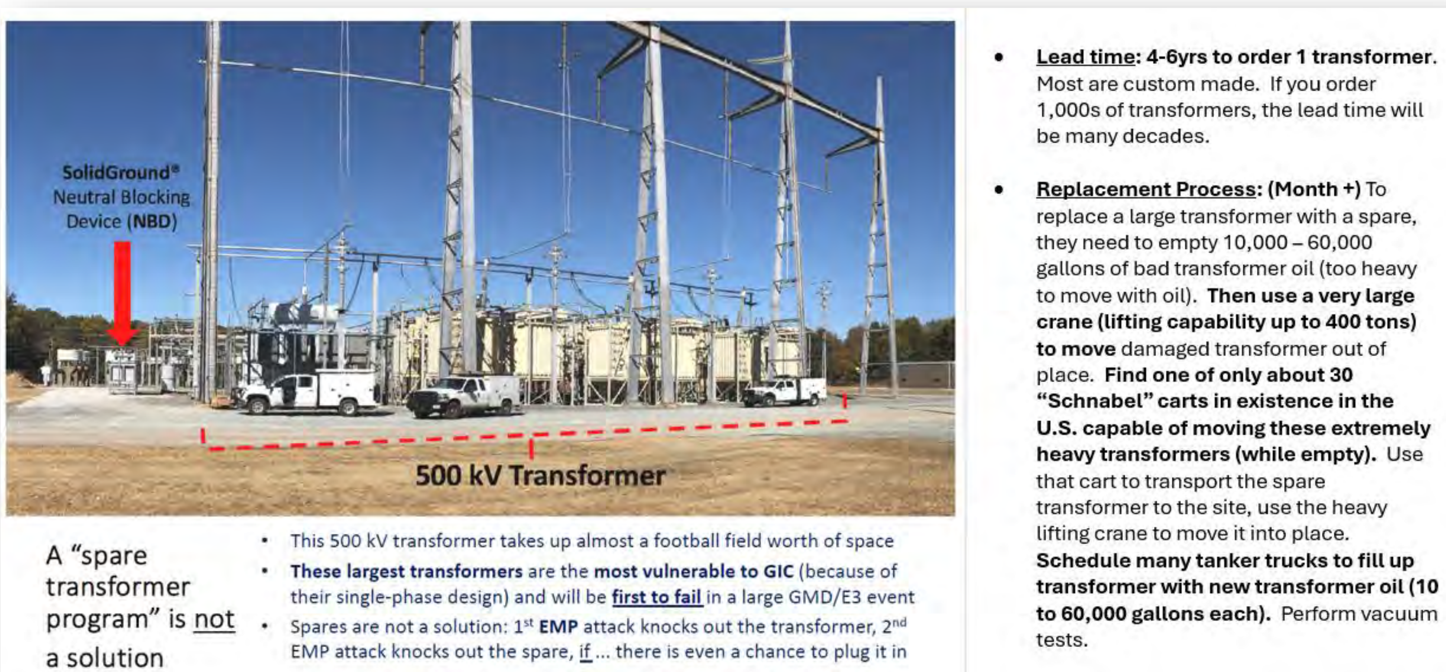
**Fact.** The **SolidGround®** capacitive neutral-blocking device has been **deployed** by **TVA**, **WAPA**, and **ATC** for **as long as 10+ years without failure** and without operational issues. It has passed **DTRA/INL** HEMP E3 validation and is considered **cost-effective**. The "prohibitively expensive argument collapses under basic cost-benefit analysis. Unmitigated GIC-related impacts are estimated at **$15 billion annually (approximate 2025 dollars)** due to low GIC induced harmonics injected into the grid by the most susceptible transformers on our power grid. Deploying "SolidGround" GIC blocking technology on 6,000 of the nation's most susceptible high voltage transformers to half-cycle saturation has a one-time cost of $4 billion (**less than one-third of one-percent of the $1.2 trillion Bipartisan Infrastructure Bill**), making mitigation a fraction of ongoing losses, paying for itself multiple times each year. In other words, this is not an untested technology or an extravagant expense; it is a straightforward and proven fix with a compelling economic case, alone, not considering the element of human suffering and death. In addition, SolidGround® can reduce or eliminate many complex and costly operating procedures (such as reducing load or spinning up generation and utilizing SVCs to supply VARs) in an attempt to reduce risk of thermal damage and blackouts related to GIC. Utilities can pre-emptively place SolidGround® units across their grid into "Blocking Mode" via SCADA whenever a GMD warning is issued by NOAA of an incoming event, or allow them to automatically block GIC whenever it is present. In the case of a surprise

E3 HEMP attack, SolidGround® detects both the E1 pulse and GIC automatically triggering into Blocking Mode.

## Myth #6 – "A spare transformer program is the solution"

Relying on spare transformers as a solution is considered to be "the Great Experiment" and it's a dangerous one. Experts within DOE and the utility industry are uncertain whether we would be even able to plug in a large spare transformer in a widescale blackout scenario with societal chaos after a severe GMD or HEMP E3 attack. Plugging in a spare transformer requires a full crew and about a month of work in "blue sky conditions" with functioning communications and a functioning grid.

The most vulnerable transformers to GIC (first to half-cycle saturate and fail) are also the largest transformers (500kV-765kV and large GSUs and Converter transformers), they hold many 10,000s of gallons of oil that needs to be transported, heated and tested. Most of these large power transformers are custom made, and take up a very large area. ABB's RecX spare transformer program never attempted to make spares in the 500 kV size or above due to their incredible size. An enemy attacking the U.S. with HEMP E3 will never allow a spare unit to be plugged in, if successful, they will hit us again and knock out the spare. Severe GMD events can last for over a week which would delay any efforts to plug in a spare, even if one were to be available.



## Myth #7 — "Neutral resistors are effective for GIC protection."

**Fact. Neutral resistors do <u>not</u> prevent half-cycle saturation**, **harmonics or reactive power losses** that result from GIC - disqualifying them as a protection option.

*"The half-cycle saturation of the great number of large power transformers on a power system is the source of nearly all operating and equipment problems caused by GIC's during magnetic storms..."* - EPRI TR-100450, 1992

*"The flow of GIC in transformers is the root cause of all power system problems, as the GIC causes half-cycle saturation to occur in the exposed transformers"* – ORNL, Meta-319, 2010, p1-20.

**Resistors** reduce GIC (and AC)...they **do <u>not</u> block GIC**. It takes very little GIC to begin saturating many of the largest HV transformers (as low as **2 to 5 Amps GIC/phase**.)

*"**Only a few amps of GIC** can result an amplification of impacts in the operation of AC current flows in the transformer."* ORNL, Meta-319, 2010, p1-20

Even reducing GIC by 60-80% utilizing resistors cannot prevent catastrophic results during a large **GMD or E3 HEMP event which can cause 100s to 1000s of Amps GIC/phase**. Each transformer half-cycle saturating due to GIC is turned into a harmonic current generator (injecting harmonics into the grid, destroying components across the grid all the way to the load) and reactive power consumer (driving the power grid towards blackout).

**Golden Rule in GIC mitigation: keep GIC <u>below 6 Amps</u> in the neutral (2 Amps/phase).** This prevents the largest "high risk design" power transformers from half-cycle saturating and injecting GIC induced harmonics into the power grid. International utilities have gone to extreme lengths stacking large resistors in series with additional resistors in an attempt reduce GIC (or stray DC in the ground from HVDC operation) to below 6 Amps to prevent transformer harmonic generation. It is for this reason SolidGround® capacitive neutral blockers for over a decade have been set to begin blocking when GIC reaches 5 Amps in the neutral...just below the 6 Amp threshold. International utilities are now beginning to tear out their large resistors and install SolidGround® which simply blocks GIC bringing it down to zero. **Blocking GIC from entering these "high risk design" transformers** not only protects those critical transformers, it **protects the rest of the power grid and critical components *from* those transformers.**

Resistors installed in the neutral 100% of the time will increase wear on transformers continually stressing the neutral insulation off our aging transformer fleet during every power system event (faults, switching transients, inrush, sympathetic inrush, etc...).

By contrast, **capacitor-based neutral blockers**—exemplified by SolidGround®—maintain a solid metallic path to ground 99.9% of the time during normal operation and **automatically block GIC** only when present through a resistor in series with a capacitor, while preserving normal AC operation and ground-fault protection 100% of the time. Real-world data on the power grid at Idaho National Labs, American Transmission Company and DOE's project(s) installing and operating SolidGround® at Tennessee Valley Authority (TVA) and Western Area Power Administration (WAPA) show **no unintended consequences**, and technical references explain why blocking with capacitors, <u>not</u> resisting with resistors, is the correct engineering approach.

**EPRI EL-3295, Project 1770-1, 1983;**

*"A **capacitor in the neutral** of transformers was determined to be the **most effective and practical** blocking device." p.9-1*

*"The **most promising** system uses **neutral blocking capacitors**..." p.vi*

*"A **capacitor, installed in the neutral** of the transformer, was selected as the **most suitable** device for blocking GIC." p.S-2*

*"The basic requirement to block dc while providing a low ohmic ac path in the neutral suggests that **capacitors are a prime candidate** for consideration." p.3-2*

**EPRI TR-100450, 1992;**

*"...inserting blocking devices in neutral leads appears to be the **most logical and effective** means of preventing GIC flow... the use of ordinary **capacitors is the best option** for a GIC neutral blocking device."*

*"The **limited effectiveness of linear resistance** unless relatively high values of resistances are used, **and the other disadvantages** associated with their use, combine to make them a **less favorable choice for blocking or limiting GIC than capacitors**."*

**"High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies." EPRI, Palo Alto, CA: 2019. 3002014979:**

*"...**capacitors** in the neutral...**effective** means of blocking the flow of GIC..."*

## Myth #8—"Widespread application of neutral capacitors would bring risk of impedance changes and ferroresonance concerns on the network."

**Fact.** This was an **early concern regarding old blocking technology** developed in the 1980s and 90s which has been **specifically addressed with the development of SolidGround®.**

The University of Manitoba completed 6 detailed reports on capacitive neutral blocking devices ("NBDs") and concluded *"As expected, frequency scans show that neutral grounding capacitors has no impact on the positive sequence impedance frequency characteristics...at harmonic frequencies (f > 60 Hz), the impact of neutral grounding capacitors on the zero sequence impedance is negligible **when the grounding capacitance is larger than 1000 µF**."*

Oak Ridge National Laboratory analyzed capacitive neutral blocking devices ("NBDs") installed on the grid and their conclusions showed that *"**distance relays operate normally** in transmission lines with NBDs inserted, **if the neutral grounding capacitance is greater than 1,000 µF**"*[102]

[102] Reference: Modeling the impact of GIC neutral blocking devices on distance protection relay operations for transmission lines, Electric Power Systems Research, Volume 180, March 2020, 106135

Old blocking technology utilized capacitors with very low capacitance (10 µF and 61 µF). SolidGround® utilizes **a resistor in series with a capacitor** bank of **high capacitance (1,289 µF)**.

SolidGround® is installed on various transformer designs at the 345 kV and 500 kV level and has been continuously operating on the power grid for over 10 years with **no negative effects to the power system**, no resetting of protection relays, no ferroresonance.

## Myth #9 Blocking GIC from entering our power grid will create "Whack-a-Mole"

Whack-a-Mole is an assumption that if you block GIC in one location, it will cause GIC to be "re-directed" and spike everywhere else. Example: If you block 10 Amps GIC at one transformer, then 10 Amps GIC (or more) will be shifted somewhere else. In essence - we can't solve the GIC problem.

**Fact.** Over 10 years of GIC data <u>refutes</u> this assumption. To study this, **DOE under Executive Order 13744 purchased SolidGround® NBDs and installed them on the most GIC monitored grid in the U.S.** This has allowed DOE to monitor GIC levels across the grid in real time as NBDs operated during many GMD events (of various angles), and to record that data to see the impact of blocking GIC.

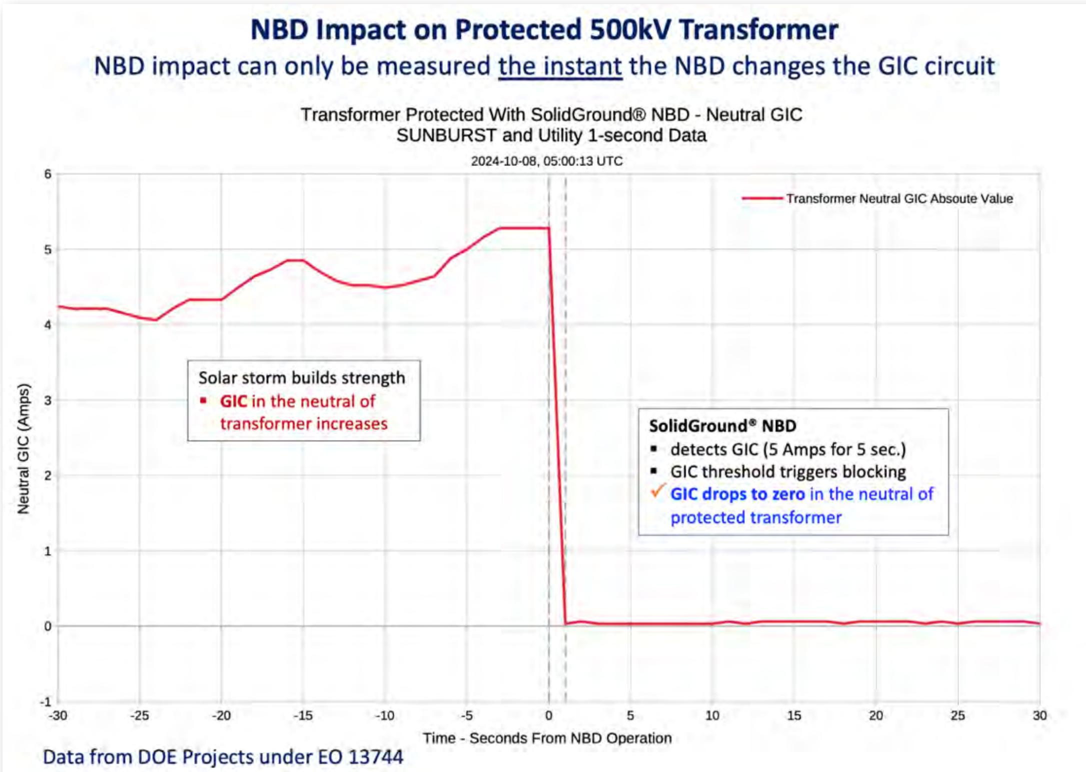
**DOE Objectives:**

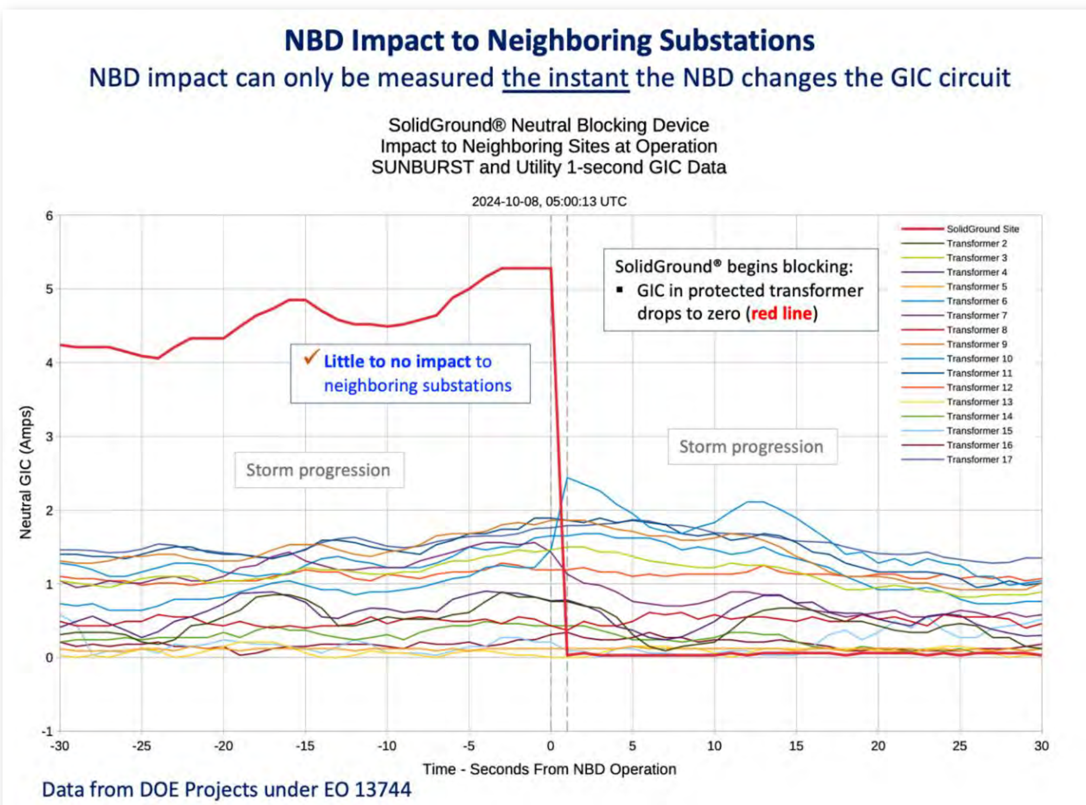
- Assess the effectiveness of SolidGround® NBDs to block GIC
- Measure any GICs re-directed to other transformers
- Use data to validate modeling and correct inaccurate assumptions

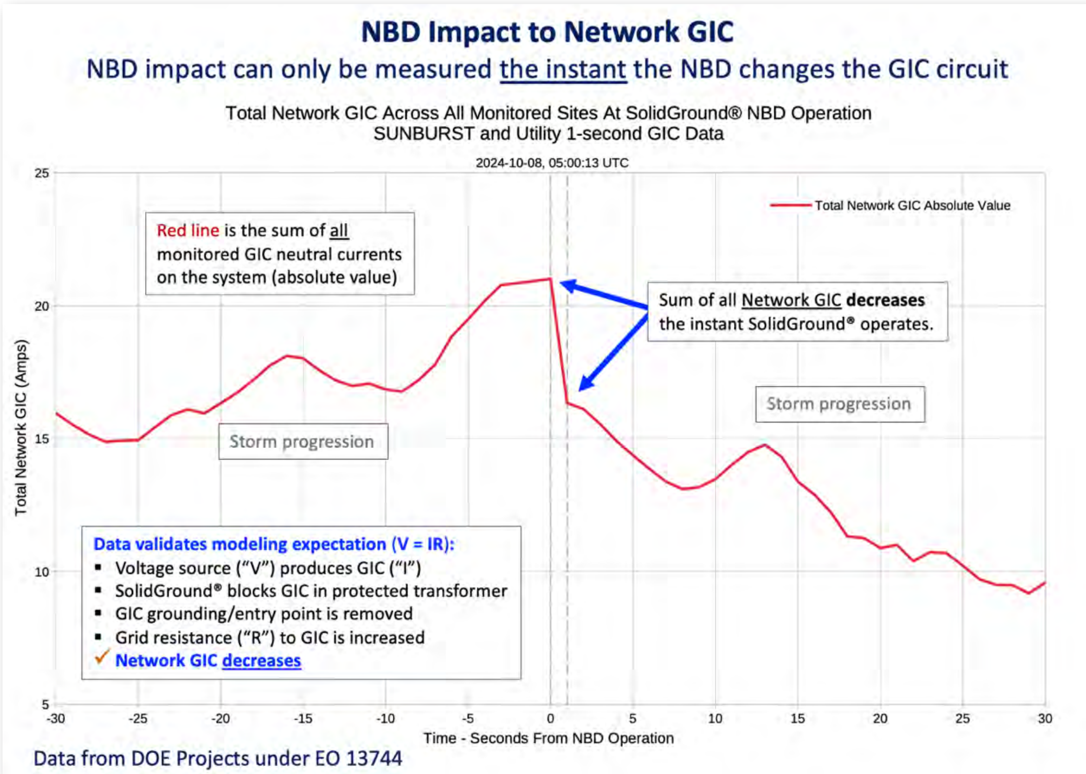
**90+ SolidGround® operations analyzed** by DOE, EPRI and EMPRIMUS during many GIC events

**Results are consistent:**

- SolidGround® NBDs operating as designed, no negative effects to power system
- GIC in neutral of protected transformer drops to zero
- Re-directed GIC is minimal and local (**V = IR**)
- **Network GIC** (sum of all GIC monitored on the system) **<u>decreases</u>**


NBD Impact on Protected 500kV Transformer
NBD impact can only be measured the instant the NBD changes the GIC circuit
Transformer Protected With SolidGround® NBD - Neutral GIC
SUNBURST and Utility 1-second Data
2024-10-08, 05:00:13 UTC
Transformer Neutral GIC Absoute Value
Solar storm builds strength
GIC in the neutral of transformer increases
SolidGround® NBD
detects GIC (5 Amps for 5 sec.)
GIC threshold triggers blocking
GIC drops to zero in the neutral of protected transformer
Neutral GIC (Amps)
Time - Seconds From NBD Operation
Data from DOE Projects under EO 13744


NBD Impact to Neighboring Substations
NBD impact can only be measured the instant the NBD changes the GIC circuit
SolidGround® Neutral Blocking Device
Impact to Neighboring Sites at Operation
SUNBURST and Utility 1-second GIC Data
2024-10-08, 05:00:13 UTC
SolidGround® begins blocking:
GIC in protected transformer drops to zero (red line)
Little to no impact to neighboring substations
Storm progression
Storm progression
SolidGround Site
Transformer 2
Transformer 3
Transformer 4
Transformer 5
Transformer 6
Transformer 7
Transformer 8
Transformer 9
Transformer 10
Transformer 11
Transformer 12
Transformer 13
Transformer 14
Transformer 15
Transformer 16
Transformer 17
Neutral GIC (Amps)
Time - Seconds From NBD Operation
Data from DOE Projects under EO 13744




DOE's data consistently shows that **blocking GIC** in the neutral of transformers **decreases Network GIC**. (i.e. GIC is not being re-directed everywhere else, grid resilience is improving). The more NBDs installed on the power grid, the more resilient the power grid becomes allowing the grid to operate through severe GIC events. **Modeling assumptions need to be updated to reflect the data.**

| % of Transformers with SolidGround® NBDs | % Reduction of Total Network GIC | % Decrease in Reactive (VAR) Consumption |
|---|---|---|
| 7% | 13.7% | 14.6% |
| 14% | 27.3% | 29.3% |
| 21% | 41.0% | 43.7% |

***Results derived from PowerWorld ™ modeling of the Wisconsin ATC Power Grid***

**E. "Re-directed" GIC is a concern today if we do not protect the power grid**

GIC will always travel the path of least resistance. During a severe GMD or E3 HEMP event, **the instant high voltage circuit breakers are operated** (intentionally via utility operating procedures or unintentionally due to GIC induced harmonics or E1 HEMP) **the GIC circuit is changed and GIC will be re-directed across the grid** in an unplanned and chaotic manner.

It is important to note that **high voltage circuit breakers** attempting to open (intentionally or unintentionally) during a severe GIC event can be catastrophically destroyed as they require "zero crossings" and **are not designed to break GIC**.

# Myth #10—"Allowing a severe GMD or E3 event to take the grid down, will save transformers from catastrophic damage."

**Fact. Grid failure itself will catastrophically damage many transformers and other components across the grid.** It is widely accepted that when the sun produces another geomagnetic disturbance larger than the NERC TPL-007 standard (i.e. "2012 CME near miss" which blasting off the back side of the sun, 1921 "Railroad Event", 1859 "Carrington event" and even larger "Miyake events") or there is a single E3 HEMP attack, our grid will go down very quickly due to severe levels of GIC induced harmonics.

On July 21st, 2016 DOE members held a meeting with various leading suppliers and utilities in the industry (DOD, INL, LANL, ABB, Siemens, Dominion, EMP Commission, EPRI, MITRE, STRATCOM, NATF...) to discuss our nations EMP Resilience Action Plan to identify specific actions "where DOE can help the most" to protect the power grid from EMP. A few important takeaways from that meeting:

- **Priority #1 – prevent grid failure**. GIC induced Harmonics from E3 and severe GMD will cause wide scale grid collapse in just 10's of seconds.
- Large scale load shedding is not possible. **Equipment is damaged in the shed/reconnect process due to switching transients, and overloading.** Shutting down grid is very risky. On and off is when you have the problems. It is not realistic.
- Allowing the grid to fail will damage transformers. **"Switch on/off – there have been transformer failures from trying to put the system back online. Turning back on could cause many problems...when things go down too quickly, things go wrong."**
- Best policy is to protect the grid to operate through a large GIC event. "Fight to the last breath to keep the system running."
- **Transformers will need E3/GMD protection**. E3 levels roughly an order of magnitude higher.
- **Neutral blocking device in Wisconsin [SolidGround®]...working as designed**
- GIC protection from GMD and E3 HEMP should be addressed concurrently
- Transformer protection is a low hanging fruit.
- **IEC International EMP Standard (IEC 61000-2-9) provides useful waveforms**

# Myth #11 — "European data accurately represent U.S. GMD risks."

**Fact.** The U.S. grid is more exposed than most European systems because of **geologic conductivity,** geomagnetic **latitude**, and because our network includes **longer east-west transmission corridors**. U.S.-specific research—such as **ORNL's** *Geomagnetic Storms and Their Impacts on the U.S. Power Grid* (**Meta-R-319**, 2010)

https://www.futurescience.com/emp/ferc_Meta-R-319.pdf shows **greater impacts** than European models predict. Importing European parameters into North American planning **systematically understates** the hazard.

## Myth #12 — "Space weather effects on the grid are invisible and negligible."

**Fact.** Space weather impacts are **measurable** in dollars and claims. **Zurich (2015)** linked GMDs to increased **electrical equipment failures**, quantifying a visible economic burden from this "invisible force" on the order of **$10 billion per year ($15 billion in 2025 dollars)**. See: *Electrical Claims and Space Weather: Measuring the Visible Effects of an Invisible Force* (Zurich, 2015), https://centerforsecuritypolicy.org/wp-content/uploads/2022/06/Appendix-F-2015Zurich-ElectricalClaimsandSpaceWeather.pdf

## Myth #13 — "The grid's design—interconnectivity and long corridors—delivers efficiency without needing additional GIC protections."

**Fact.** The very features that boost efficiency—**interconnectivity**, **long high-voltage corridors**, and large **loop areas**—**amplify** GIC risk per **Faraday's Law**. Even **moderate** events can inject meaningful current into transformer neutrals. Efficiency and reliability are not the same thing; absent hardware that **blocks GIC entirely** (see *Proven and Cost-Effective Mitigation – Keeping GIC Out of Transformers*, p. 4), efficiency-driven topology can convert a space-weather fluctuation into a system-wide vulnerability.

## Myth #14 — "Grid decay from HEMP E3 is gradual and manageable."

**Fact. E3 HEMP** produces **rapid GIC peaks** that bias cores into saturation quickly, increasing the likelihood of **transformer damage, harmonics** and **blackouts**. The notion of a slow, easily managed decay ignores both measured signatures and system dynamics. For detail, see **ORNL**, *The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid* (**Meta-R-321**, 2010): https://www.ferc.gov/sites/default/files/2020-05/ferc_meta-r-321.pdf

These myths are no longer tenable. The physics, the operational experience, and the economic evidence all point in the same direction: targeted, hardware-based **GIC blocking** is practical, proven, and vastly cheaper than the status quo. Dispelling misinformation clears the way for the only responsible course—**immediate deployment of capacitive neutral-blocking devices on the ~6,000 large power transformers identified "high risk designs" to GIC (quickest to half-cycle saturate) in order to protect those transformers, and protect the grid *from* those transformers**—so that the next severe solar storm or a potential HEMP event does not become a preventable national catastrophe.

# Appendix III – "SAVE Transformers" Secretary of Energy Emergency Order Template

*Order No. ____*

Pursuant to the authority vested in the Secretary of Energy by section 202(c) of the Federal Power Act (FPA) and section 301(b) of the Department of Energy (DOE) Organization Act and for the reasons set forth below, I hereby determine that an emergency exists across the continental United States due to a vulnerability of high voltage transformers to geomagnetically induced currents, also known as ground induced currents (GICs), and that issuance of this Order will meet the emergency and serve the public interest.

*Findings*

America's electric grid, integral to every aspect of modern life, faces existential threats from solar weather [through coronal mass ejections (CMEs) that cause geomagnetic disturbances (GMDs)] and high altitude nuclear electromagnetic pulse (HEMP), both capable of crippling electric power systems. The high voltage transformers critical to sustaining the electric grid are vulnerable to geomagnetically induced currents, also known as ground induced currents (GICs), which are induced in the earth by naturally occurring geomagnetic disturbances (GMDs) or the late-time (E3) component of high altitude electromagnetic pulse (HEMP) and enter the electric grid through the ground connected neutral wires of transformers.

The Extra High Voltage (EHV) transformers (345 kV – 765 kV) are the most vulnerable to GIC per their design (as they half-cycle saturate at very low GIC), are also the hardest to replace, many of them custom made with production lead times as long as 4-6 years, and require massive logistical and transportation challenges during their replacement process even during ideal "blue sky" conditions with a fully functioning grid, economy and society.

The GIC threat posed to these critical transformers is dependent on numerous factors, including the transformer's size, design and age, the ground conductivity in the region of the electric grid, and magnetic field produced by GMD or E3 HEMP.

In June 1992, the Electric Power Research Institute found that the aging of power transformers increases their susceptibility to GIC due to degraded insulating oil condition and coil condition (see "EPRI TR-100450, 1992").

In January 2021, The National Security Council recommended "that U.S. electrical systems and other critical infrastructure elements can be assessed for disruption and damage susceptibility up to the benchmark HEMP waveforms characterized by peak electric field strengths of 80 V/km for E3a (blast), and 50 V/km for E3b (heave), respectively," (See "Final HEMP Memo January 12, 2021 – Department of Energy").

In May 2025, the International Electrotechnical Commission (IEC) updated its international standard for E3 HEMP to a peak electric field strength environment of 85 V/km (see "IEC 61000-2-9, Edition 2.0 2025-05").

The current standard established by the North America Electric Reliability Corporation (NERC) to protect transformers and the grid from failure due to GIC, fails to require utilities to consider the design type and age of their transformers, establishes a “benchmark” peak electric field of only 8 V/km in Quebec, and utilizes a “scaling factor” to allow utilities to “scale down” per their geomagnetic latitude to consider a peak electric field of ~2 V/km across the center of CONUS and only 0.8 V/km across the southern states (while the GMD threat often decreases with geomagnetic latitude, the E3 HEMP threat is higher at lower geomagnetic latitudes due to its generation mechanism), engendering the real possibility of wide-area GIC-caused blackout with transformer and grid equipment failures (see “NERC TPL-007”).

ORDER

Given the above circumstances, I have determined that it is necessary and in the public interest for the United States of America that all covered entities conduct a survey of covered equipment to determine vulnerabilities to GIC.

> Covered entities include every electric utility and electric project developer, owner and operator, regardless of ownership or operation by the public or private sector within the state, regardless of whether that utility is subject to the jurisdiction of the North American Electric Reliability Corporation (NERC), and regardless of the regional transmission operators or independent system operators with which it operates.
>
> Covered equipment includes all power transformers with primary voltage of 100 kV or greater and capacity of 25 MVA or greater and all Generator Step-Up (GSU) transformers with secondary voltage of 100 kV or greater and capacity of 25 MVA or greater

Based on my determination of an emergency set forth above, I hereby order:

A. Every covered entity shall conduct a technical assessment survey of all covered equipment within its jurisdiction to determine its vulnerability to geomagnetically induced currents, also known as ground induced currents (GICs), which are induced in the Earth by naturally occurring geomagnetic disturbances (GMDs) or the late-time (E3) component of high-altitude electromagnetic pulse (HEMP).

B. Specifically, covered entities shall use the analytic waveform plotted in Figure A.5 of “IEC 61000-2-9, Edition 2.0 2025-05” in their operating models to determine the susceptibility of their transformers to GICs associated with a peak magnetic field strength environment of 20,000 nT for E3 HEMP, which for a typical low conductivity ground conductivity in the United States will produce a peak electric field environment of 85 V/km, based on the recently updated International Electrotechnical Commission (IEC) international standard. (Evaluating the worst-case E3 HEMP threat to high voltage transformers and the grid will also consider severe GMD threats.)

C. Covered entities shall undertake GIC modeling under the assumption that their transformers are operating fully loaded at the time when the operating environment experiences the GIC insult utilizing the late-time E3 HEMP waveform in IEC 61000-2-9, Edition 2.0 2025-05.

D. Because the aging of power transformers increases their susceptibility to GIC due to degraded insulating oil condition and coil condition, covered entities shall consider the age of the transformers surveyed and de-rate those transformers according to ANSI/IEEE Standard C57.110 and IEEE Standard C57.91 when analyzing transformer susceptibility. After confirming and considering the age, condition, and loading of each transformer, the peak geoelectric operating environment (e.g. 85 V/km), and the ground conductivity profile, covered entities shall identify which transformers would be susceptible to the following effects: (a) Half-cycle saturation (b) GIC induced harmonics; (c) VAR consumption; and, (d) Generation of hot spots in the core or structural elements, (e) oil or insulation degradation, and report the potential impacts of each variable's susceptibility to GIC.

E. No later than 180 days from the passage of this order, and while utilizing strict operational security for Critical Energy Infrastructure Information (CEII), covered entities shall provide a detailed report to (_Insert DOE Recipient__) with copies to their state's public utility commission, to the governor and appointed chief of homeland security, and to the state legislature.

F. The report shall contain the following data for all transformers and substations found to be susceptible to GIC based on the above survey parameters: (a) Transformer Brand (b) Transformer Place of Origin [nation where manufactured] (c) Transformer Design Specifications [i.e. windings and core configuration, winding impedances, winding DC resistances (specify whether assumed or measured), 1 phase vs. 3 phase, capacity (MVA), voltage (kV) (d) Transformer Age (e) Transformer Site Location [redacted for CEII] (f) Transformer Purpose [GSU, Auto, Step-down, Converter] (g) Transformer Replacement Lead Time and Replacement Cost.

G. In addition to providing the above data in spreadsheet form, covered entities shall consider how to most expeditiously protect their transformers from GIC, based on the totality of the circumstances (design, purpose, age, replacement lead time, etc.).

H. Covered entities shall not consider "operating procedures" such as load shedding and VAR supply as sufficient forms of GIC protection since adverse GIC effects can occur rapidly (may be no warning with E3) and over large regions that overwhelm operational reaction capabilities, and procedures cannot block GIC from entering an operating electric grid.

I. The report shall also provide the following: (a) Recommended solutions to protect the grid against GIC by preventing or reducing the half-cycle saturation of transformers, (b) Total cost to implement GIC protection of all vulnerable transformers owned and operated by the covered entity and (c) a priority list of transformers considering individual transformer risk, transformers threat to the remaining grid if unprotected (half-cycle saturating generating harmonics) and associated critical infrastructure/service loss.

J. As part of this report, covered entities shall also provide their recommendations for funding the deployment of this GIC protection, which can include both government grant opportunities and rate recovery.

K. This Order shall be effective from ______ on _____, and shall expire at 00:00 AM EST on ____. Renewal of this Order, should it be needed, must be requested before this Order expires.

Issued in Washington, D.C. at ______________________________________.

___________________________
Chris Wright
Secretary of Energy

cc: FERC Commissioners
Chairman Laura V. Swett
Commissioner David Rosner
Commissioner Lindsay S. See
Commissioner Judy W. Chang

# Appendix IV – "SAVE Transformers" Act – Long Version

AN ACT requiring utilities and electric grid operators to assess and report the vulnerability of high-voltage transformers to geomagnetic and electromagnetic disturbances, and to recommend mitigation measures to protect the state electric infrastructure.

Findings:

1.] America's electric grid, integral to every aspect of modern life, faces existential threats from solar weather [through coronal mass ejections (CMEs) that cause geomagnetic disturbances (GMDs)] and high altitude nuclear electromagnetic pulse (HEMP), both capable of crippling electric power systems; and

2.] The high voltage transformers critical to sustaining the electric grid are vulnerable to geomagnetically induced currents, also known as ground induced currents (GICs), which are induced in the earth by naturally occurring geomagnetic disturbances (GMDs) or the late-time (E3) component of high altitude electromagnetic pulse (HEMP) and enter the electric grid through the ground connected neutral wires of transformers; and

3.] The Extra High Voltage (EHV) transformers (345 kV – 765 kV) are the most vulnerable to GIC per their design (as they half-cycle saturate at very low GIC), are also the hardest to replace, many of them custom made with production lead times as long as 4-6 years, and require massive logistical and transportation challenges during their replacement process even during ideal "blue sky" conditions with a fully functioning grid, economy and society; and

4.] The GIC threat posed to these critical transformers is dependent on numerous factors, including the transformer's size, design and age, the ground conductivity in the region of the electric grid, and magnetic field produced by GMD or E3 HEMP; and

5.] In June 1992, the Electric Power Research Institute found that the aging of power transformers increases their susceptibility to GIC due to degraded insulating oil condition and coil condition (see "EPRI TR-100450, 1992"); and

6.] In January 2021, The National Security Council recommended "that U.S. electrical systems and other critical infrastructure elements can be assessed for disruption and damage susceptibility up to the benchmark HEMP waveforms characterized by peak electric field strengths of … 80 V/km for E3a (blast), and 50 V/km for E3b (heave), respectively," (See "Final HEMP Memo January 12, 2021 – Department of Energy"); and

7.] In May 2025, the International Electrotechnical Commission (IEC) updated its international standard for E3 HEMP to a peak electric field strength environment of 85 V/km (see "IEC 61000-2-9, Edition 2.0 2025-05"); and

8.] The current standard established by the North America Electric Reliability Corporation (NERC) to protect transformers and the grid from failure due to GIC, fails to require utilities to consider the design type and age of their transformers, establishes a "benchmark" peak electric field of only 8 V/km in Quebec, and utilizes a "scaling factor" to allow utilities to "scale down" per their geomagnetic latitude to consider a peak electric field of ~2 V/km across the center of CONUS and only 0.8 V/km across the southern states (while the GMD threat often decreases with geomagnetic latitude, the E3 HEMP threat is higher at lower geomagnetic latitudes due to its generation mechanism), engendering the real possibility of wide-area GIC-caused blackout with transformer and grid equipment failures (see "NERC TPL-007");

Therefore,

The State of __ (Insert State Name)____hereby establishes the "SAVE [Survey All Vulnerable Electric Transformers Act] Transformers Act", to be managed by _ (Insert State Agency)___.

Definitions:

1.] Covered entities: entities covered by this act include every electric utility and electric project developer, owner and operator, regardless of ownership or operation by the public or private sector within the state, regardless of whether that utility is subject to the jurisdiction of the North American Electric Reliability Corporation (NERC), and regardless of the regional transmission operators or independent system operators with which it operates.

2.] Covered equipment: includes all power transformers with primary voltage of 100 kV or greater and capacity of 25 MVA or greater and all Generator Step-Up (GSU) transformers with secondary voltage of 100 kV or greater and capacity of 25 MVA or greater.
Requirements:

Every covered entity shall by (________(Insert Date)______) conduct a technical assessment survey of all covered equipment within its jurisdiction to determine its vulnerability to geomagnetically induced currents, also known as ground induced currents (GICs), which are induced in the Earth by naturally occurring geomagnetic disturbances (GMDs) or the late-time (E3) component of high altitude electromagnetic pulse (HEMP); and,

1.] Specifically, covered entities shall use the analytic waveform plotted in Figure A.5 of "IEC 61000-2-9, Edition 2.0 2025-05" in their operating models to determine the susceptibility of their transformers to GICs associated with a peak magnetic field strength environment of 20,000 nT for E3 HEMP, which for a typical low conductivity ground conductivity in the United States will produce a peak electric field environment of 85 V/km, based on the recently updated International Electrotechnical Commission (IEC) international standard. (Evaluating the worst-case E3 HEMP threat to high voltage transformers and the grid will also consider severe GMD threats.)

2.] Covered entities shall undertake GIC modeling under the assumption that their transformers are operating fully loaded at the time when the operating environment experiences the GIC insult utilizing the late-time E3 HEMP waveform in IEC 61000-2-9, Edition 2.0 2025-05.

3.] Because the aging of power transformers increases their susceptibility to GIC due to degraded insulating oil condition and coil condition, covered entities shall consider the age of the transformers surveyed and de-rate those transformers according to ANSI/IEEE Standard C57.110 and IEEE Standard C57.91 when analyzing transformer susceptibility. After confirming and considering the age, condition, and loading of each transformer, the peak geoelectric operating environment (e.g. 85 V/km), and the ground conductivity profile, covered entities shall identify which transformers would be susceptible to the following effects: (a) Half-cycle saturation (b) GIC induced harmonics; (c) VAR consumption; and, (d) Generation of hot spots in the core or structural elements, (e) oil or insulation degradation, and report the potential impacts of each variable's susceptibility to GIC.

4.] No later than 180 days from the passage of this act, and while utilizing strict operational security for Critical Energy Infrastructure Information (CEII), covered entities shall provide a detailed report to (_Insert Agency__) with copies to the public utility commission, to the governor and appointed chief of homeland security, and to the state legislature.

5.] The report shall include, for each susceptible transformer and substation: Transformer brand; transformer place of origin, including nation where manufactured; transformer design specifications, including windings and core configuration, winding impedances, winding DC resistances (specify whether assumed or measured), and phase type (single-phase or 3-phase); transformer capacity in megavolt-amperes (MVA); transformer voltage level in kilovolts (kV); transformer age; transformer site location, redacted for CEII; transformer purpose (e.g., generator step-up, autotransformer, step-down, converter), redacted for CEII; transformer replacement lead time; and transformer replacement cost.

6.] In addition to providing the above data in spreadsheet form, covered entities shall consider how to most expeditiously protect their transformers from GIC, based on the totality of the circumstances (design, purpose, age, replacement lead time, etc.).

7.] Covered entities shall not consider "operating procedures" such as load shedding and VAR supply as sufficient forms of GIC protection since adverse GIC effects can occur rapidly (may be no warning with E3) and over large regions that overwhelm operational reaction capabilities, and procedures cannot block GIC from entering an operating electric grid.

8.] The report shall also provide the following: (a) Recommended solutions to protect the grid against GIC by preventing or reducing the half cycle saturation of transformers, (b) Total cost to implement GIC protection of all vulnerable transformers owned and operated by the covered entity and (c) a priority list of transformers considering individual transformer risk, transformers threat to the remaining grid if unprotected (half-cycle saturation harmonic generation) and associated critical infrastructure/service loss.

9.] As part of this report, covered entities shall also provide their recommendations for funding the deployment of this GIC protection, which can include both government grant opportunities and rate recovery.
This act takes effect at __(Insert Date)_____.

# Appendix V – “SAVE Transformers” Act – Short Version

AN ACT requiring utilities and electric grid operators to assess and report the vulnerability of high-voltage transformers to geomagnetic and electromagnetic disturbances, and to recommend mitigation measures to protect the state electric infrastructure.

1. Short title. This chapter shall be known as "Survey All Vulnerable Electric [SAVE] Transformers Act."

2. Findings.

I. America’s electric grid is critical to modern life and faces existential threats from solar weather events (coronal mass ejections—CME), geomagnetic disturbances—GMDs, and high altitude nuclear electromagnetic pulse—HEMP, all capable of disabling electric power systems.

II. High voltage transformers are especially vulnerable to geomagnetically induced currents—GICs—whether induced by GMDs or HEMP E3 component, entering the grid through ground-connected neutral wires.

III. Extra High Voltage (EHV) transformers (345 kV–765 kV) are most vulnerable and difficult to replace, with production lead times of up to 4–6 years.

IV. GIC vulnerability is influenced by transformer characteristics, ground conductivity, and the magnetic field intensity from GMD or E3 HEMP.

V. Aging transformers are more susceptible to GIC due to degraded insulating oil and coil condition.

VI. Federal and international standards highlight the importance of transformer assessment and protection against these threats.

SURVEY ALL VULNERABLE ELECTRIC TRANSFORMERS ACT

A:1 Purpose. The purpose of this chapter is to require electric utilities and electric project developers to assess and report the vulnerability of high-voltage transformers to geomagnetically induced currents (GICs) caused by geomagnetic disturbances (GMDs) and high altitude electromagnetic pulse (HEMP), and to recommend mitigation strategies to protect critical electric infrastructure.

A:2 Definitions. In this chapter:

I. “Covered entity” means any electric utility or electric project developer, owner, or operator within the state, regardless of public or private ownership or jurisdiction under the North American Electric Reliability Corporation (NERC).

II. “Covered equipment” means any power transformer with a primary voltage of 100 kV or greater and capacity of 25 MVA or greater, and any generator step-up transformer with a secondary voltage of 100 kV or greater and capacity of 25 MVA or greater.

III. “GIC” means geomagnetically induced current, also known as ground induced current, resulting from naturally occurring GMDs or the late-time (E3) component of HEMP.

IV. "Critical energy infrastructure information protocols," "critical electric infrastructure information protocols," or "CEII" means specific engineering, vulnerability, or detailed design protocols and procedures related to proposed or existing critical infrastructure, whether physical or virtual, that relate to the production, generation, transmission, transportation, or distribution of energy, the unauthorized disclosure of which could pose a risk to the security, reliability, or integrity of the infrastructure; such protocols are designated as confidential and exempt from public disclosure, as their release could be useful to a person planning an attack or otherwise causing harm to the infrastructure.

A:3 Assessment Requirements.

I. Each covered entity shall, no later than January 1, 2027, conduct a technical assessment of all covered equipment to determine vulnerability to GICs.

II. The assessment shall:

(a) Utilize the waveform in Figure A.5 of IEC 61000-2-9, Edition 2.0 (2025-05), modeling a peak magnetic field strength of 20,000 nT and corresponding electric field of 85 V/km.

(b) Assume transformers are fully loaded during GIC exposure.

(c) Account for transformer age and condition using ANSI/IEEE Standard C57.110 and IEEE Standard C57.91.

(d) Identify susceptibility to half-cycle saturation, GIC-induced harmonics, reactive power consumption, hot spot generation, and insulation degradation.

A:4 Reporting Requirements.

I. No later than 180 days after passage of this act, each covered entity shall submit a report to the U.S. Department of Energy, with copies to the public utilities commission, the governor, the chief of homeland security, and the legislature.

II. The report shall include, for each susceptible transformer and substation:

a) Transformer brand; transformer place of origin, including nation where manufactured; transformer design specifications, including windings and core configuration, winding impedances, winding DC resistances (specify whether assumed or measured), and phase type (single-phase or 3-phase); transformer capacity in megavolt-amperes (MVA); transformer voltage level in kilovolts (kV); transformer age; transformer site location, redacted for CEII; transformer purpose (e.g., generator step-up, autotransformer, step-down, converter), redacted for CEII; transformer replacement lead time; and transformer replacement cost.
(b) Spreadsheet-formatted data and narrative analysis.
(c) Recommended solutions to protect the grid against GIC by preventing or reducing the half cycle saturation of transformers.
(d) Total cost to implement GIC protection.
(e) Priority list of transformers by damage risk and critical infrastructure impact.
(f) Funding recommendations, including potential grant sources and rate recovery mechanisms.

A:5 Operational Standards. Covered entities shall not rely solely on operational procedures such as load shedding or reactive power supply to mitigate GIC risk. Such procedures shall not be considered sufficient protection under this chapter.

A:6 Confidentiality. All data submitted under this chapter shall be handled in accordance with CEII protocols as defined in A:2. Location and purpose data shall be redacted from public reports.

Effective Date. This act shall take effect _______________.

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# Next Steps - Stay Informed and Engaged

This report addresses urgent national security matters that require immediate and decisive action. The urgency is heightened by a range of historical and persistent challenges, including bureaucratic inertia, regulatory capture, political influence, and the pursuit of profit. Given the complexity and evolving nature of these issues, it is both wise and necessary to enable this report to be actively updated.

To support this adaptability, a QR code has been included with this report. By scanning the code, readers will gain access to a webpage hosting the latest version of this report as well as additional educational material, media articles, and real-time updates regarding legislative resolutions, bills, and executive actions at both the federal and state levels.

Public monitoring of federal and state executive, legislative, and regulatory actions is essential for maintaining oversight and accountability. Our Coalition thus urges "We the People" to stay engaged.

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