Protect our Electric Grid – Before it's Too Late

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Unless mitigation hardware is installed, the electrical grid – and all the critical infrastructures which depend on it – are at risk of catastrophic failure… from natural causes.

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All Critical Infrastructures Depend on The Electric Grid

Modern civilization depends on electricity for every aspect of life and for the functioning of the wide range of critical infrastructures that sustain it. Almost without exception, the owners and operators of these critical infrastructures consume electricity from an outside "electric grid" rather than producing it on-site. This means that if the electric grid were to fail, resulting in widespread and long-term blackouts, these life-sustaining infrastructures would grind to a halt.

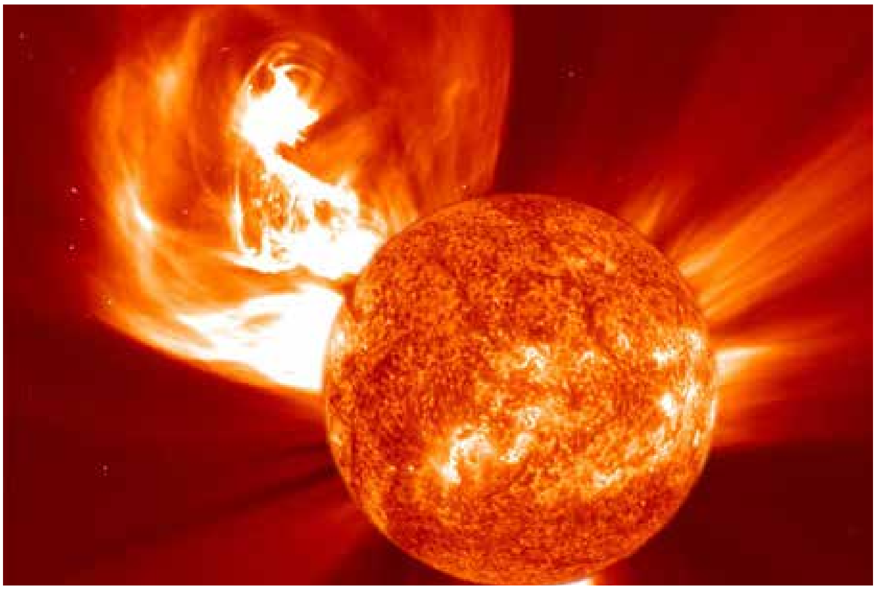
Modern societies are not prepared to live even a short time without electricity, especially in urban environments. In July 1977 a lightning strike took out three electrical substations in New York and caused a cascading power failure across the river in New Jersey. In less than one hour the entire city of New York was in total darkness. Civilization broke down after only 24 hours without electricity. In the ensuing chaos over 550 police officers were injured in the line of duty, 4,500 looters had been arrested and property damage was estimated at $300 million.

Suburban and rural populations may only be slightly more insulated to the immediate societal chaos from a blackout, but they are far from immune to its long-term devastating effects. Cold weather brought down the electric grid in Texas in February 2021 and in a blackout lasting only three days, more than 240 people died and the Texas economy sustained economic losses in the tens of billions of dollars.

While the state of Texas took aggressive action to fortify its grid against cold weather in response to this catastrophe, neither Texas, nor the rest of America, are prepared for the devastation that could come from another threat from Mother Nature – the sun.

The Sun: A Source of both Energy and Danger

Most people regard the sun as a positive source of energy for the planet – nurturing plant life and powering solar panels to help generate electricity. And while we know that we must be protected from the harmful UV rays the sun produces, which cause injury such as sunburn and skin cancer, most don't realize that the sun can produce even more powerful effects, damaging infrastructure both in space and on earth.



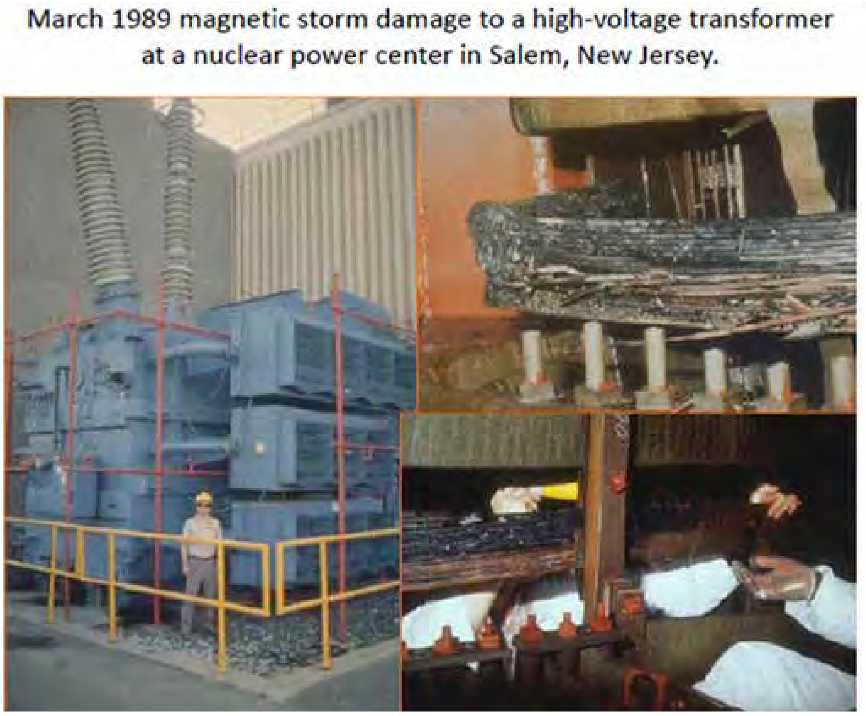
Coronal Mass Ejection (CME) captured on camera by NASA – NASA's Goddard Space Flight Center/STEREO/Bill Thompson

Scientists in the late 19th century observed that the Sun produces "sunspots" and "solar flares." These events sometimes correspond to incredible arrays of lights in the night sky (such as the Aurora Borealis AKA "Northern Lights".) Sometimes, these visual events are followed by physical phenomena on earth – such as the massive solar storm in 1859 that caused Aurora Borealis to be seen as far south as New Orleans and Cuba.

The corresponding effects on earth during that 1859 solar storm (known as the "Carrington Event") included telegraph machines catching fire – which scientists later determined was the result of ground induced currents (GICs) traveling through the earth's crust. Eventually scientists discovered these GICs were created by the earth's magnetic field when it is struck by the invisible magnetized particles expelled from the sun during the storm – something they named a "Coronal Mass Ejection" (CME).

Solar Weather Damages Transformers & Other Infrastructures

When a CME strikes earth's magnetosphere, it causes a Geomagnetic Disturbance (GMD). This disturbance creates large ground induced currents (GICs) in the earth's crust "looking" for the "path of least resistance." Long conductors, such as telegraph lines, railroads, and – now – the long transmission lines of the electric power grid, quickly become that "path." These damaging currents in the ground travel up the ground connection of transformers, into the electric grid, across high voltage/low resistance transmission lines, causing thermal and harmonic damage to connected equipment. This includes large power transformers such as the one catastrophically damaged during a



This transformer sustained major damage from GICs induced by the March 1989 Solar Storm. Photo credit: Dr. Jeffrey J. Love, USGS

much smaller solar storm in March 1989 at a nuclear power plant in Salem New Jersey.

It is important to note that we have not experienced a devastating solar super storm since the modern grid was developed. Each year as we expand the grid and connect the neutrals of additional transformers to the ground, we provide more entry points for GIC into the grid and it becomes more vulnerable. The March 1989 Solar Storm that damaged the above transformer and blacked out Quebec is regarded as a "40-year" solar storm (i.e. the moderate type that strikes earth roughly every 40 years). Just 9 hours without power as a result of this event caused USD13.2 billion in economic loss.

The 1859 Carrington Solar Storm is considered a much more powerful "100-year" storm and would thus cause much more catastrophic and widespread damage to transformers. Lloyd's of London estimates the economic cost of a Carrington-class solar storm on the North American electric grid at between USD600 billion to 2.6 trillion based on value of lost electrical load, not to mention the immense loss of human life.

It is a statistical certainty that the earth will experience another Carrington-class or larger event in the future. Unless modern societies take action to install mitigation hardware to block GICs produced by solar weather, such an event could result in the catastrophic loss of the electric grid.

But it's not just 40 and 100-year storms that cause damage to electric infrastructure connected to long transmission lines. A joint study by the global insurance leader Zurich and Lockheed Martin concluded that space weather has "an average impact on the order of USD10 billion per year each for both the overall US and European economies." This is due to the relatively small GICs generated during normal solar activity that travel through the crust of the earth, invade the electric grid through the grounded neutral connection of transformers, causing transformers to saturate and generate harmful "harmonics" which then travels down transmission lines into machinery powered by the grid. This means that critical infrastructure owners may experience malfunctions and increased maintenance requirements of grid-connected machinery specifically because harmful GICs were not blocked at the point of entry at the high voltage generation and transmission level of the electric grid.

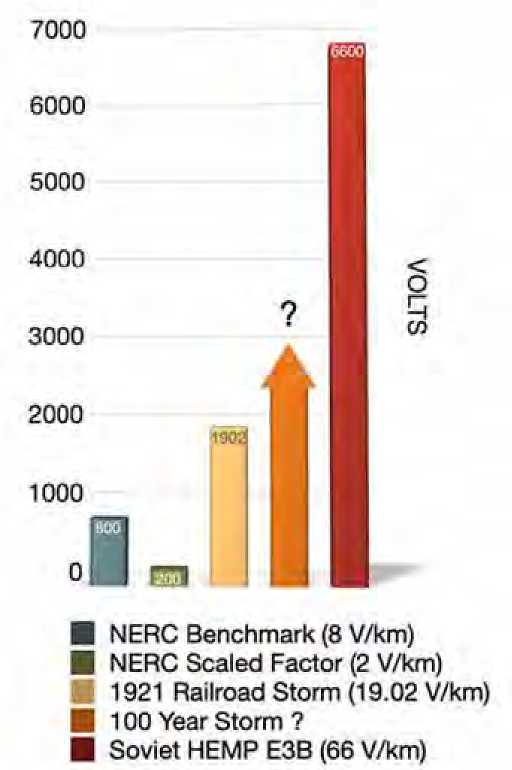
Critical infrastructure owners and operators worldwide cannot afford to prematurely lose equipment and grid operators definitely cannot afford to lose transformers during a time when supply chains are already strained. Russia's present war against the Ukraine and its targeting of electric infrastructure has placed major demand on electrical components such as transformers. Additionally, the worldwide exponential growth in the electrification of infrastructure (ranging from transportation to cookware) has increased demand–causing modern-day lead times to now extend into a range of 4-6 years for large transformers. What this means is that nations cannot afford to lose even a small number of transformers to harmful GICs without major, potentially catastrophic, consequences.

North America's Decade of Inaction

Since May 2013, the agency of the United States government that regulates the bulk power grid (FERC) has required the electric utility industry in North America to establish and enforce a standard to protect the grid, especially those irreplaceable transformers, against a 100-year solar storm. National security experts, engineers, and solar weather scientists have warned for 11 years that the standard set by utilities is insufficient, even dangerously low, a reality recently confirmed in a peer-reviewed study by world-renowned scientists.

Nearly two years ago the U.S. Secretary of Energy Advisory Board (SEAB) was advised of the transparent deficiency in the current solar storm standard for the electric grid. Verbal and written testimony to the SEAB revealed the startling low level of protection required by the standard, which won't even be enforced until 2028.

The field strength of a solar event is measured in volts per kilometer ("V/km") and directly relates to how large the resulting GICs will be. The testimony pointed to a case study for the Virginia / Washington D.C. area and included a bar graph depicting the field strength (2 V/km) the current standard requires to protect against (in green) versus the field strength levels (and resulting GICs) produced in the 1921 Railroad Storm (19.02 V/km - in yellow), the larger Carrington event (in orange), and even those produced by Soviet high altitude nuclear tests (66 V/km), since nuclear EMP causes a similar and even stronger field strength and resulting GICs on the grid (in red).



This bar graph (utilizing the average 100 km length of a transmission line) was included in testimony to the U.S. Secretary of Energy Advisory Board (SEAB) and depicts the current level of protection of the grid in Virginia (green) versus known and suspected hazard levels (yellow, orange, and red).

The Good News: It's a Fixable Problem

The good news is that there are known, tested, and affordable technological solutions to protect our vital transformers and other critical infrastructures against GICs caused by solar weather. These are neutral blocking devices (NBDs) that can block these harmful ground induced currents at the point of entry, preventing them from invading the electric grid. NBDs not only protect irreplaceable transformers and high voltage breakers from damage, but also block out routine GICs that occur regularly, causing harmonics "downstream" in the grid and harming other critical infrastructures.

One such NBD, produced by Emprimus, is known as "SolidGround". It is a standard "one size fits all" product for all high voltage transformers (regardless of design) which is simply inserted in the transformer's neutral connection. Instead of running a high voltage transformer's copper wire directly into the ground, the utility runs the copper wire through the grounded NBD. The NBD then automatically detects and blocks the ground induced currents from entering the grid through that copper ground wire during a solar storm. A utility doesn't need to touch the high voltage phase lines that run the electricity to the rest of the grid, but rather install the NBD on the transformer's ground connection.

After years of use in the live power grid in at least three critical infrastructure substations in the North American electric grid, this "SolidGround" system has emerged as a tested and confirmed solution to mitigate the destructive impact of GICs. For example, American Transmission Company (ATC) has operated the "SolidGround" NBD since 2015. In 2019, Mr. Jim Vespalec, the Director of Asset Planning & Engineering for ATC, testified in front of the U.S. Senate Committee on Homeland Security and Governmental Affairs, reporting flawless performance with "several dozen" successful operations and "no adverse operating complications."

Similarly, the Western Area Power Administration (WAPA) has been utilizing the "SolidGround"

"SolidGround" on 345KV transformer in the ATC grid in Wisconsin (9+ years of testing)

"SolidGround" NBD protecting DOE's 345 kV transformer in the WAPA grid in South Dakota.

NBD solution since November 2022, where it has detected GIC and automatically engaged its protection 17 times in the past 12 months alone. Additionally, the Tennessee Valley Authority (TVA) implemented the "SolidGround" NBD system on a massive $20 million 500 kV transformer and it has also demonstrated its efficacy during critical events engaging its protection multiple times during solar events, with no problems.

What all this means is that "SolidGround" is activating and working during even very minor solar weather events, blocking GICs and preventing the resulting harmonics that can damage other critical infrastructures resulting in large economic loss on an annual basis. It also means that the technology will have no problem detecting and mitigating significant currents associated with the larger "40-year" or "100-year" storms that could devastate large power transformers and blackout the entire electric grid.

Solar Storm Protection is Affordable

Given the statistical near certainty that earth will be struck by a major solar storm in the future, the transparently defective protection standard, the $10B annual economic losses from routine solar weather and the availability of at least one extensively tested solution already operating in at least three locations in the North American grid, one might wonder why more action hasn't been taken. Some wrongly assume the effort would be too costly.

Not all portions of the grid and not all transformers are vulnerable to the GICs generated by solar weather. For those which are vulnerable, the "SolidGround" solution costs approximately $500,000 per transformer. Using this cost estimate and an analysis of vulnerable transformers, independent experts from the Foundation for Resilient Societies estimate that it would cost $4.1 billion to harden the entire U.S. electric grid against the devastating impact of GICs produced by solar weather. This estimate closely matches the estimates of Mr. Scott McBride of the U.S. Department of Energy's prestigious Idaho National Laboratory (INL) in his 2018 testimony before the U.S. Senate Homeland Security and Governmental Affairs Committee.

The Solution is "Bottom Up" Action

Despite the aforementioned warnings, and the fact that the U.S. Government passed a $1.2 trillion Infrastructure Bill in recent years, literally no action has been taken on the part of the current U.S. Department of Energy to protect the North American grid. This means that it is up to the states and the electric industry to take action.

The fastest way to solve this problem is through the creation of financial incentives and penalties by the entities who regulate utilities at the state and local level. Admittedly, electric utilities face daunting regulations from all quarters, ranging from environmental to security, and often find themselves in an impossible position where following one regulation will cause them to break another. When faced with such quandaries, they often end up choosing to "break" the regulations with the least financial penalties. Similarly, when choosing how and where to invest time, talent, energy, and resources – they ask themselves "where's the money?"

Understanding these basic tendencies in the wake of Winter Storm Uri in Texas, the state legislature passed laws that empowered the Texas Public Utility Commission to (1) create an effective weatherization protection standard at the state level, (2) impose financial penalties for grid operators who violate the standard, and (3) provide for "cost recovery" mechanisms to cover the costs of upgrades to meet the standard. This largely "solved" the cold-weather problem for the state's electric grid.

Admittedly, Texas is unique in that it has its "own grid" and does not fall under the jurisdiction of the U.S. Federal Energy Regulatory Commission (FERC), enabling it to solve the cold weather problem much faster and more effectively than the federal bureaucracy under FERC. Therefore, Texas can – and should – take the same actions to protect against the looming threat from solar weather. Other states can, and must, explore how to do the same.

Conclusion

"Bottom up" action to protect our electric infrastructure from solar weather will only happen if a few conditions are met:

• First, there must be sufficient awareness about the gravity of the threat. Fortunately, the award-winning documentary "Grid Down, Power Up" narrated by celebrity Dennis Quaid can provide that awareness to the public at large.

• Second, there must be an acknowledgement of the presently insufficient solar storm protection standard established by the U.S. FERC. Fortunately, the facts have been well-documented and made available to the public through official testimony to the U.S. Secretary of Energy. State and local regulators need only to verify these facts to begin taking action.

• Third, because critical infrastructure owners and operators often pay much more for electricity than the common citizen, it will be imperative for them to understand and support the effort to require utilities to upgrade their systems with NBDs to mitigate solar weather. Utilities will undoubtedly pass on their costs to these customers through increases in the rate base.

Ultimately, critical infrastructure operators can provide greater resilience for the communities they serve by exploring methods of generating needed power on-site or locally through all-hazards resilient microgrids and reducing dependency on the outside electric grid. The U.S. Department of Homeland Security's "Resilient Power Working Group" has even published a best practices document that helps operators explore these options. This process, though, will take a long time.

Therefore, we need to protect the grid we have before it's too late.

"SolidGround" NBD protecting a 500 kV transformer in the TVA grid. This transformer would cost upwards of $20 million, and years to replace if it were destroyed by ground induced currents from solar weather. The "SolidGround" unit protecting this transformer costs approximately $500k, or 2.5% of the value of the total asset.