RECOMMENDATIONS OF

THE FOUNDATION FOR RESILIENT SOCIETIES

TO STRENGTHEN THE FINAL REPORT OF

THE MAINE PUBLIC UTILITIES COMMISSION TO

THE MAINE STATE LEGISLATURE

ON MITIGATION OF

GEOMAGNETIC DISTURBANCES AND ELECTRIC MAGNETIC PULSE RISKS

TO THE MAINE ELECTRIC GRID

In re: Maine PUC Docket 2013-00415

December 18, 2013

www.resilientsocieties.org

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1.0 The Strategic Context for Maine Initiatives to Protect the Safety and Reliability of Maine's Electric Grid

The State of Maine has taken the lead in addressing existential threats to 21st century societies, by mandating through state legislation (H.P. 106 – L.D. 131, 2013 Ch. 45 resolves) comprehensive examination of measures to mitigate the effects of geomagnetic disturbances and electromagnetic pulse(s) on Maine's electric transmission system.

The Commission's Draft Report contains an unrealistic assessment of the capabilities of the designated federal regulator, the Federal Energy Regulatory Commission (FERC), to mandate cost-effective reliability standards for all states. The Draft Report of the Maine PUC does not appropriately recognize that reliability standards must be initiated and developed by the North American Electric Reliability Corporation (NERC) and then approved or remanded by FERC. FERC cannot rewrite a NERC proposed reliability standard; instead, FERC must remand the standard to NERC for further consideration. If NERC were to propose nearly endless "research" instead of enacting a needed standard, FERC cannot implement its own substitute standard. FERC cannot independently perform standard-setting tasks.[1]

NERC has a track record of slow standard-setting, passage of standards lacking substantive protections for public safety, deletion of needed standard projects, and retirement of already passed standards. Given this track record, the public interest could be harmed if the Maine PUC recommends that NERC be the sole standard-setting body to develop and enforce protection standards for the Maine grid.

There is a void in prior published assessments of "the costs of potential mitigation measures" for EMP protection at the state level, a gap which might be remedied by the Commission's final report. However, the Draft Report by the Maine PUC fails to fulfill these legislative mandates at Sec. 1(3) through Sec. 1(6) of year 2013 Ch. 45 resolves and therefore may not address costs of EMP/GMD mitigation measures:

[1] The North American Electric Reliability Corporation (known as NERC) serves as the designated Electric Reliability Organization. Only the ERO can propose federal reliability standards, and the ERO must propose a standard before it can be adopted by FERC. Because NERC had not proposed any standard for grid protection from solar geomagnetic disturbances between the Hydro Quebec solar storm of 1989 and the year 2012, FERC, for the first time since the Energy Policy Act of 2005 on its own initiative (*sua sponte*), mandated that NERC develop standards for *operating procedures*, then for *hardware protection* of critical grid equipment. See FERC Docket RM12-22-000, leading to FERC Order No. 779, May 16, 2013. We discuss glaring deficiencies of the NERC proposed "operating procedures" submitted to FERC in November 2013. FERC may *remand* the proposed operating procedures or approve them. Even the most rigorous operating procedures would have limited benefits for public safety. We discuss this topic in Section 1.2 of our comments. If individual states adopt more stringent standards to protect the safety and reliability of their electric grids, FERC has the authority to block subsequent NERC-proposed standards that would undercut the state standards. See section 1.2 and 1.3 of our Comments.

Sec. 1 (3) Estimate the costs of potential mitigation measures and develop options For low-cost, mid-cost and high-cost measures; and

Sec. 1 (4) Examine the positive and negative effects of adopting a policy to incorporate mitigation measures into the future construction of transmission lines and the positive and negative effects of retrofitting existing transmission lines; and

Sec. 1 (5) Examine any potential effects of the State adopting a policy under subsection 4 on the regional transmission system; and

Sec. 1 (6) Develop a time frame for the adoption of mitigation measures….

1.1 The Strategic Context: Why There Is Continuing Urgency for Electric Grid Protection

Recent findings about the magnitude and frequency of massive coronal mass ejections from the sun indicate that time is of the essence in implementing protective measures, including hardware protection of the expensive, long-time-to-replace high voltage transformers, essential communications systems, and automatically programmed (SCADA) equipment essential to modern grid operations.

At the December 2013 conference of the American Geophysical Union in San Francisco, solar scientist Daniel Baker (University of Colorado—Boulder) presented evidence that a coronal mass ejection (CME) on July 23, 2012 was the most energetic of all CMEs ever recorded, and likely exceeded the geomagnetic intensity of the Carrington event of 1859. Professor Baker noted that the July 2012 coronal mass ejection came during the relatively inactive Solar Cycle 24. He remarked:

> The Carrington storm and the 2012 event show that extreme space weather events can happen even during a modest solar cycle like the one presently underway," Baker said. "Rather than wait and pick up the pieces, we ought to take lessons from these events to prepare ourselves for inevitable future solar storms."[2]

Bill Murtagh, Program Coordinator, Space Weather Prediction Center of the NOAA Space Weather Prediction Center in Boulder, Colorado, further explained at the December 2013 Dupont Summit,[3] that the largest-magnitude solar geomagnetic storm impacts on the planet earth have occurred during times of moderate solar sunspot frequency. The following graph shows that the two highest magnitude solar storms (in a graph depicting sunspot frequency over the past 250 years), the Carrington event of 1859 and the 1921 New York Railroad geomagnetic disturbances occurred during just modest-frequency sunspot cycles and not during high frequency sunspot cycles:

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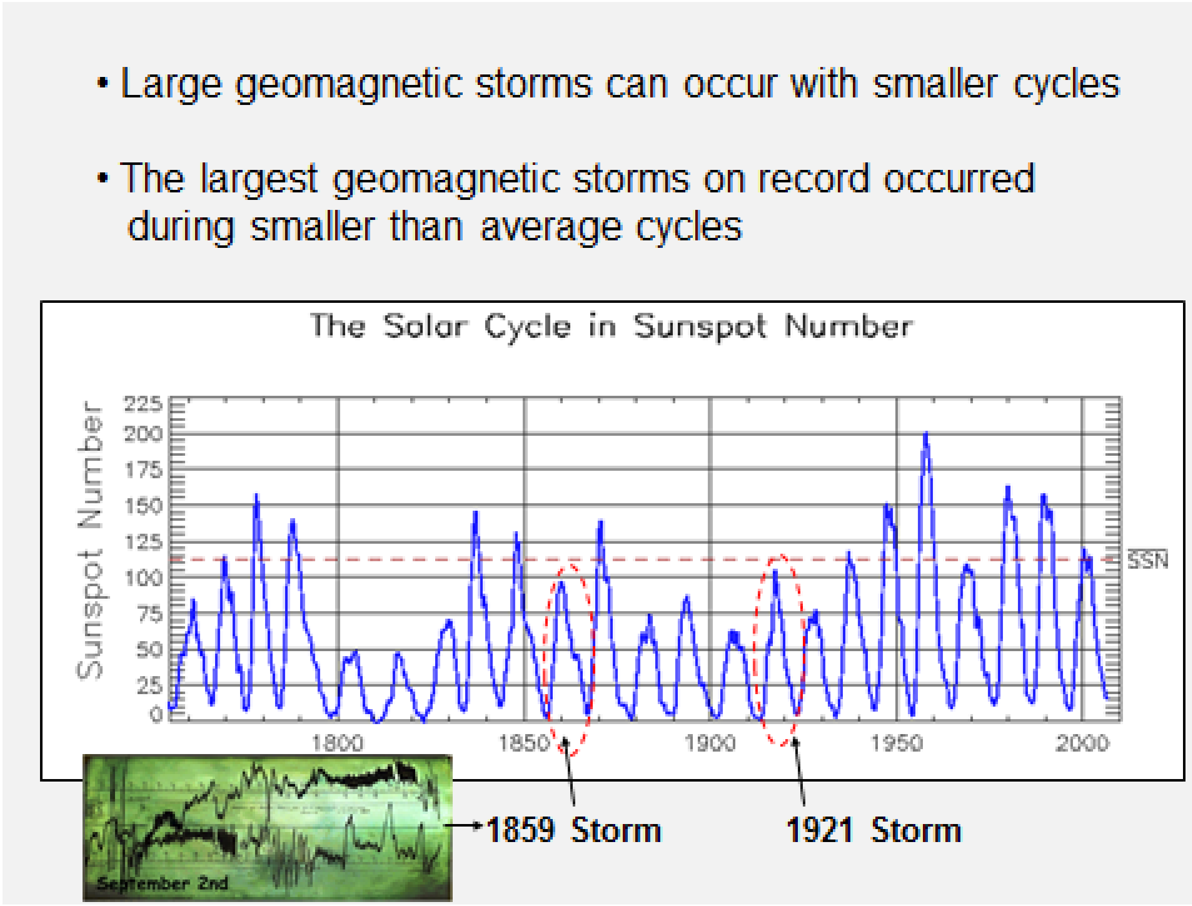
[2] Press Release, December 10, 2013, for American Geophysical Union presentation, San Francisco, CA.

[3] William Murtagh, NOAA Space Weather Prediction Center, "Space Weather Update," Infraguard EMP-SIG Dupont Summit, Washington, D.C. December 6, 2013, Viewgraph 5, courtesy of Dr. Murtagh.



Source: William Murtagh, NOAA Space Weather Prediction Center, "Space Weather Update," Infraguard EMP-SIG Dupont Summit, Washington, D.C. December 6, 2013.

The July 23, 2012 CME, with the highest energy levels in recorded history, occurred during a Solar Cycle 24 with below-average sunspot frequency. But had the earth been in the pathway of this CME, without hardware protection for the electric grid, we would be unable to file Comments in this Maine PUC Docket due to the absence of the internet and the collapse of the grid.

For a super-CME event of magnitude of the July 23, 2012 event and headed directly at planet earth, any "operating procedure" other than complete de-energizing of transformers and generators would be ineffective. Below is an image of that event.

We ask both the Commissioners of the Maine PUC and Maine state legislators to contrast **opportunities for electric grid protection while the global economy and its supporting infrastructures are intact**, in contrast to the extraordinary constraints that would limit **opportunities for post-collapse recovery efforts** following a global, national, or even regional electric grid collapse.

What would happen when emergency diesel generators (EDGs) at hospitals and police stations run out of diesel fuel? When regional diesel depots cannot pump more fuel? When refineries cannot produce or ship more diesel fuel?

How could replacements for irreparably damaged extra high voltage transformers be manufactured and shipped to areas without a functional electric grid and social structure? If replacement orders swamped production capacity, and if production capacity was crippled by lack of electric power at manufacturing sites? And if foreign governments insist that transformers produced in Japan, or China, or Germany, or Austria be reserved for domestic deliveries rather than international deliveries? Following a major solar storm or a high altitude EMP attack, the much-touted Department of Energy/NERC STEP program (for spare transformers) will enable some replacements of 345 kV transformers, but overall, there will be nowhere near the number of spare transformers required to restore a fully-functioning regional or national electric grid.

Dr. George H. Baker, Professor Emeritus at James Madison University, terms this challenge "the vulnerability of complexity."

Without prior action to protect critical equipment, even the *assessment* of critical needs – once the grid has collapsed – will be a challenge that is likely to set back post-disaster recovery and reconstruction. Which equipment is damaged but repairable, and which is a total loss? How can "black start" operations proceed, once the batteries at electric sub-stations are depleted, and once fuel for emergency diesel generators at control rooms becomes unavailable? What international relief would be essential and with what priority?

The largest electric utility in the State of Maine, Central Maine Power, has 6 operational or planned SCADA systems, one each for its 345 kV substations. It has or plans another 74 SCADA systems, more or less, for its lower voltage substations, often at unmanned sites.[4] SCADA systems without low-cost electromagnetic protection (about $10,000 per site[5]) are vulnerable to man-made E1 damage, and are also vulnerable to intense solar geomagnetic storms, quasi-DC currents, or E3 damage. Altogether, the electric utilities in the State of Maine may have some 200 to 300 SCADA systems which, if protected before an electromagnetic catastrophe, could play key roles in system recovery and reconstruction. But SCADA systems also depend upon reliable (off-grid) power and reliable telecommunications. If Maine allows its electric grid to collapse, rather than mandate standards and act to require low-cost protections, a calamity that could have been averted will be the responsibility of those entrusted to assure the reliability of the grid and the public safety for the citizens of Maine. [6]

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[4] See NARUC, Investigation into Needs and Standards for a Maine Smart Grid Coordinator, 2012, at p. 17.

[5] Estimate of Dr. George H. Baker. Specially designed metal containers and cabling could protect SCADA systems, battery chargers, batteries, and protected communications equipment).

Battery chargers that are connected via Ethernet connections or other long wires may be vulnerable to large E1 voltages on the signal wires. Some battery chargers, if not protected, may be subject to E3 damage. Information received from Bill Kaewert, President & CTO, SENS (Stored Energy Systems, LLC), Dec. 17, 2013.

[6] The state savings clause in Title 16 U.S.C. section 824o(i) preserves the right of states to assure safety for electric grid equipment and to assure public safety. A state may adopt standards to assure the adequacy of in-state electricity transmission and distribution. Barring a circumstance where a state adopts in-state reliability standards that result in *reduced reliability* in other states or the bulk power system, FERC has the authority to decline

1.1.1 Why NERC-Proposed "Operating Procedures" Are of Limited Value, and Are Substantially Less Cost-Effective than Hardware Protection

A major impediment to action in protecting the North American electric power grid against major solar storm geomagnetic disturbance (GMD) and nuclear electromagnetic pulse (EMP) effects is that the electric power industry is understandably swayed by the familiar, the convenient, and the bottom line.

Without a doubt, Carrington-class solar storms and EMP effects are unfamiliar. The North American electric power grid has never experienced them. These are 'black swan' events which, if we fail to take protective action, could result in wide-area blackouts lasting months or years. It is unfortunate that familiarity and profitability are the touchstones of acceptability. Strategic advantage in public debate all too often goes to the acceptable.

Thus there is the present tendency is to downplay the likelihood of the long-term grid outages caused by a major solar storm or nuclear EMP event. Even though a greater-than-Carrington magnitude solar storm erupted just 17 months ago, NERC and its electric utility membership has proposed reliance on "operating procedures" without even assessing potential financial costs of in the aftermath of a Carrington class event.

To counter the "strategic advantage of the acceptable," it is crucial that we create public awareness of the existential consequences of GMD and EMP. This must include identifying important and pervasive misconceptions concerning GMD/EMP. A major misconception is that GMD/EMP effects can be countered solely by well-conceived 'operational procedures.' However, given the complexity of the possible combinations and permutations of multiple grid failure mechanisms from GMD/EMP, operational procedures will not reliably suffice.

For instance, operational procedures proved ineffective in preventing the 2003 Northeast blackout that was precipitated by a single failure point involving tree contact with a transmission line. Grid models indicate that GMD and EMP may induce hundreds to thousands of failure points. In 1989, during a moderate solar storm GMD, the electric power grid of the entire Province of Quebec went dark in 90 seconds - there was not enough time to implement operational procedures. The complexity and rapidity

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approval of NERC-proposed reliability standards that would undercut or allow injunctions against implementation of state reliability standards already in place.

Where is the North American Electric Reliability Corporation in this pre-disaster planning process? To date, NERC has discarded a standard development project for physical protection of critical equipment; it has eliminated a standard development project for equipment monitoring that could have mandated GIC monitoring for all extra high voltage transformers; it has declined to perform financial analysis of the uses and costs of "operating procedures" for solar geomagnetic disturbance mitigation, though required by FERC Order 779; it has enabled electric utilities to withdraw significant assets from a mandatory "blackstart" equipment inventory; and it has delayed effective cyber-security standards. To date, NERC by its practices has demonstrated a greater commitment to risk-shifting to the public than to effective and timely protection of the grid from GMD or EMP hazards. Without the implementation of a FERC approved reliability standard, an electric utility may claim it is immune from liability for even gross negligence for malfeasance or nonfeasance. The price of deferring cost-effective FERC standards and follow-up implementation to protect the grid may be societal collapse. Hence state-adopted reliability standards, implemented with supportive FERC coordination, may be essential to protect 21st century electric grids.

of grid failure during a Carrington-class event, or even just a 1921 New York Central Railroad event will overwhelm the ability of electric utilities to respond with operation procedures, no matter the good intentions of some operators.

For more detail on the pitfalls of operating procedures, see Appendix 2.

1.1.2 Two Classes of "Operating Procedures" Are Not a Substitute for Hardware Protection

The first set of "operating procedures" that could be beneficial only during moderate solar storm relates to the generation of both prompt generating reserves and preparation of additional *reactive power* capacity. The second set of "operating procedures" that could reduce grid recovery times after a super-solar storm would be to exercise, validate, and enable the de-energizing of critical (unprotected) electric grid equipment upon strategic and tactical warning of a Carrington class or New York Railroad class solar storm.

The Foundation for Resilient Societies reviewed solar storm "operating procedures" of ISO-New England and various likely imbalances of electric supply and demand during magnitude solar storms. Our report of March 2013 projected likely imbalances of regional electric supply and demand. Extended blackouts could result. Triggering events might be: the loss of a high voltage DC Intertie from Canada to Maine; or the outage of the Chester, Maine static VAR compensator; or the concurrent loss of ISO-New England generating facilities operating without neutral ground blocking devices or series capacitors. The Maine and ISO-New England report is available online. See the Interim Report on the Maine and ISO Electric Grid.

In a *moderate solar geomagnetic storm*, operating procedures could result in augmented generating capacity, and augmented reactive power preparations. The financial losses for non-economic dispatch and societal costs of extended blackouts by relying on these "operating procedures" – so far not analyzed by NERC as required by FERC Order No. 779 -- would most likely exceed the costs of purchasing grid-protective hardware, with positive returns on investment in less than one solar half cycle (about 10.5 years).

For *the major solar geomagnetic storm*, or for a *high-altitude EMP event*, mere operating procedures (other than de-energizing of critical equipment if time permits) would be ineffective.

1.1.3 Engineered Solutions that Utilize Hardware or Space Enclosures Can Protect Electric Grids Without Reliance upon "Operating Procedures".

The good news is that operational procedures are not needed if the grid is physically protected against GMD and EMP. Furthermore, affordable hardware is available to protect the heavy-duty components of the generation and transmission systems against GMD/EMP. These components include extra-high voltage (EHV) transformers; generator stations; static VAR compensators; and dynamic VAR compensators as they become available.

These grid elements represent the "long poles" in the protection tent since their procurement and replacement timelines are measured in months at a minimum and often one to two years. The nationwide cost for hardware protection is estimated to be in the single digit billions of dollars, a microfraction of the losses that would occur from a protracted blackout (based on National Academy of Science and Lloyds of London estimates, losses will be in the trillions of dollars). Physical protection is well worth the investment.

The State of Maine is at greater risk each year, during the ongoing build out of the $1.4 billion Maine Power Reliability Program (MPRP) between the years 2010 and 2015. Extra high voltage transmission lines, many in parallel, inadvertently create a more extensive antenna system. Testimony of John Kappenman before the Maine State legislature and elsewhere confirms that parallel configurations for extra high voltage (EHV) transmission lines could have the unintended effect of nearly doubling geomagnetic induced currents in unprotected Maine transmission systems.[7] Without the installation of hardware protection, the EHV transformers, SCADA controllers, and other grid equipment are becoming more vulnerable to a solar storm at any given level of magnitude. Maine Central Power estimates that only eight percent (8%) of the costs of the Maine Power Reliability Program (MPRP) are to be borne by Maine's electric ratepayers. The Draft Maine PUC Report fails to highlight this important fact. See http://www.mainepower.com/about-mprp.htm# According to Maine Central Power Co., 92 percent of transmission system upgrade costs for the Maine Power Reliability Program are to be borne by ratepayers in the other five New England states.

Some portions of the to-be-merged holding company, Emera Maine, which takes effect on January 1, 2014, are not interconnected with the ISO-New England regional grid. Hence, costs to protect this portion of the Maine grid will be borne by rate-payers in this service region of the state.

So long as FERC determines that additional Maine transmission system protection costs to better cope with GMD and EMP for the portions of the state that interconnect with other states in the ISO-New England grid are (1) consistent with the Federal Power Act's section 824o, and (2) do not reduce the reliability of electric service in other states, then the Maine utility costs recommended in these comments should also be allocatable to other states – to the extent that other states will benefit. And other states will benefit if Maine's imports of hydropower from Canada, and interconnections to the ISO-New England grid become more dependable – even during a solar geomagnetic storm.

1.2 Why State Protective Initiatives Are Needed To Complement Federal Initiatives.

We have previously explained why the standard-setting process for the electric grid depends upon standard proposals from an industry-dominated entity, NERC. We have previously described actions by NERC to eliminate existing standards and to block new standards at the federal level, such as mandatory equipment monitoring of grid-critical equipment. We have noted that the Maine Power Reliability

[7] Kappenman testimony, Maine state legislature, Comm. On Government Oversight, March 20, 2013.

Program inadvertently increases risks of grid collapse, because the upgrades as designed in years 2008-2010 did not include designs to mitigate geomagnetic disturbances, or EMP risks. There is a compelling need for state reliability standards and state action to require installation of cost-effective hardware protections.

Does the State of Maine have the authority to create its own standards, yet also obtain cost recoveries through review via ISO-New England and tariff approvals by FERC? We believe the answer is yes.

1.2.1 The State Savings Clause in the Federal Power Act, 16 U.S.C. § 824o, Subsection (i).

(i) Savings provisions

(1) The ERO shall have authority to develop and enforce compliance with reliability standards for only the bulk-power system.

(2) This section does not authorize the ERO or the Commission to order the construction of additional generation or transmission capacity or to set and enforce compliance with standards for adequacy or safety of electric facilities or services.

(3) Nothing in this section shall be construed to preempt any authority of any State to take action to ensure the safety, adequacy, and reliability of electric service within that State, as long as such action is not inconsistent with any reliability standard, except that the State of New York may establish rules that result in greater reliability within that State, as long as such action does not result in lesser reliability outside the State than that provided by the reliability standards.

(4) Within 90 days of the application of the Electric Reliability Organization or other affected party, and after notice and opportunity for comment, the Commission shall issue a final order determining whether a State action is inconsistent with a reliability standard, taking into consideration any recommendation of the ERO.

(5) The Commission, after consultation with the ERO and the State taking action, may stay the effectiveness of any State action, pending the Commission's issuance of a final order.

State authority to set electric safety and reliability standards, and to implement them, derives from the "savings provisions" under the Federal Power Act combined with other state authorities, including state police powers and existing state authority to regulate intrastate transmission and electric distribution.

On first impression, the "savings provisions" under Section 215 of the Federal Power Act appear to provide opportunities for higher reliability standards in Hawaii and Alaska (these non-contiguous states are exempt from FERC regulation under subsection (k)) and the State of New York. New York State is permitted to enact "higher reliability standards" than the remaining 47 states "as long as such action does not result in lesser reliability outside the State than that provided by the [FERC] reliability standards."

Maine's coastal geography subjects the state to high-saline water, high latitude, and grid edge GMD effects. Common sense would allow the State of Maine higher reliability standards to cope with solar storms than would be allowed the State of New York.

One modality to overcome the inequity of this unjustified favoritism for the State of New York is to obtain cooperative assistance from the Federal Energy Regulatory Commission.

If FERC is satisfied that Maine will adopt only cost-effective mitigation measures and that these mitigation measures will not "result in lesser reliability outside the State than that provided by the [FERC] reliability standards," FERC can act as a protector of improved grid reliability in the several states.

FERC does not have authority to initiate reliability standard-setting, but FERC can disapprove NERC proposed standards that would halt ongoing state initiatives to raise electric reliability within the several states. So FERC is a potentially significant ally, so long as the State of Maine coordinates its reliability upgrades with FERC and the FERC staff.

The Maine PUC Commissioners should pay close attention to comments, guidance, and technical assistance that the FERC staff provides, under authority of federal law.[8] Well-coordinated electric reliability upgrades in the State of Maine should qualify for FERC approval of tariffs, so that reliability improvements that benefit ISO-New England and not just Maine ratepayers have cost-sharing with the other New England states.

1.2.2 Why NERC's Action in Eliminating a Mandatory Standard for Equipment Monitoring Enables State Standards for Mandatory Equipment Monitoring

In our Recommendations section, our Foundation proposes that the State of Maine commence its grid reliability upgrades with two low-cost initiatives. The first initiative is to mandate the installation of Geomagnetic Induced Current (GIC) monitors at all Maine PUC-jurisdictional electric utilities having transformers have high-end voltage over 200 kV.

On a voluntary basis, American Transmission Co. in Wisconsin has installed 23 GIC monitors at the boundaries of the ATC transmission service area, and at key internal nodes. This enables observation and modeling, and modeling validation, as ATC considers where to install neutral ground blocking equipment. Preliminary research indicates that installing neutral ground blocking devices at the perimeter of the system, including major AC And DC interties, reduces overall geomagnetic currents within the ATC transmission system. Moreover, various modeling efforts, including Idaho National Laboratory, Emprimus jointly with PowerWorld, Manitoba Hydro with Emprimus, and other ongoing assessments indicate that the introduction of neutral ground blocking devices in selected EHV transformers both protects these transformers from solar storm damage (overheating and vibration); and reduces GIC currents in unprotected transformers elsewhere in the system and in neighboring electric systems.

[8] Due to the December 18, 2013 filing deadline, we will not have the opportunity to comment upon FERC submissions anticipated for filing on December 18, 2013 in Maine PUC Docket 2013-00415. If the Maine Commission on its own initiative extends the Comment deadline, the Foundation will consider further comments on these important issues of federalism in state standard setting.

The elimination of an in-development equipment monitoring standard by NERC, starting with the RISC Committee of NERC in May 2013; proceeding to the Standards Committee in June 2013; and approved by the Board of Trustees of NERC thereafter, may have a fortunate consequence for the State of Maine. NERC's termination of an in-development standard, Project 2012-01, "Equipment Monitoring and Diagnostic Devices," eliminates both potential technical requirements and any prospective federal obligation for electric utilities to install and report to regulatory entities, regional coordinators, or emergency operations centers: GIC levels, GIC alarms, and indicators of impacts on the health of critical equipment. (See the Foundation's filing before FERC in Docket RM12-22-000: Comments on Elimination of NERC Project 2012-01.)

Consequently, *there is no federal equipment monitoring standard approvable by FERC that could conflict with a mandatory GIC monitoring and reporting standard that Maine or other states could create by PUC rule-making or by state legislation.*

So a GIC monitoring mandate for the State of Maine would be protectable under the "savings provision" of Section 215 of the Federal Power Act.

Any lesser future NERC-proposed standard for mere "disturbance monitoring" will be too late, in event of a "sudden impulse" geomagnetic storm or a severe solar storm that would provide just 17 to 18 minutes, more or less, between ACE satellite reception and devastating impacts on earth. Equipment monitoring in moderate level solar storms can assist before a severe solar storm in identifying step-by-step mitigation measures for the Maine electric grid.

It may be no accident that NERC's year 2013 elimination of a prospective mandate for GIC monitoring equipment at all extra high voltage transformers provided a rationale for the exclusion of all "generator operators" from duties to participate in "operating procedures" to cope with future solar storms. With this proposed standard eliminated, "generator operators" might be unaware of geomagnetic conditions at their sites; hence, NERC has excused all "generator operators", the entities operating vulnerable generator step-up transformers, from mandatory participation in "operating procedures."

NERC's recently approved operational procedure standard also excludes grid load-balancing authorities from direct involvement in GMD grid protection procedures. See NERC Standard EOP-010-1 and our letter to the NERC Board of Trustees in Appendix 1, before NERC adoption of "operating procedures" that exclude both "balancing authorities" and "generator operators" from mandatory participation.

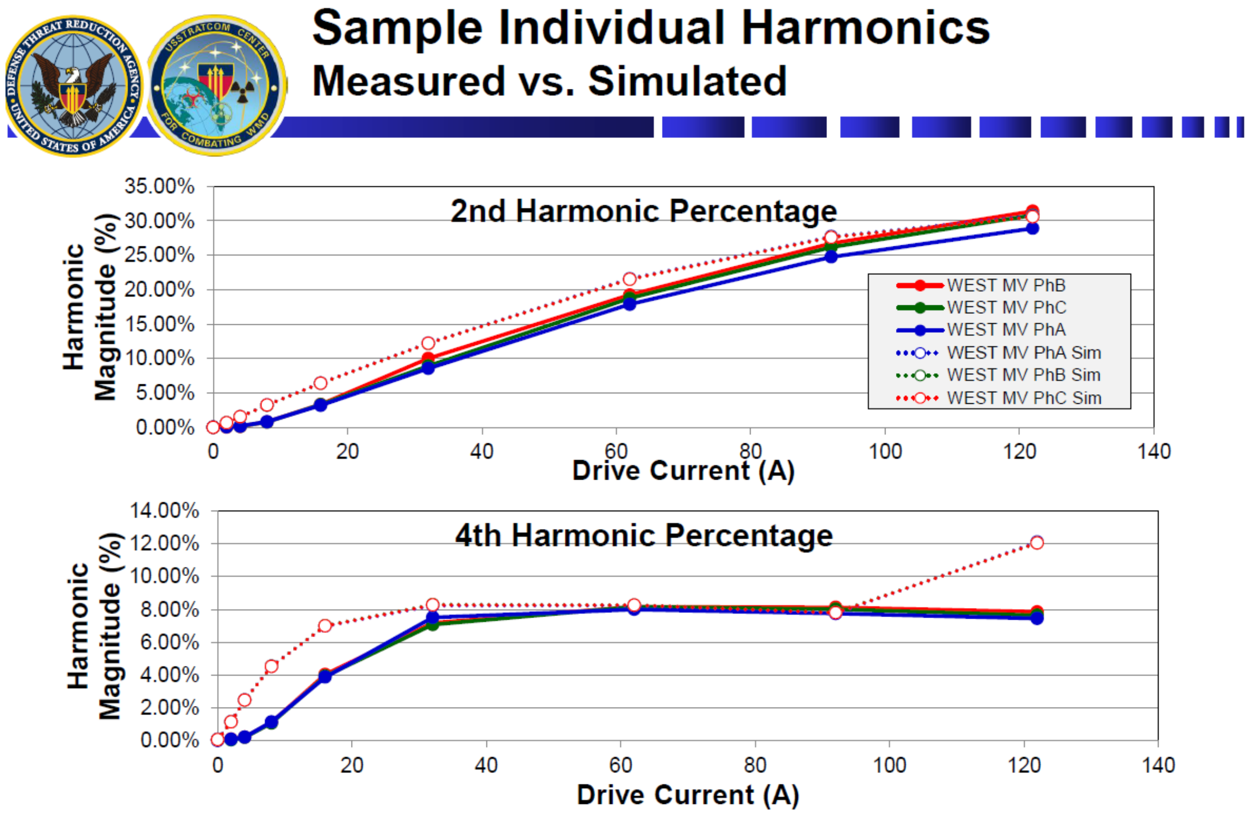
A technical expert from Maine Central Power declared during a recent meeting with the Maine PUC Chair that electric utilities in the State of Maine have an obligation to demonstrate, via annual tests, that they can operate independently of the bulk power system that FERC regulates under NERC proposed standards.

FERC can also exercise its existing authority to disapprove prospective industry-initiated "reliability standards" that would undercut initiatives in the several states to protect the safety and adequacy and reliability of the electric grids in the various states.

Conclusion: Maine has current authority to implement state-based reliability standards to assure the safety of energy facilities in the State, and to ensure public safety, and the adequacy and reliability of electric service in the State of Maine. Maine utilities have an obligation to assure they can operate independently of the interstate bulk power system. And Maine rate payers should be able to continue cost-sharing with the other New England states' rate-payers, so long as Maine coordinates its reliability upgrades cooperatively with FERC and experts on the FERC staff. The Maine Power Reliability Program has to date allocated 8 percent of upgrade costs to Maine ratepayers and 92 percent to rate-payers in the other five New England states.

1.3 Results of Idaho National Labs Testing for Harmonic Distortion During DC Current Injection

Idaho National Labs (INL) has tested for harmonic distortion during simulated GIC conditions by using DC current injection. Below is page 24 from the Defense Threat Reduction Agency presentation "DTRA MHD-E3 Program Overview; GMD Workshop; Michael R. Rooney, DTRA/NT; 27-28 August 2013." Slide 24 shows harmonic distortion of 30% with DC current injection of 120 amps. INL disclosed during the December 2013 Dupont Summit that this harmonic distortion was enough to cause test platform UPS to switch to battery backup. Notably, GMD impacts disclosed by Central Maine Power to the Maine Legislature Joint Standing Committee on Energy, Utilities and Technology contain a line on problems with customer UPS systems during a past solar storm. Both the INL test results and real-world impacts in Maine show that solar storms can affect not only grid operations, but also customers that depend on distortion-free electric power. Because customers cannot always reliably switch to battery or generator backup systems, this INL data shows that an unprotected grid puts customer operations at risk during solar storms.



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2.0 Recommendations for Maine Initiatives to Protect the Safety and Reliability of Maine's Electric Grid

2.1 Low Cost Initiatives

These low-cost options enable continuous monitoring of likely grid failure points and protect heavy-duty components of the grid including EHV transformers and large generators that take the longest times (months to years) to remanufacture and replace. Added benefit accrues because these components are the highest priority in terms of expediting system recovery.

2.1.1 GIC Monitors

Phase A: Mandatory installation of Geomagnetic induced current (GIC) monitors at critical transformers and other grid-critical equipment under MPUC jurisdiction; and MPUC request for voluntary reporting by other Maine entities with GIC monitors in operation. GIC monitors cost only $10,000 per unit installed, according to a vendor of the devices. Installing about 20 GIC monitors at all 345 kV transformers and at Static Var Compensator sites would cost roughly $200,000.

2.1.1.1 State Standards Not in Conflict with Federal Standards

With NERC's elimination of a standard for mandatory equipment monitoring, FERC lacks authority to set its own standard. Thus, standards for equipment monitoring that might enacted by states are not in conflict with any FERC standard, and offer the potential to improve operating procedures and to encourage voluntary installation of hardware protective equipment.

2.1.2 Neutral Ground Blocking Devices

Phase B: Mandatory installation of GIC blocking equipment at all MPUC jurisdictional electric utilities for designated "critical equipment". Approximate costs are $350,000 per substation protected according to Emprimus, a vendor for the devices. Total costs for about 14 to 16 EHV transformers would be in the range of $5 to $6 million for the State of Maine.

2.1.2.1 State Standards Not in Conflict with Federal Standards

Technical studies by Emprimus confirm that neutral ground blocking equipment both improves reliability of the directly-protected equipment and, by reducing GICs in the high voltage transmission system, improves reliability of unprotected transformers, and, for cases modelled thus far, will not reduce reliability in other states. Based on Emprimus studies, it is apparent that Maine PUC reliability standards would be both authorized and protected under the savings clause of the Federal Power Act§824o(i).

2.1.3 Protecting SCADA Controllers for Maine Electric Utilities.

Central Maine Power projects about 80 SCADA systems for their transmission system operations. We estimate a total of 200 to 300 SCADA systems for all Maine PUC-jurisdictional utilities in the State of Maine. At a cost of about $10,000 per unit, these SCADA systems could be protected for a statewide cost of about $2 million to $3 million.

The same metal containment systems that can protect SCADA systems can also protect battery chargers and some batteries and telecommunications devices for only nominal additional costs.

Consistent with the above estimates, acquiring GIC monitors, neutral ground blockers for EHV transformers, and containment systems for electric utility SCADA systems might be acquired for less than one percent (1%) of the capital costs of the Maine Power Reliability Program (RPRP) which is projected to cost about $1.4 billion when completed in year 2015.

2.2 Mid-Range Cost Initiatives

2.2.1 Complementary GIC blocking of Uninterruptible Power Systems (UPS) Equipment within Micro Grids, Paper Mills, Hospitals, Data Centers, and Other Facilities with On-Site Generation

Many facilities with on-site generation utilize uninterruptible power supply (UPS) equipment to filter unreliable power from the commercial grid. Equipment to filter and limit poor quality power can be of special value in the State of Maine, which has an unusually high proportion of self-generating facilities compared to other states. Maine has the highest proportion of net electric generation within the industrial sector for all six New England states. Roughly 33 to 34 percent of Maine net electric generation is in the industrial sector. Almost all of the net exportable power is generated in the industrial sector, and by wind farm and biomass facilities.[9]

[9] See the annual and monthly reports on net electric output issued by the U.S. Energy Information Administration.

The Maine PUC should consider adding to its website links to helpful resources on technologies that can improved the quality of electric power, so that even non-jurisdictional electricity generators in the state can improve the reliability of their power generation and can improve the robustness of equipment that can be damaged by power surges. Furthermore, the Maine Technology Institute might be an appropriate institution to partner with the Maine PUC and Maine electric utilities in promoting the adoption of power filtering and power stabilizing equipment for critical needs throughout the state, including adoption by private generating facilities such as pulp and paper mills and other industrial firms. Most of these costs would be borne by the private sector on a voluntary basis.

2.2.2 Current Limiting Equipment for Electric Utilities.

It is our understanding that "current limiting equipment" has recently become available to electric utilities. This equipment rapidly detects power spikes or power surges, and limits the range of power, measured in amps, that enter electric substations. It is our understanding that electric utilities that order "current limiting" equipment can obtain E1 protection (limiting fast rise-time voltage spikes) at modest additional cost.

2.2.3 E1 Protection Equipment.

E1 blocking equipment that utilizes metal oxide varistors (MOV) or spark gaps can be purchased to install immediately adjacent to extra high voltage transformers and other grid critical equipment. Metal oxide varistor devices may be damaged by one or more EMP pulses; hence, spares must be on hand. Some EHV transformer designs include built-in metal oxide varistors. MOV devices typically cost less than $10,000 per unit of equipment protected.

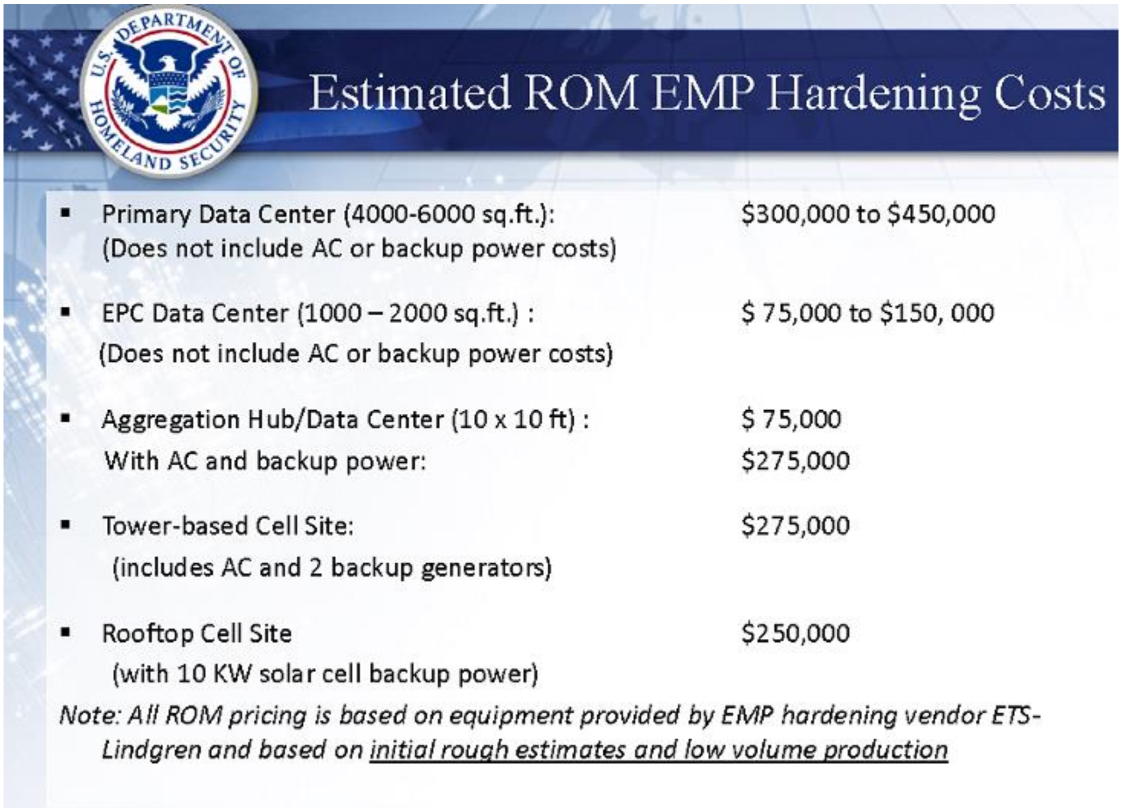
At substantially higher cost than MOVs, ultra-fast detectors, and ultra-fast switches using tube technology can provide protection against E1 surges, and be reset for repeated protection of critical equipment without use of spares.

We estimate a cost of $10,000 per site to house SCADA systems and backup batteries and battery chargers in shielded cabinets at 345kV and 115kV substations.

Discussion with SENS-USA, a vendor of substation battery chargers, indicates that some of their chargers have passed E1 testing. SENS-USA chargers sell for approximately $5,000-$30,000 per substation.

Emergency diesel generators (EDGs) can also be protected against EMP at a cost increment of 15-30%, according to AZ-Tech, a manufacturer of this equipment.

We present the following Rough Order of Magnitude (ROM) cost estimates from the U.S. Department of Homeland Security for E1 protection:



2.3 High Cost Initiatives

2.3.1 Protection of Grid Control Rooms against both E1 and E3 Hazards.

At least one U.S. electric utility, Centerpoint, has voluntarily protected a control room against E1 risks at a cost of about $8.75 million. Major electric utility control centers within Maine that are subject to Maine PUC jurisdiction include: Central Maine Power, operating in Augusta, including operation of an Outage Management System (OMS); Bangor Hydro electric Co.; and Maine Public Service Co. We assume that even after the merger of the latter two electric utilities into Emera Maine on January 1, 2014, there will be three major State of Maine electric utility control centers that are candidates for E1 hardening. Because smaller control centers tend to cost lesser amounts, it is possible that all three of these Control Centers could be E1 hardened for a combined cost of approximately $25 million.

Finally, at the suggestion of Rep. Andrea Boland of the Maine state legislature, we have considered the rough costs to protect the Maine State Emergency Operations Center located at 45 Commerce Drive in Augusta, Maine. This is a small portion of a large one-story building; the Maine EOC occupies just 12,000 square feet of this far larger structure.[10] With a square footage of about 8.6 percent of the Control Center that has been protected in Texas for under $9 million dollars, we estimate the costs to protect the Maine Emergency Operations Center for E1 and E3 hazards to be about $1 million dollars.

[10] Information provided by the MEMA Emergency Operations Center, Dec. 18, 2013.

Underground facilities can be protected at substantially lower costs.

3.0 Summary of Recommendations

Our preliminary review of options for the State of Maine to protect critical grid infrastructure from both solar geomagnetic storms and from man-made EMP risks came up with a surprising conclusion: For relatively low cost, less than one percent (1%) of the capital costs of the Maine Power Reliability Program, about $14 million or less, Maine can, by Maine PUC mandate or by legislation require installation and information sharing from GIC monitors at critical transformer sites; can require installation of neutral ground blocking equipment at all of the 345 kV transformers in the State; can protect electric utility SCADA controllers that are essential for reliable grid operations; and can also protect some ancillary battery chargers, batteries, and telecommunications.

These options are within what we consider the “low cost” range, well worth investing to prevent grid collapse and the extraordinary harms that might thereafter result.

Other options include the hardening against E1 and E3 hazards of electric utility control centers and the State of Maine Emergency Operations Center, for a combined cost of perhaps $20 to $30 million dollars.

Countering certain non-nuclear intentional radio-frequency devices would be within the “high-cost options.” These devices can defeat some of the “mid-range “mitigation measures, but are unlikely to disrupt electric grids over large regions simultaneously.

From a regulatory perspective, the Maine PUC has the authority to act now, through rule-making proceedings, to establish standards for equipment monitoring and equipment protection.

The “savings provisions” in Section 215 of the Federal Power Act should suffice to enable the State of Maine to act to improve the safety of electric facilities and the adequacy of Maine electric service during solar storms or man-made EMP hazards.

By taking action now, the State of Maine can remedy its current course, which is to operate a statewide transmission system unprotected against solar storms and man-made electromagnetic pulse.

By coordinating its actions with the Federal Energy Regulatory Commission and its staff, Maine can protect its cost-sharing opportunities, because the entire New England electric grid will benefit from Maine’s initiatives.

We appreciate the opportunity to provide these recommendations in the rather limited, 12-day period that the Commission has afforded for public comments.

Respectfully submitted by

William R. Harris, Secretary and Director
Thomas S. Popik, Chairman and Director
George H. Baker, Professor-Emeritus and Director, for

THE FOUNDATION FOR RESILIENT SOCIETIES
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APPENDIX 1. Letter to NERC Board of Trustees Regarding Proposed Standard on Operating Procedures

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November 1, 2013

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Atlanta, GA 30326

Dear Trustees:

Scheduled for your November 7th Board of Trustees meeting is "Agenda Item 8a—Geomagnetic Disturbance Mitigation—EOP-010-1." We urge you to vote "no" on approval of this standard and to send the standard back to the NERC Standards Committee. The standard should be promptly redrafted to include Balancing Authorities, Generator Operators, and Transmission Operators having transformers with high side voltage at 100 kV and higher.

Standard EOP-010-1 was drafted in response to Order 779 of the Federal Energy Regulatory Commission (FERC) for a standard for operating procedures to protect the Bulk Power System against Geomagnetic Disturbance (GMD). The standard, as drafted, is technically inadequate, cost ineffective, and will not protect the American public for the following reasons:

1. While the FERC-approved Bulk Electric System definition includes transmission at voltages at 100kV and above, and while multiple GMD impacts on Static VAR Compensators and other equipment operating between 100kV and 200kV were reported by electric utilities during the March 1989 solar storm, Standard EOP-010-1 would

exempt Transmission Operators with equipment operating between 100 kV and 200 kV. Transmission Operators operate Static Var Compensators, capacitors, and other equipment designed to provide reactive power and to stabilize transmission networks during GMD. Attached to this letter is a listing of March 13, 1989 storm impacts on critical equipment operating at less than 200 kV. These real-world and non-trivial GMD impacts during a moderate storm with geoelectric fields of only 2 volts/kilometer invalidate the Standard Drafting Team's summary determination that "The effect of GIC in networks less than 200 kV has negligible impact on the reliability of the interconnected transmission system." The pseudo-scientific study of the NERC Standard Drafting Team, "Network Applicability, Project 2013-03, EOP-010-1, Summary Determination" is an example of a report that is consistent with an apparent policy goal of NERC's membership, but which ignores available scientific evidence.

2. Geomagnetically-Induced Current (GIC) monitors are commercially available and can be installed for as little as $10,000 each, which is far less than the cost of a technical study to see if a GIC monitor might be required.[1] Nonetheless, Standard EOP-010-1 has no requirement for GIC monitoring or the mandatory sharing of GIC data with Reliability Coordinators and would therefore require Reliability Coordinators to force "blind" operating procedures on Balancing Authorities, Transmission Operators, and Generator Operators, increasing blackout risks to the public and imposing costs on ratepayers due to "off-cost dispatch" of bulk power transmissions.
3. While Generator Step Up (GSU) transformers are a major GMD vulnerability according to a study by the Oak Ridge National Laboratory, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Generator Operators are exempted from specific responsibility in Standard EOP-010-1. In notable contrast, NERC's own GMD Task Force recognized the vulnerability of GSU transformers and developed a "Geomagnetic Disturbance Operating Procedure Template—Generator Operators" which was formally approved by the Planning Committee in February 2013 and also endorsed by the Operating Committee. The Standard Drafting Team exempts Generators Operators from Standard EOP-010-1 because Generator Operators have no current requirement for GIC monitoring devices and absent GIC data, "the GOP would not have the technical basis for taking steps on its own and would instead take steps based on the RC or TOP's Operating Plans, Processes, or Procedures." This convenient rationale is proposed in the NERC document "Functional Entity Applicability, Project 2013-03, EOP-010-1, Summary Determination" and ignores that the lack of required GIC monitoring is completely the result of a defectively drafted standard; see Item 2 above. In essence, the Standard Drafting Team proposes that Generator Operators pay up to $250,000 for a technical study to see if their equipment might be vulnerable to GIC rather than install a GIC monitor for $10,000 and find out for sure. The Standard Drafting Team also believes that the real-time responsibilities of Generator Operators under fast-moving GMD conditions

[1] For example, Bonneville Power Administration paid $253,000 for modeling of GIC in their network.

are already covered in the NERC Functional Model. In fact, the deficiencies in the NERC Functional Model during GMD conditions are a primary rationale for FERC Order 779.

4. While Balancing Authorities are responsible for scheduling reactive power, spinning reserves, demand response, and other real-time mitigative steps during GMD, these entities are exempted from specific responsibility in Standard EOP-010-1. The Standard Drafting Team believes that the real-time responsibilities of Balancing Authorities under fast-moving GMD conditions are already covered in the NERC Functional Model. In fact, the deficiencies in the NERC Functional Model during GMD conditions are a primary rationale for FERC Order 779.
5. The "Requirements and Measures" in Standard EOP-010-1 are so non-specific that utilities could easily develop paper plans to satisfy the requirements of the standard, but these plans could be ineffective during severe or even moderate solar storms.[2]

For further background on these deficiencies in the standard, please see our comments filed and available in the official record for Standard EOP-010-1 on the NERC web page for "Project 2013-03 Geomagnetic Disturbance Mitigation."

Any reasonable person would likely conclude that Standard EOP-010-1, as currently drafted, is not compliant with the requirements of FERC Order 779. Moreover, the proposed exemption of networks with high side voltage between 100 kV and 200 kV is not compliant with the requirements of FERC Order 773, which established a "bright line threshold" of 100 kV for the Bulk Electric System.

Oak Ridge National Laboratory estimates that a severe solar storm would interrupt power to as many as 130 million Americans. Accordingly, a reliability standard to prevent a blackout from GMD should deserve the highest level of attention and thoughtful consideration from NERC and its independent trustees. However, past meetings of the NERC Board of Trustees have had only perfunctory discussion about GMD risks to the American public—an example being the trustee meeting that approved the now-discredited NERC report, "2012 Special Reliability Assessment: Effects of Geomagnetic Disturbances on The Bulk Power System." Instead, the independent trustees have had a practice of quickly and mechanistically moving through numerous agenda items, voting to "approve" on each item.

As independent trustees of NERC, it is your fiduciary duty to have a substantive and public discussion of the merits and shortfalls of Standard EOP-010-1 at your November 7th meeting. Again, we urge you to vote "no" on EOP-010-1, Agenda Item 8a, because this defective standard would not protect the American public from long-term and widespread electric grid outages caused by solar storms.

[2] For an example of GMD operating procedures that would probably meet the requirements of Standard EOP-010-1, but would nonetheless be inadequate, see our study of ISO-New England operating procedures, "Solar Storm Risks for Maine and the New England Electric Grid and Potential Protective Measures" available at: http://resilientsocieties.org/images/Interim_Foundation_Report_on_Maine_Solar_Storm_Risks_March_19_2013.pdf.

Sincerely,

Thomas S. Popik
Chairman, Foundation for Resilient Societies

Attachment: March 13, 1989 Geomagnetic Disturbance Chronology of Reported North American Power Grid Events

cc:
Jon Wellinghoff, Chairman, FERC
David Morenoff, Acting General Counsel, FERC

March 13, 1989 Geomagnetic Disturbance
Chronology of Reported North American Power Grid Events

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

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

APPENDIX 2. Pitfalls of Reliance on Operational Procedures to Protect Maine's Electric Power Grid against Major Solar Storm Geomagnetic Disturbances and Nuclear EMP

G. H. Baker

Foundation for Resilient Societies

December 2013

A tendency exists to downplay the likelihood of a Carrington event and its associated consequences. It is crucial that we identify and redress important and pervasive misconceptions concerning GMD to overcome our current industry inertia with respect to physical protection of the North American electric power grid against the challenging effects of GMD. We must absolutely deal with the GMD and EMP threats.

Operational procedures are not enough. Public-private cooperation will be needed to begin and prevail in implementing low-risk physical protection of our most critical infrastructure sector. It is crucially important to note that NERC has no plans for developing corresponding across-the board physical protection standards. Thus states are well-advised not to wait for NERC solutions, but rather to take their own steps to ensure that their electric power systems and services are physically protect against GMD and EMP. And state officials and citizens must urge their regulatory officials accountable for ensuring that grids are physically protected.

Operational procedure-based solutions offered by NERC in their recent adopted EOP-01 grid protection standard are inadequate for a number of reasons. The following is an itemized list of ten pitfalls accompanying reliance on operational procedures to protect the electric power grid:

1. Grid operators will be reluctant to shed load to customers due to insurance rules, even though load-shedding reduces the probability of grid collapse and damage to EHV transformers. Utility companies know that if customer electric power is lost due to GMD, they will not liable be liable for losses; but if customer power is lost due to intentional human action to deenergize the grid or portions of it, power companies can be held liable. (Ref. Lloyds of London report on GMD effects and liabilities, statements by insurance company representatives at 2012 Electric Infrastructure Security Summit at UK Parliament).

2. The 15-45 minute warning time provided by the ACE satellite or its successor will be inadequate for grid operators to conference in making the decision and then executing required operational procedures. Participants in the 2011 National Defense University GMD response exercise indicated that they would be hard-pressed even to get all the players to the table within such a short time interval. And, once hit, the grid fails very quickly. We note that, in 1989, during a moderate solar storm GMD, the electric power grid of the entire Province of Quebec went dark in 90 seconds. August 2003 event evolved over much more slowly (1:31pm – 4:10pm) with much more time available to take action. Nonetheless, power companies were unable to react fast enough.

3. Grid operators will not have adequate information on the state of the grid to implement correct operational procedures. Because most of the grid is not monitored for excess GIC, operators will be "flying blind" with respect to the state of grid and which portions need remedial action. Information gaps will exist as in August 2003 – where operators unaware of tree contact. Sensors needed to monitor GMD/EMP stressors on critical grid components have not been installed. Lack of visibility has led to errors in past operational procedure actions that made matters worse.

4. There is no control center with large enough visibility to control operational procedure response on a national scale. Lack of information on neighboring grids impairs proper procedural response. A national control/coordination center does not exist. Because the geographic coverage of solar storm can be continental in scale, such control visibility is necessary.

5. Operational procedures have not been adequate during large-scale blackouts of more simple cause. Past events provide ample evidence that operational measures are problematic. For instance, operational procedures proved ineffective in preventing the 2003 Northeast blackout that was precipitated by a single failure point involving tree contact with a transmission line. Recent grid models indicate that GMD and EMP will engender hundreds to thousands of failure points. The complexity and rapidity of grid failure during a Carrington-class event will overwhelm the ability of electric utilities to respond, to prevent grid failure using any suite of operational procedures, no matter how well-conceived and practiced. Hurricane Sandy blackout physical damage outstripped procedural protection means. Physical damage to grid components will be a factor in GMD/EMP events as well.

6. Unforeseen grid equipment malfunctions have greatly impaired grid operators' ability to respond during major blackouts in the past. Operational procedures during the 2003 Northeast power blackout were greatly impaired by computer control system malfunctions and software problems. Critical grid state monitoring, logging and alarm equipment failed. The control area's SCADA and emergency management systems malfunctioned. The shut-down of hundreds of generators over multiple states was unanticipated as was the failure of tens of transmission lines. Confusion and inoperative control systems lead to many frantic phone calls. And, any early failure of major grid components caused by the GMD or EMP environment will impede implementation of subsequent operational procedures.

7. GMD and EMP will affect communication systems necessary for coordination of operational procedures. Long-line internet and telecommunications networks will experience large overvoltages from GMD and EMP E1/E3 environments, likely causing their debilitation. GMD and EMP also impede signal propagation of HF/VHF/UHF radio systems and GPS systems. Thus grid communication and control systems necessary to execute operational procedures cannot be relied on – just when they are needed the most.

8. It is not possible to anticipate all grid failure point combinations and time sequences during GMD/EMP events in order to adequately plan and exercise GMD/EMP event operational procedures. Normal grid failures are not indicative of GMD/EMP failures. Operators are familiar with single equipment failures but when multiple points fail near simultaneously under GMD/EMP stress and the failures interact and cascade, operators will have difficulty understanding and responding to prevent further damage. In most complex human-machine systems, the interactions literally cannot be seen Prof. Charles Perrow of Yale defines “normal accidents” in complex infrastructure systems as involving system interactions are not only unexpected, but are incomprehensible for some critical period of time. For example, the post-mortem on what happened during the 2003 blackout took electric power grid experts six months to figure out.

9. ISO/RTO’s don’t have cross-jurisdictional authority to enforce shutdown of neighboring grids – sometimes required to avoid large scale blackouts, as in the August 2003 Northeast Blackout. During that catastrophe, First Energy was asked to shed load by its neighboring grid operators but First Energy declined, in part because an inoperable software program reduced operator visibility of grid conditions. According to the NERC after action report, load shedding would have prevented the ensuing North East blackout.

10. Draft NERC GMD operational procedures recently submitted to FERC are not comprehensive. The plans do not apply to generator authorities or load-balancing authorities. The NERC operational procedures also exempt portions of the grid operating below 200KV from operational procedures.

APPENDIX 3: Cost Figures for Emprimus Solid Ground System

Solid Ground Pricing

- ABB has proposed Solid Ground to several potential customers
  - Price for ranges from $210k to $250k depending on the quantity
  - Estimates of contractor installation costs range from $25k to $50k
  - Total cost ranges from $235k to $300k per Solid Ground installation
  - One Solid Ground can protect from one to three transformers

Solid Ground Average Cost is about $80k to $100k per Transformer