Maine Public Utilities Commission

Draft Report In Accordance With Resolves 2013, Ch. 45 Relating to Geomagnetic Disturbance And Electromagnetic Pulse

Notice of Inquiry

Maine Public Utilities Commission

Docket No. 2013-00415

December 6, 2013

I. Introduction

In this report, the Commission provides information regarding Geomagnetic Disturbances (GMD) and Electromagnetic Pulse (EMP) as requested in Resolves 2013, ch. 45. The Report does not make any recommendations regarding mitigation of GMD and EMP.[1]

II. Background

The Legislature passed a resolve during its 2013 session that requires the Commission to "examine the vulnerabilities of the State's transmission infrastructure to the potential negative impacts of a geomagnetic disturbance or electromagnetic pulse capable of disabling, disrupting or destroying a transmission and distribution system and identify potential mitigation measures." Resolves 2013, ch.45 (The Resolve). The Resolve directs the Commission to:

1. Identify the most vulnerable components of the State's transmission system;
2. Identify potential mitigation measures to decrease the negative impacts of a geomagnetic disturbance or electromagnetic pulse;
3. Estimate the costs of potential mitigation measures and develop options for low-cost, mid-cost and high-cost measures;

[1] Other than requesting a recommendation regarding allocation between shareholders and ratepayers of the costs of mitigating the effects of GMD and EMP, the Resolve does not request any recommendations from the Commission. As discussed in Section V(C), below, the Commission does not make any recommendation on cost allocation because cost recovery for transmission is within the jurisdiction of the Federal Energy Regulatory Commission (FERC). The Commission observes, however, that the cost of facilities required to provide safe and adequate service are generally borne by customers (whether those costs are under state or federal jurisdiction) rather than shareholders in the absence of a showing of imprudence.

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;

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

6. Develop a time frame for the adoption of mitigation measures; and

7. Develop recommendations regarding the allocation of costs to mitigate the effects of geomagnetic disturbances or electromagnetic pulse on the State's transmission system and identify which costs, if any, should be the responsibility of shareholders or ratepayers.

The Resolve also tasks the Commission with actively monitoring the efforts by the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), ISO New England (ISO-NE) and other regional and federal organizations to develop reliability standards related to geomagnetic disturbances (GMD) and electromagnetic pulse (EMP).

Finally, the Resolve requires the Commission to report to the Legislature on the results of its examination of the matters outlined above and on the progress of regional and national efforts to develop reliability standards related to GMD and EMP by January 20, 2014.

On August 21, 2013, the Commission issued a Notice of Inquiry (NOI). The NOI directed Maine investor- owned electric Transmission and Distribution (T&D) Utilities (Central Maine Power Company, Bangor Hydro-Electric Company and Maine Public Service Company) to respond to the following:

1. Identify the most vulnerable components of the T&D utility’s transmission system;

2. Provide information about the T & D utility’s present practices or mitigation measures to protect the transmission system from GMD or EMP;

3. Discuss the extent to which present practices or mitigation measures can handle GMD or EMP events;

4. Identify additional potential mitigation measures that could be implemented to decrease the negative impacts of GMD or EMP;

5. Estimate the costs of those potential mitigation measures to decrease the negative impacts of GMD or EMP (please include low-cost, mid-cost and high-cost measures);

6. What are 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 to incorporate mitigation measures?

7. What are any potential effects of the State adopting a policy under 6 above on the regional transmission system?

8. What would be a reasonable time frame for the adoption of any additional mitigation measures?

9. Provide any recommendations regarding the allocation of costs to mitigate the effects of geomagnetic disturbances or electromagnetic pulse on the State's transmission system and identify which costs, if any, should be the responsibility of shareholders or ratepayers;

10. Discuss the relationship of any possible mitigation measures that might be undertaken by the State of Maine to measures that might result from the FERC rule. Specifically, is it possible that if Maine implements mitigation requirements in advance of NERC and FERC that such requirements might result in additional costs that might not have been necessary if mitigation requirements were not imposed on Maine T &D utilities?

11. Discuss whether there are any jurisdictional bars to Maine’s adoption of mitigation measures;

12. Provide information regarding any other state’s adoption of mitigation measures related to GMD and EMP, including citations to the relevant statutes and rules;

13. Provide any comments filed by the T & D utility at NERC regarding Stage 1 of the FERC GMD rulemaking;[2] and

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[2] These comments were due on August 12, 2013. CMP and BHE/MPS stated that they did not file any comments at NERC regarding NERC’s development of a GMD reliability standard.

14. Provide, to the extent information is available, information on the extent or frequency of GMD or EMP events in Maine and the extent of any damage to the transmission system caused by those events.

In addition, the NOI requested that ISO-NE and the Northern Maine Independent System Administrator (NMISA) provide any information about their own operating procedures that would help to address these issues. We also asked ISO-NE and NMISA to discuss the procedures under which it would review any design features or hardening devices that might be used to mitigate the effects of EMP or GMD on the transmission system and what standard it would apply in such reviews.

The NOI also invited any interested person to file comments on any of the issues outlined in the NOI and in the Resolve.

Comments were filed by the following:

- ISO New England Inc. (ISO-NE)
- Central Maine Power Company (CMP)
- Bangor Hydro-Electric Company/ Maine Public Service Company (BHE/MPS)
- Office of the Public Advocate (OPA)
- Representative Andrea Boland
- Foundation for Resilient Societies
- Frederick Faxvog, Ph.D.
- Center for Security Policy
- Emprimus LLC (Emprimus)
- Charles Manto
- Electric Infrastructure Security Council (EISC)

- Cynthia Ayers
- R. James Woolsey
- Michael Laracy, Sr.
- Curtis Birnbach
- Alberto Raul Ramirez Orquin, Ph.D.

III. GMD

A. Definitions

A GMD occurs when the magnetic field embedded in the solar wind is opposite that of the earth. This disturbance, which results in distortions to the earth's magnetic field, can be of varying intensity and has in the past affected the operation of pipelines, communications systems, and electric power systems. Oak Ridge National Laboratory, Electric Utility Industry Experience with Geomagnetic Disturbances at xiii (1991), available at http://www.ornl.gov/~webworks/cpr/v823/rpt/51089.pdf. GMDs can induce currents, called Geomagnetically-Induced Currents (GIC), into the bulk power system. Severe GMDs have the potential to pose operational threats to the bulk power system. "High Impact, Low Frequency Event Risk to the North American Bulk Power System, a Jointly Commissioned Summary Report of the North American Electric Reliability Corporation and the U.S. Department of Energy's November 2009 workshop, June 2010," available at the following link: http://www.nerc.com/pa/CI/Resources/Documents/HILF_Report.pdf.

How the GIC moves through electric infrastructure can depend on factors such as distance to the magnetic pole, geology, proximity to bodies of water, and the orientation, length and voltage of power lines. Longer, extra-high voltage

(EHV) voltage lines are exposed to larger GIC and equipment in more northern latitudes is most likely to be affected. “Geomagnetic Storms: An Evaluation of Risks and Risk Assessments, Office of Risk Management and Analysis, May 2011” at 6. Maine and New Hampshire both are susceptible to GIC. Additionally, the Maine and New Hampshire EHV transmission system is generally oriented North-to-South, which heightens the likelihood of GIC traveling across the neutral phase of the lines. One source estimates the at risk EHV transformer capacity for Maine at 24% and that for New Hampshire at 97%. NERC 2010 Report at 76.

B. The Maine Transmission System and Interconnections

The EHV electric system in Maine consists of two 345 kV transmission lines connected to New Hampshire to the South and West and the Maine Electric Power Company (MEPCO) line and Northern Reliability Interconnect (NRI) 345 kV lines connecting to the New Brunswick system. The MPS territory has no EHV components and is interconnected to the New Brunswick system by a 138 kV and two 69 kV interties.

C. Existing Monitoring Equipment

With approximately 100 high voltage transformers within New England, ISO-NE relies on two GIC monitoring stations—at Chester, Maine and at the Seabrook nuclear power plant in New Hampshire. Comments from the Foundation for Resilient Societies at 8. Currently, the New Brunswick system does not have any GIC specific monitoring or protection devices installed; however, Nova Scotia Power does monitor current at the 345 kV transformer level and is required to report disturbances to the New Brunswick System Operator (NBSO) under NBSO TO-OP-10.[3]

D. Impact of GMDs

1. Historical Events

The most recent major solar event, known as the Halloween Storm, occurred between October 29 and November 4, 2003. On October 29, the storm reached the Earth in 19 hours after leaving the sun. Electric utilities in Northern Europe reported impacts from the storm including a one-hour black out in Malmo, Sweden. In addition, on November 4 one of the most powerful x-ray flares ever detected caused damage to satellites.[4]

National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum OAR SEC88[5] describes the performance of the United States based electric utilities during the 2003 Halloween Storm:

> Electrical companies took considerable efforts to prepare for and be aware of the storm onsets. Companies received the standard suite of geomagnetic storm watches, warnings and alerts, but SEC staff also supplemented standard support with several phone discussions. Preventive action helped to counter the GIC stresses that were observed. A representative from the North American Electric Reliability

[3] On October 13, in accordance with the New Brunswick *Electricity Act* (S.N.B. 2013, c.7), adopted on June 21, 13, the NBSO became part of the New Brunswick Power Corporation (NBPC). The NBSO division of the NBPC is now known as the NB Power-System Operator (NBPSO). NBPC has stated that all operations will remain unchanged and that all current functions carried out by the NBSO will continue to be carried out by the former NBSO staff under the NBPC. Thus the NBSO TO-OP-10 remains in effect.

[4] The Kp index measures the severity of a GMD. For a description of the Kp index, see NPCC C-15, Appendix B, appended to this report as Attachment 1.

[5] NOAA Halloween Space Weather Storms of 2003: http://www.swpc.noaa.gov/Services/HalloweenStorms_assessment.pdf.

> Council (NERC) commented: "Although the bulk electric system was not significantly affected by the solar activity, some systems reported higher than normal GIC's that resulted in fluctuations in the output of some generating units, while the output of other units was reduced in response to the K-index forecast." Responses to warnings included reducing system load, disconnecting system components, and postponing maintenance.

Another major GMD event in North America occurred in Quebec on March 13, 1989. This incident affected the Hydro Quebec (HQ) electric infrastructure and caused a widespread outage affecting nearly six million HQ customers for approximately nine hours. Additional damage was reported across North America, including damage to a 500 kV transformer at a nuclear facility in New Jersey. Other extra high voltage (EHV) electrical equipment in the United Kingdom was reportedly damaged as a result of the same solar storm.

The most severe recorded space weather event, known as the Carrington Event, lasted from August 28 to September 4, 1859, and it affected several continents. The Carrington event disrupted telegraph networks. One study estimated that "the economic costs associated with a catastrophic geomagnetic storm similar to that of the Carrington Even could measure in the range of several trillion dollars. "Risk Management Issue Brief, Office of Risk Management and Analysis, May 2011," available at the following link: http://www.dhs.gov/xlibrary/assets/rma-geomagnetic-storms.pdf. Another major event occurred May 14-15, 1921 and also disrupted operation of much of the telegraph system across the Eastern United States as well as disabling switching and signal equipment on the New York Central Railroad system.

2. Types of Equipment at Risk of Damage from GMD

According to the NPCC C-15, Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems, https://www.npcc.org/Standards/Procedures/c-15.pdf, the primary devices at risk due to GMD are:

1. Power Transformers

   The presence of GIC produces off-setting dc excitation in a transformer, resulting in some degree of core saturation. This can cause the production of harmonic currents that can distort system voltages and cause protective relay operation due to the flow of neutral current to ground. Core saturation can also result in internal localized heating of the core and windings, and degradation of winding insulation. Saturated transformers are reactive power sinks, using up system reactive capacity, resulting in voltage depression.

2. Instrument Transformers

   The effects described in power transformers can also occur in other magnetic equipment such as potential and current transformers, resulting in the misoperation of protective relaying.

3. HVDC Systems and Static VAR Compensators

   Operations at or near the minimum or maximum current rating of HVDC circuits increases the potential for commutation failures, jeopardizing continuity of service. These systems require a sinusoidal voltage to properly commutate current transmission. Voltage distorted by harmonics may be severe enough to cause commutation failures and result in shutdown of such systems. Filter banks, including capacitor banks, associated with these systems will tend to overload due to harmonic current and may result in tripping.

4. Shunt Capacitor Banks

   Shunt capacitor banks will tend to overload due to harmonic current, typically the third harmonic.

5. Generators

Automatic voltage regulators (AVR) associated with generators require representative voltage signals to control the dc field current on generators. Distorted ac voltage input to the AVR may result in uncertain translation of the ac signals for control, possibly resulting in a cyclical level of excitation on the generator, and hence real and reactive power output may vary in an abnormal manner. Overheating may occur in large generators due to imbalances in phase currents and harmonic distortion in voltages, which result from the saturation of power transformers. Turbine mechanical vibration may be excited by the presence of increased harmonic rotor current.

6. Transmission Lines

Harmonic frequencies in the system voltage can increase the magnitude of the voltage required to be switched by circuit breakers. Harmonics increase transmission losses and cause interference to communications systems.

7. Overall System Impact

Transformer saturation results in increased VAR consumption and harmonic injection into the system. These harmonic currents can result in capacitor bank overloading and their tripping, generator tripping and misoperation of static VAR compensators. This could further deplete the system of reactive VAR support and impact the overall system performance and security. The power systems are becoming more vulnerable to GIC effects due to longer transmission lines, decreased reactive margins and greater dependence on static VAR compensators and high voltage dc control.

NPCC C-15 at page 5.

D. FERC and NERC Proceedings

1. Description of FERC Rule

On May 15, 2013, the Federal Energy Regulatory Commission (FERC) directed the NERC to submit to the Commission for approval proposed Reliability Standards addressing the impact of GMD on the reliable operation of the

Bulk –Power System (BPS). See Order No. 779, *Reliability Standards for Geomagnetic Disturbances,* 143 FERC ¶ 61,147 (2013) reh' denied, 144 FERC ¶ 61,113 (2013) (Order No. 779). Order No. 779 directs NERC, in stage one, to submit, within six months of the effective date of the Final Rule, one or more Reliability Standards that would require owners and operators of the BPS to develop and implement operational procedures to mitigate the effects of GMDs. NERC's stage one filing is due in January of 2014. In stage two, NERC is required to submit, within 18 months of the effective date of the Final Rule, one or more Reliability Standards that require owners and operators of the BPS to conduct initial and on-going assessments of the potential impact of benchmark GMD events on BPS equipment and the BPS as a whole.

2. Status of NERC Compliance

On November 7, 2013, the NERC Board of Trustees approved standard EOP-010-1, Geomagnetic Disturbance Operations the purpose of which is "to mitigate the effects of geomagnetic disturbance (GMD) events by implementing Operating Plans, Processes and procedures." EOP-010-1(3). NERC filed this proposed standard at FERC on November 14, 2013 in Docket RM14-0100, available at the following link:

http://elibrary.ferc.gov/idmws/file_list.asp?accession_num=20131114-5150.

NERC states that "as a high-impact, low-frequency event, GMDs pose a unique threat to Bulk-Power System reliability, and the proposed Reliability Standard is intended to lessen the impact of such events." NERC filing at 3. It further states:

> The proposed Reliability Standard is an important first step in addressing the issue of GMDs and can be implemented relatively quickly. While responsible entities will develop and implement Operational Procedures or Operational Processes, NERC will continue to support those efforts through the GMD Task Force, for example, by identifying and sharing Operating Plans, Processes, and Procedures found to me the most effective.

Id. at 4.

The proposed standard applies to Reliability Coordinators and Transmission Operators. It requires each Reliability Coordinator to develop, maintain and implement a GMD Operating Plan that coordinates GMD Operating Procedures within its Reliability Coordinator Area. The plan must include a description of activities designed to mitigate the effects of GMD events on the reliable operation of the interconnected transmission system within the Reliability Coordinator Area and a process for the Reliability Coordinator to review the GMD Operating Procedures of Transmission Operators in the Reliability Coordinator Area. Further, each Reliability Coordinator is required to disseminate forecasted and current space weather information as specified in the GMP Operating Plan.

The proposed standard also requires each Transmission Operator to develop, maintain and implement Operating Procedures to mitigate the effects of GMD events on the reliable operation of its respective system. Included in these required operating procedures are (1) steps or tasks to receive space weather information; (2) System Operator Actions to be initiated based on predetermined conditions and (3) the conditions for terminating the Operating Procedure or Operating Process. The proposed standard also has provisions for reviewing and monitoring GMD Operating Plans and Procedures.

C. Current Operating Procedures to Address GMD

Awareness and communication are essential prior to and during a GMD event. Federal agencies such as the Space Environment Center of the NOAA and Natural Resources Canada (NRCAN) track and report on space weather events. When solar activity warrants, these agencies provide alerts to NERC, which are then transmitted to the NPCC and distributed to member operators. The Solar Terrestrial Dispatch system is the primary conduit for alerting operators of solar activity. ISO-NE also has an arrangement whereby it is notified by New York ISO when moderate GIC is predicted. ISO-NE comments at 3. These notifications provide heightened system awareness and allow operators to ready the system should they need to take preventative or corrective action. See NPCC C-15, Appendix A for the notification path used by NPCC for communicating geomagnetic activity to the electric utilities in the NPCC region.[6]

ISO-NE detailed the steps it can take in the event of a GMD event:

> Beyond monitoring the weather, ISO-NE can implement actions from its operating procedure to help prepare the region's power grid to withstand or minimize the impact of GICs. Those actions may include redispatching generators to outputs that maximize their ability to respond to voltage fluctuations resulting from GICs; working with transmission operators to discontinue maintenance work and restore out of service high-voltage transmission lines, wherever possible; and reducing the amount of electricity that flows on transmission lines.

ISO-NE Comments at 2.

[6] Document C-15; http://www.ncpp.org/Standards/Procedures/c-15.pdf

ISO-NE has also adopted Control Room Operating Procedures specific to the occurrence of a GMD event.[7] During a GMD event, among other things, ISO-NE could take a series of actions as outlined below:

- Call for the discontinuance of maintenance work and restore transmission lines that are out of service
- Avoid taking long transmission lines out of service
- Maintain system voltage to protect against voltage swings
- Allow for the availability of Chester SVC and capacitor banks to respond to potential voltage deterioration
- Adjust line loading on certain direct current lines to be within the 40%-90% range of nominal rating of each pole for Phase II, Cross Sound Cable and Highgate
- Reduce load on ties to 90% or less of security limits
- Keep ten-minute spinning reserves above 50% as these units will prove reactive power, if geomagnetic disturbance is severe operator should consider forcing more spinning reserves with reactive reserve capability online
- Consider posturing units at economic minimum output to provide more room for reserves and reactive capability
- Bring on equipment capable of synchronous condenser operation online to provide reactive power reserve
- Confirm that monitoring equipment is in-service
- Consider tripping large shunts and series capacitor banks and static VAR compensators.

Id.

CMP and BHE report that operating procedures related to communication protocols during a GMD event are currently in place. These

[7] CROP.24003 available at: http://www.iso-ne.com/rules_proceds/operating/sysop/cr_ops/crop_24003.pdf.

procedures provide guidance when communicating system conditions and actions within the companies as well as to outside parties. In addition to complying with the NERC, ISO-NE and NPCC requirements described above, CMP indicated that it maintains the additional practices and mitigation measures listed below:

- CMP Maine Operating Procedure MOP-10, Power System Emergency Reporting, Attachment 20 – Solar Magnetic Disturbance, shows the communications required for SMD notifications of different severities. CMP Common Control Room Procedure CCRP-12, Solar Magnetic Disturbances, provides the communications and actions to take place upon notice of an SMD event.

- The CMP control room monitors the ground induced current (GIC) monitor and alarm installed at the Chester SVC. Beyond warnings and alerts, this monitor allows the CMP system operator to see the impact on the grid here in Maine.

- CMP installs pressure and temperature monitoring and alarms on all substation transformers with a winding voltage of 34.5 kV and above. This information can be used by system operators to monitor the transformer conditions as a result of GMD (or other) events and to re-posture the system to relieve stressed conditions.

- In responding to GMD events and system conditions, CMP operators are authorized to take any actions to preserve system reliability without seeking permission. This authorization includes shedding load or disconnecting transformers.

ISO-NE and CMP provide system operator training for GMD and EMP. CMP Comments at 3. CMP procedures are attached to the CMP comments. BHE also lists these measures and practices. BHE Comments at 2.

MPS is not a member of ISO-NE and is not subject to the ISO-NE operating procedures. The NBPC serves as the Reliability Coordinator for New Brunswick, Prince Edward Island, Nova Scotia and Northern Maine, which includes the MPS system. NBPSO currently notifies MPS operators of forecast space weather events. MPS/BHE comments at 2. The New Brunswick Energy and Utility Board is responsible for adopting, monitoring and enforcing of NERC Reliability Standards. New Brunswick *Electricity Act* at http://www.gnb.ca/legis/bill/pdf/57/3/Bill-39.pdf. NBPC, as a member of the Northeast Power Coordinating Council (NPCC) is obligated to conduct its operations in compliance with criteria, guides and procedures established by NPCC. NPCC Amended and Restated Bylaws (2012).

In its comments regarding current practices or measures being taken to protect from a GMD or EMP event, BHE/MPS attached the NBSO procedures, TO-OP-10, Solar Magnetic Disturbances.[8] These procedures outline the following steps:

> The NBSO as the Reliability Coordinator must notify NSPI, PEI, MPS and all major power plants, especially Point Lepreau when Solar Magnetic Disturbances are forecast or if any affects are experienced. NSPI will notify the NBSO if Nova Scotia monitors indicate a SMD.
>
> On receiving a geomagnetic a forecast of SMD activity predicting at least a 40% probability of activity at levels of Kp7, Kp8 or Kp9, receiving notification that SMD activity is in progress at levels of Kp7, Kp8 or Kp9, or receiving notification that significant geomagnetically induced currents (GIC) have been observed, system operators may evaluate the situation and implement the following actions as appropriate for their power system.
>
> 1. Discontinue maintenance work and return isolated high voltage transmission lines to service. Avoid taking long lines out of service.
> 2. Avoid opening grid lines while an SMD is in progress.
> 3. Adjust the system 230 and 345 kV voltage to between 95% and 98% (if system conditions permit) to protect against voltage swings.

[8] These operating procedures are in effect for the NBPSO.

4. Adjust the loading on HVDC circuits to be within the 40% to 90% range of their nominal rating.

5. Reduce the loading on interconnections and critical transmission lines to 90%, or less, of their agreed limits.

6. Loading on generators should not exceed 95% of full load to provide reserve power and reactive capacity.

7. Evaluate switching out large capacitor banks where applicable.

8. Synchronize available generators to manage system voltage and distribute spinning reserves.

9. In the event of extended severe solar magnetic disturbance, pay particular attention to temperature behavior of critical tie transformers.

10. Run Sisson, Mactaquac 5 and 6 as Synchronous condensers if possible.

NBSO TO-OP-10 at 2-3.

In its report on the 2003 Halloween Storm, NOAA assessed the effectiveness of the operational procedures employed by the US based electric utilities:

> Electrical companies took considerable efforts to prepare for and be aware of the storm onsets. Companies received the standard suite of geomagnetic storm watches, warnings and alerts, but SEC staff also supplemented standard support with several phone discussions. Preventive action helped to counter the GIC stresses that were observed. A representative from the North American Electric Reliability Council (NERC) commented: “Although the bulk electric system was not significantly affected by the solar activity, some systems reported higher than normal GIC’s that resulted in fluctuations in the output of some generating units, while the output of other units was reduced in response to the K-index forecast.” Responses to warnings included reducing system load, disconnecting system components, and postponing maintenance.

Technical Memorandum OAR SEC88.[9]

Some commenters expressed concern with relying on operating procedures as the sole mechanism for mitigating the effects of GMD. For example, Emprimus states that relying solely on operating procedures is not sufficient for adequately protecting the electrical grid during a GMD event because:

> 1) an operator will not have enough time or accurate information to determine what actions to take, 2) there are too many variables to be simulated and modeled ahead of time to train the operators, and 3) operator actions are inadequate to maintain grid stability and to protect critical equipment for solar super storms and EMP.

Emprimus comments at 3.

The Foundation for Resilient Societies states that because the ISO-NE region has not experienced a solar event as severe as the 1989 Quebec storm, the effectiveness of the ISO-NE operating procedures has not been tested and therefore it is not known whether these procedures will be sufficient to protect the electrical grid. Comments of the Foundation for Resilient Societies at 2. The EIS Council states that the operational procedures currently in place will help reduce the impact of small GMD events but cautions that operational procedures alone are not sufficient to protect against the 100-year class event (such as the Carrington Event). EIS comments Appendix Brief responses to Selected NOI Questions.

FERC found that while operational procedures are a necessary first step in mitigating the effects of GMD, they are not the only step. Thus in discussing Stage Two of compliance with the GMD rule, FERC stated:

[9] NOAA Halloween Space Weather Storms of 2003: http://www.swpc.noaa.gov/Services/HalloweenStorms_assessment.pdf.

> Owners and operators of the Bulk-Power System cannot limit their plans to considering operational procedures or enhanced training alone, but must, subject to the vulnerabilities identified in the [vulnerability] assessments, contain strategies for protecting against the potential impact of the benchmark GMD events based on factors such as the age, condition, technical specifications, system configuration, or location of specific equipment.

Order No. 779 at P54.

E. GMD Monitoring and Mitigation Measures and Cost Estimates

1. Mitigation Measures and Cost Estimates

In response to the NOI's direction to the T & D utilities to identify potential mitigation measure that could be implemented to decrease the negative impacts of GMD or EMP, CMP stated that "NERC, FERC, and EPRI are actively investigating potential measures to decrease the impact of GMD and EMP. CMP will evaluate the measures proposed from these organizations and will implement those that are applicable to CMP's system and are prudent." CMP's Comments at 3. In addition, CMP listed the following other potential GMD mitigation measures and provided cost estimates for these monitoring and mitigation measures:[10]

1. Install additional GIC monitoring sites on other 345 kV sites for a more complete picture of system impacts as they occur: $200,000 per site.
2. Investigate options to disable certain system protection schemes at risk of false trips during severe GMD events. $200,000 in addition to the specific per site disabling protection scheme costs
3. Support regional analysis of the impact of potential GMD events on the bulk power system. $200,000 to $400,000.
4. Purchase GE's Power System Load Flow program, modeling the system, analyzing the results and reporting on findings $300,000.

[10] BHE/MPS provided a similar list to that of CMP.

Other interested persons provided cost estimates. For example, Emprimus, which develops and produces systems that are intended to protect electric equipment against the effects of GIC, states that the cost of its SolidGround systems range from $250,000 to 350,000 (per transformer unless the transformers are in close proximity to each other) and installation costs are approximately $25,000 to $50,000 per installation. It estimated total costs for installing its protection system in Wisconsin would be $5.2 million but that the cost for Maine may be lower because it has fewer HV and EHV transformers than Wisconsin. Emprimus also states that monitoring capability is provided by its system and notes that another supplier provides GIC detection equipment at a cost of $10,000.

The Foundation for Resilient Societies estimates the cost of GIC monitoring equipment at $10,000 per unit. It states that "for about $200,000, as many as 20 GIC monitors could be deployed at critical transformer locations within the Maine transmission system." Supplemental and Reply comments of the Foundation for Resilient Societies at 4-5. It estimates that electric utilities could install neutral current blocking devices for approximately $300,000 per substation. Overall, the Foundation for Resilient Societies estimates that the equipment cost to protect Maine from solar storms would be $4.2 million. Comments of the Foundation for Resilient Societies in Response to 14 Questions Propounded by the Public Utilities Commission of the State of Maine at 11. In projecting the costs and benefits of programs to mitigate the effects of GMD, the Foundation for Resilient Societies states that the economic benefits of "diverting most of the Geomagnetically Induced Currents (GICs) from entering the EHV transmission networks of Maine and ISO-

New England" should be considered. Id. The Foundation for Resilient Societies lists the following benefits:

- Reducing the costs of providing reactive power to stabilize voltage within the Maine transmission and distribution system;
- Reducing the percentage of wholesale power dispatched at "off cost" prices due to grid congestion during moderate or severe geomagnetic disturbances;
- Reducing downpowering of electric generating facilities to prevent damage from GIC;
- Higher capacity utilization with the Maine electric utility industry, at least theoretically resulting in reduced wholesale prices for electric generation, even in deregulated markets;
- Increased throughput of electric power (increased imports and increased exports) of Maine transmission entities, reducing the cost per kilowatt hour for more efficient use of the same capital equipment;
- Potential macroeconomic benefits to the State of Maine if Maine becomes a first mover in providing more reliable electric grid services, thereby attracting data center construction and employment, or location of other industries that require highly reliable electric power to achieve corporate goals; and
- Benefits of "averted costs" through protection from severe, widespread, or long-lasting electric blackouts in event of a major GMD, measured in savings of life, avoidance of environmental contamination, and preservation of economic activity.

Id. at 12.

In addition, the Foundation for Resilient Societies proposed an electric reliability demonstration project that would:

> model the impacts and cost-effectiveness of *neutral ground blocking equipment*, in parallel to what is underway in Wisconsin; and to model the options for protection of system voltage stability through demonstration of various equipment to: improve the reliability in solar storms of the Chester Maine SVC resource, or the substitution of dynamic VAR compensators that utilize ultra-fast switching equipment not available in prior decades;

> and alternatives, including the introduction of series capacitors, such as have been utilized in other northern hemisphere electric grids.

Foundation for Resilient Societies Reply Comments at 7.[11] No cost estimate was provided for this proposed demonstration project.

2. Localized Cost Implications

ISO-NE cautions that if Maine implements mitigation requirements in advance of NERC and FERC, that these costs may not get regionalized under the ISO-NE tariff. "Localized Costs" are transmission project costs not necessary from an engineering perspective, but required by a local or state authority. Because ISO-NE will not adopt mitigation measures (in addition to the operating procedures already in place) in advance of the NERC compliance process, any individual utility adoption of additional mitigation measures before such measures are adopted by NERC and approved by FERC may be determined by ISO-NE to be localized costs. CMP, BHE and MPS recommend that adoption of any new mitigation measures await the completion of the NERC compliance with the FERC rule.

IV. EMP

A. Definition

An EMP is a high-intensity burst of electromagnetic energy that can occur naturally as a result of a solar storm or be a result of an intentional attack

[11] We note that all of the cost estimates discussed herein relate to devices that would be implemented on the transmission system. However, generating units also are susceptible to damage from GMD and EMP. The Commission does not have information on the additional cost to protect generation from the effects of GMD. This information may be developed as part of the second stage of NERC's compliance with Order No. 779.

aimed at crippling critical infrastructure. Attacks can range from a high-altitude detonation of a nuclear device, which would affect a widespread target zone, to the use of weapon systems which rely on radio frequency (RF) to attack specific targets such as a building's or an aircraft's electronic equipment.

The EMP Commission has described EMP events as follows:

> Gamma rays from a high-altitude nuclear detonation interact with the atmosphere to produce a radio-frequency wave of unique, spatially varying intensity that covers everything within line-of-sight of the explosion's center point. It is useful to focus on three major EMP components.
>
> FIRST EMP COMPONENT (E1)
>
> The first component is a free-field energy pulse with a rise-time measured in the range of a fraction of a billionth to a few billionths of a second. It is the "electromagnetic shock" that disrupts or damages electronics-based control systems, sensors, communication systems, protective systems, computers, and similar devices.
>
> SECOND EMP COMPONENT (E2)
>
> The middle-time component covers roughly the same geographic area as the first component and is similar to lightning in its time-dependence, but is far more geographically widespread in its character and somewhat lower in amplitude. In general, it would not be an issue for critical infrastructure systems since they have existing protective measures for defense against occasional lightning strikes. The most significant risk is synergistic, because the E2 component follows a small fraction of a second after the first component's insult, which has the ability to impair or destroy many protective and control features. The energy associated with the second component thus may be allowed to pass into and damage systems.
>
> Third EMP COMPONENT (E3)
>
> The final major component of EMP is a subsequent, slower-rising, longer-duration pulse that creates disruptive currents in long electricity transmission lines, resulting in damage to electrical supply and distribution systems connected to such lines. The sequence of E1, E2, and then E3 components

of EMP is important because each can cause damage, and the later damage can be increased as a result of the earlier damage.

Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume 1 (2004), Executive Summary at 5-7.

B. Possible Harm

The impact of an EMP created by the detonation of a nuclear bomb is both different in character and likely far more catastrophic than that affected by historic blackouts. In particular:

1) The EMP impact is virtually instantaneous and occurs simultaneously over a much larger geographic area. Generally, there are neither precursors nor warning, and no opportunity for human-initiated protective action. The early-time EMP component is the "electromagnetic shock "that disrupts or damages electronics-based control systems and sensors, communication systems, protective systems, and control computers, all of which are used to control and bring electricity from generation sites to customer loads in the quantity and quality needed. The E1 pulse also causes some insulator flashovers in the lower-voltage electricity distribution systems (those found in suburban neighborhoods, in rural areas and inside cities), resulting in immediate broad-scale loss-of-load. Functional collapse of the power system is almost definite over the entire affected region, and may cascade into adjacent geographic areas.

2) The middle-time EMP component is similar to lightning in its time-dependence but is far more widespread in its character although of lower amplitude—essentially a great many lightning-type insults over a large geographic area which might obviate protection. The late-time EMP component couples very efficiently to long electrical transmission lines and forces large direct electrical currents to flow in them, although they are designed to carry only alternating currents. The energy levels thereby concentrated at the ends of these long lines can become large enough to damage major electrical power system components. The most significant risk is synergistic, because the middle and late-time pulses follow after the early-time pulse, which can impair or destroy protective and control features of the power grid. Then the energies associated with the middle and late-time EMP thus may pass into major system components and damage them. It may also pass electrical surges or fault currents into the loads connected

> to the system, creating damage in national assets that are not normally considered part of the infrastructure per se. Net result is recovery times of months to years, instead of days to weeks.
>
> 3) Proper functioning of the electrical power system requires communication systems, financial systems, transportation systems, and—for much of the generation—continuous or nearly continuous supply of various fuels. However, the fuel-supply, communications, transportation, and financial infrastructures would be simultaneously disabled or degraded in an EMP attack and are dependent upon electricity for proper functioning. For electrical system recovery and restoration of service, the availability of these other infrastructures is essential. The longer the outage, the more problematic, and uncertainty-fraught the recovery will be.

Id. at 19.

C. EMP Mitigation Measures and Cost Estimates.

The utilities did not provide specific costs for EMP mitigation. However, in its comments BHE/MPS stated that the companies currently "use design factors such as adequate phase spacing, shielding of electronic components, and field sensors to monitor system performance in planning, designing and operations to protect the system from GMD or EMP." BHE/MPS comments at 3.

Former Central Intelligence Agency (CIA) Director, R. James Woolsey states: "Robust EMP hardening of a state grid can typically be achieved for $40 million (much less for smaller states like Maine, more for larger states) which amortized over time can be reduced to a trivial cost." Woolsey Comments at 4.

The EMP Commission stated in its report:

> It is not practical to try to protect the entire electrical power system or even all high-value components from damage by an EMP event. There are too many components of too many different types, manufactures, ages and designs. The cost and time would be prohibitive Widespread collapse of the electrical power system in the area affected by EMP is virtually inevitable after a broad geographic EMP attack, with even a modest number of unprotected components. Since this is a given, the focus of protection is to retain and restore service to critical loads while permitting relatively rapid restoration.

Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse, (EMP Report) April, 2008, at 45-46. The Report stresses the importance of a mitigation plan to be "jointly developed by the Federal Government and the electric power industry, instilled into systems operations, and practiced to maintain a ready capability to respond. It must also fully coordinated with interdependent infrastructures, owners and producers." Id. at 52.

One of the biggest concerns with GMD or EMP events is the damage to high voltage transformers. In October 2011, NERC published a Special Report: Spare Equipment Database System[12] in which one of the recommendations was for NERC to develop a database that would "facilitate timely communications between those needing long-lead time equipment damaged in a HILF event and those equipment owners who may be able to share existing equipment being held as spares by their organization." Special Report: Spare Equipment Database System – October 11 at page 1. This database is now operational. In addition, utilities may rely on mutual aid agreements with affiliates and other utilities for inventory of spare equipment.

The EMP Report notes that NERC already has a spare component database for such large items as transformers or breakers, but that this database "must now be revised to accommodate an EMP attack environment." Id at 56. Thus, the EMP Report suggests that DHS must work with NERC and industry to

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[12] Available at the following link: http://www.nerc.com/docs/pc/sedtf/SEDTF_Special_Report_October_2011.pdf.

identify the need for additional spare components or materials and delivery capability for these items.

The EISC suggests that "holding a sufficient number of spare transformers on site in order to more quickly replace damaged transformers is another option, as is de-rating transformers to ensure higher magnetic and thermal margins. De-rating may not be sufficient, however, for severe GMD or EMP scenarios." EISC Comments at 36.

V. Need for Coordination and Jurisdictional Considerations

Based on the comments received by the Commission, there appears to be a need for coordination among federal and state agencies and the electric industry in establishing GMD and EMP mitigation plans.

A. ISO-NE England Approval of Changes to the Transmission System

Under the ISO-NE Open Access Transmission Tariff (OATT), a transmission owner is required to submit to ISO-NE for review proposed plans for changes to its transmission facilities rated 69kV or higher "which may have a significant effect on the stability, reliability or operating characteristics of the Transmission Owner's transmission facilities, the transmission facilities of another Transmission Owner, or the system of a Market Participant." ISO-NE OATT § I.3.9. The Transmission Owner may not make the change if ISO-NE determines that there will be a significant adverse impact on "the reliability or operating characteristics of the Transmission Owner's transmission facilities, the transmission facilities of another Transmission Owner, or the system of one or more Market Participants, the Market Participant or Transmission Owner shall not proceed to implement such plan unless the Market Participant (or the Non-Market Participant on whose behalf the Market Participant has submitted its plan) or Transmission Owner takes such action or constructs at its expense such facilities as the ISO determines to be reasonably necessary to avoid such adverse effect." Id. at § I.3.10

Thus, if CMP and BHE sought to add equipment to mitigate the effects of GMD or EMP, ISO-NE would determine whether there would be any significant adverse impacts on the ISO-NE transmission system. If it determined that there would be a significant adverse effect, the utilities would not be granted permission to install the equipment unless they took steps identified by ISO-NE to avoid the adverse impact.

With regard to potential effects of adopting GMD and EMP mitigating measures, BHE states:

> Potential effects include burdening adjacent areas unprotected from GMD, including adjacent transmission operators and adjacent transformers with increased risk. Also, New Hampshire has been noted as potentially the most vulnerable state in the US for GMD and non-coordinated measures in Maine could exacerbate the effects for New Hampshire or other adjacent areas.

BHE/MPS comments at 5.

FERC has also recognized the importance of coordinating mitigation plans across regions. Thus it has required that "the NERC standards development process should consider tasking planning coordinators, or another functional entity with a *wide-area* perspective, to coordinate mitigation plans across Regions under the Second Stage GMD Reliability Standards to ensure consistency and regional effectiveness*."* Order 779 P82.

B. NPCC and NERC

In addition to ISO-NE, the NPCC would also review the installation of relay protection systems for any equipment connected to the bulk transmission system in Maine. CMP comments at 5. Further, NERC has underscored the importance of coordinating mitigation efforts:

> The interconnected and interdependent nature of the bulk power system requires that risk management actions be consistently and systematically applied across the entire system to be effective. The magnitude of such an effort should not be underestimated. The North American bulk power system is comprised of more than 200,000 miles of high-voltage transmission lines, thousands of generation plants, and millions of digital controls. More than 1,800 entities own and operate portions of the system, with thousands more involved in the operation of distribution networks across North America. These entities range in size from large investor-owned utilities with over 20,000 employees to small cooperatives with only ten. The systems and facilities comprising the larger system have differing configurations, design schemes, and operational concerns. Referring to any mitigation on such a system as "easily-deployed," "inexpensive," or "simple" is an inaccurate characterization of the work required to implement these changes.
>
> As mitigating options are further considered, it is also important to note that it is impossible to fully protect the system from every threat or threat actor. Sound management of these and all risks to the sector must take a holistic approach, with specific focus on determining the appropriate balance of resilience, restoration, and protection. A successful risk management approach will begin by identifying the threat environment and protection goals for the system, balancing expected outcomes against the costs associated with proposed mitigations.
>
> This balance must be carefully considered with input from both electric sector and government authorities. Building on the inherent resilience of the system and enhancing the response of the system as a whole to unconventional stresses should be a cornerstone of these efforts. Determining appropriate cost ceilings and recovery mechanisms for protections related to HILF risks will be critical to ensuring a viable approach to addressing them. The electricity industry and government authorities must also coordinate to improve two-way information sharing and communication practices relative to HILF risks. The sector is heavily reliant on information from the public sector for each risk discussed in this document.

NERC 2010 HILF Report, Executive Summary.

C. FERC Jurisdiction over Transmission Cost Recovery

The Resolve asks the Commission for a recommendation on allocating the costs of mitigation measures between shareholders and ratepayers. Recovery of transmission costs is within FERC's jurisdiction. Thus, issues regarding cost recovery for GMD or EMP mitigation measures, to the extent these mitigation measures involved the transmission system, would be determined by the FERC.

D. Department of Homeland Security Role in Coordinating EMP Responses

The EMP Report concluded that the DHS has the responsibility and authority to coordinate responses to EMP attacks.

> As a result of the formation of Department of Homeland Security (DHS) with its statutory charter for civilian matters, coupled with the nature of EMP derived from adversary activity, the Federal Government, acting through the Secretary of Homeland Security, has the responsibility and authority to assure the continuation of civilian U.S. society as it may be threatened through an EMP assault and other types of broad scale seriously damaging assaults on the electric power infrastructure and related systems.
>
> It is vital that DHS, as early as practicable, make clear its authority and responsibility to respond to an EMP attack and delineate the responsibilities and functioning interfaces with all other governmental institutions with individual jurisdictions over the broad and diverse electric power system. This is necessary for private industry and individuals to act to carry out he necessary protections assigned to them and to sort out liability and funding responsibility. DHS particularly needs to interact with FERC, NERC, state regulatory bodies, other governmental institutions government facilities, such as independent power plants, to contribute their capability in a time of national need, yet not interfere with market creation and operation to the maximum extent practical.
>
> DHS, in carrying out its mission, must establish the methods and systems that allow it to know, on a continuous basis, the state of the infrastructure, its topology, and key elements. Testing standards and measurable improvement metrics should be defined as early as possible and kept up to date.

EMP Report at 54.

On February 12, 2013, the President issued Presidential Policy Directive/PPD-21, Critical Infrastructure Security and Resilience (Directive). The Directive "refines and clarifies the critical infrastructure-related functions, roles and responsibilities across the Federal Government, as well as enhances overall coordination and collaboration." Directive at 1. The Directive tasks the Secretary of Homeland Security with providing strategic guidance, promoting a national unity of effort, and coordinating the overall Federal effort to promote the security and resilience of the Nation's critical infrastructure. The Directive outlines additional responsibilities of the Secretary of Homeland Security. The Directive directs DHS to:

- Develop a situational awareness capability that addresses both physical and cyber aspects of how infrastructure is functioning in near-real time
- Understand the cascading consequences of infrastructure failures
- Evaluate and mature the public-private partnership
- Update the National Infrastructure Protection Plan
- Develop comprehensive research and development plan

In addition, the Directive tasks DHS with other responsibilities such as aiding in prioritizing assets and managing risks to critical infrastructure, recommending security and resilience measuring for critical infrastructure prior to, during and after an event or incident and supporting incident.

V. CONCLUSION

The material discussed in this report indicates that GIC, whether produced by GMD or EMP, presents a serious threat to the reliability of the bulk power system and thus to the ability of Maine's utilities to provide safe and reliable service. The comments also describe a variety of options for prevention and mitigation, some of which appear to be available at relatively modest costs. The comments also indicate, however, that federal and regional authorities with appropriate expertise and jurisdiction have been and are continuing to work to address the risks and consider the costs and benefits of mitigating the effects of GMD and EMP, and that there is a strong indication from those federal and regional authorities that coordination on a national and regional level in any prevention or mitigation efforts is vital due to the highly integrated nature of the bulk power system.

VI. COMMENT DEADLINE

The deadline for submitting comments on this draft report is **December 18, 2013.**

Attachment 1

Appendix B
Solar Activity Reporting Form

The predictive measure of solar activity reported by the Solar Terrestrial Dispatch is the Kp index, a scale divided into 27 zones of solar activity. A description of these zones and the relationship between the observed Kp index and typically observed GIC activity follows:

<table>
<tr><th>Kp Index</th><th>Solar Activity</th><th>GIC Activity</th></tr>
<tr><td>**0o**</td><td rowspan="4">**Quiet**</td><td rowspan="13">**No GICs**</td></tr>
<tr><td>**1-**</td></tr>
<tr><td>**1o**</td></tr>
<tr><td>**1+**</td></tr>
<tr><td>**2-**</td><td rowspan="3">**Unsettled**</td></tr>
<tr><td>**2o**</td></tr>
<tr><td>**2+**</td></tr>
<tr><td>**3-**</td><td rowspan="6">**Active**</td></tr>
<tr><td>**3o**</td></tr>
<tr><td>**3+**</td></tr>
<tr><td>**4-**</td></tr>
<tr><td>**4o**</td></tr>
<tr><td>**4+**</td></tr>
<tr><td>**5-**</td><td rowspan="3">**Minor Storm**</td><td rowspan="6">**Low Level GICs**</td></tr>
<tr><td>**5o**</td></tr>
<tr><td>**5+**</td></tr>
<tr><td>**6-**</td><td rowspan="3">**Major Storm**</td></tr>
<tr><td>**6o**</td></tr>
<tr><td>**6+**</td></tr>
<tr><td>**7-**</td><td rowspan="3">**Severe Storm**</td><td rowspan="3">**Moderate GICs**</td></tr>
<tr><td>**7o**</td></tr>
<tr><td>**7+**</td></tr>
<tr><td>**8-**</td><td rowspan="5">**Very Severe Storm**</td><td rowspan="5">**Strong GICs**</td></tr>
<tr><td>**8o**</td></tr>
<tr><td>**8+**</td></tr>
<tr><td>**9-**</td></tr>
<tr><td>**9o**</td></tr>
</table>