Written Testimony
Before
Joint Standing Committee on Energy, Utilities and Technology
State of Maine Legislature
Regarding Legislative Document 131,
An Act to Secure the Safety of Electrical Power Transmission Lines

by
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We conducted a study of the adequacy of ISO-New England operating procedures during solar storms. Upon examination, their numbers just don't add up, despite electric utility assurances to the contrary. Any person in Maine with family and friends dependent on electric power could get discouraged and even overwhelmed by our testimony. However, the good news is that the electric grid problems caused by solar storms can be cost-effectively remedied using commercially available technology. The legislature of the State of Maine has within its power to investigate this situation and to serve as a leadership example for the rest of the nation.

We respectfully suggest that the Committee ask the following questions of ISO-New England, Central Maine Power, and Bangor Hydro before the Committee during the upcoming work session on the Act. Our explanation of the facts, circumstances, and rationale behind each question is presented in italics. "Geomagnetic disturbances" and "Geomagnetically Induced Current" (GIC) result from solar storms; these terms are used throughout this testimony.

Executive Summary

We make the following key points in our testimony as a rationale for questions of utilities:

- ISO-New England solar storm operating procedures have not been proven during severe storm conditions. (pp. 2-3)
- ISO-New England has kept records during solar storms that should be disclosed to the Committee and the public. (pp. 3-4)
- ISO-New England monitoring of GIC flows during solar storms is likely to be inadequate for prudent operator actions; records of past GIC monitoring should be disclosed to the Committee and the public. (pp. 4-5)
- Solar storms have already caused major system contingencies in the ISO-New England control area. (p. 7)
- Loss of generation and transmission resources during even moderate solar storms could result in inadequate allowance for unplanned outages, inadequate real-time emergency reserves, and resulting electric grid blackout for the citizens of Maine. (pp. 8-12)

- Solar storms can cause safety issues for nuclear power plants in New England. (pp. 12-13)
- Solar storms can result in transformer failure and long-term blackouts. (pp. 13-14)
- Ratepayers are likely to incur additional costs because hardware protection against solar storms has not been installed. (p. 14)
- The cost of installing hardware protection against solar storms is likely to be only pennies per year, per ratepayer. (pp. 14-15)

Utility Operating Procedures during Solar Storms and Resulting Geomagnetic Disturbances

Is it correct that operating procedures "SOP- RTMKTS.0120.0050 Implement Solar Magnetic Disturbance Remedial Action" of ISO-New England and "Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems" of the Northeast Power Coordinating Council are controlling solar storm procedures for the State of Maine?
"*Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems" of the Northeast Power Coordinating Council is available on their website at:*
https://www.npcc.org/Standards/Procedures/c-15.pdf

As of February 21, 2013 the document "SOP- RTMKTS.0120.0050 Implement Solar Magnetic Disturbance Remedial Action" of ISO-New England was available on their website at:
http://www.iso-ne.com/rules_proceds/operating/sysop/rt_mkts/sop_rtmkts_0120_0050.pdf

As of March 5, 2013, the ISO-New England procedures were no longer available at this link; instead, a message "404 Page not found" was displayed.

Can complete copies of ISO-New England solar storm operating procedures be provided to the Committee and to the public? *It is our position that these operating procedures were once public and should be provided to the Committee and to the public.*

The Central Maine Power representative at the February 19, 2013 hearing referred to "143 pages of operating procedures" for solar storms for his company. Moreover, he stated:

> "Finally, on this subject, you should be assured that Central Maine Power has equipment and operating procedures in place that have been protecting our system from geomagnetic disturbances and ground induced currents for years. I have reams of materials that describe the operating procedures and equipment that we have in place to protect our bulk power systems."
>
> "ISO-NE, the operator of the bulk power system in New England has its owns (sic) set of procedures that are outlined in a 78 page powerpoint presentation titled Geomagnetic

> Disturbances, High Altitude Electromagnetic Pulses, and High Power Microwave Pulses. I can provide a copy if the committee would like to see it."

It is our position that operating procedures and associated materials that are referred to in public testimony to assert that the public is protected from geomagnetic disturbance should be made public. Moreover, it is our position that the 78 page Powerpoint presentation offered to the Committee should be requested of Central Maine Power and also provided to the public.

When an individual utility in New England needs to take its equipment offline or downrate during a solar storm to prevent damage, how is this accounted for in the ISO-New England operating procedures? *We could not find this contingency in the ISO-New England operating procedures. We are particularly concerned because the Seabrook nuclear power plant downrated to 68% during a small solar storm on July 16, 2012.*

Have detailed simulations of solar storm operating procedures for the ISO-New England control area under various solar storm scenarios been conducted? *It is our position that without advance modeling of operating procedures, operators will not be able to make sound decisions during rapidly evolving solar storms. PJM Interconnection is currently modeling its system under solar storm conditions. It is our position that ISO-New England cannot have confidence in its solar storm operating procedures until its control area is modeled.*

Have operating procedures for Maine utilities been tested during solar storms of equivalent intensity to the March 1989 storm that caused a blackout for the Province of Quebec? *It is our understanding that "SOP- RTMKTS.0120.0050 Implement Solar Magnetic Disturbance Remedial Action" of ISO-New England was first implemented on February 13, 2003. The Central Maine Power representative at the February 19, 2013 Committee hearing stated, "Geomagnetic disturbances are not rare events. They sometimes occur several times a month, and our operating procedures have protected our system well." Because there have been no solar storms in New England of intensity equivalent to the March 1989 storm since February 13, 2003, it is our position that the ISO-New England operating procedures have not demonstrated their effectiveness; rather, these are hypothetical measures that may or may not work in severe or even moderate storm conditions. Any utility statements that operating procedures have "protected our system well" need to be carefully questioned by the Committee to determine their applicability in all circumstances.*

Geomagnetic Disturbance Recordkeeping

It is our understanding that the ISO-New England operating procedures mandate that solar storm intensity, operator actions taken, and equipment damage be recorded in a special form, "Attachment A – SMD Reporting." Can the Committee and public stakeholders see these records of Solar Magnetic Disturbance (SMD) reporting for ISO-New England? *Event reporting per Attachment A was in effect during the "Halloween Storms" of 2003 and several subsequent solar storms of lesser intensity. Access to these records should allow the Committee and the public to independently assess the risk of geomagnetic disturbance to the citizens of Maine.*

Since ISO-New England has been keeping records of "Attachment A – SMD Reporting," how many geomagnetic disturbances of the following intensity been observed and recorded in the "Attachment A" form and on what dates, per Table 1 of the ISO-New England operating procedures?

Table 1		
GIC Level	**Severity**	**XFMR Neutral DC Current**
1	Minor	5-14 Amps
2	Moderate	15-29 Amps
3	Major	30-59 Amps
4	Severe	>60 Amps

The Central Maine Power representative at the February 19, 2013 Committee hearing stated, "Geomagnetic disturbances are not rare events. They sometimes occur several times a month, and our operating procedures have protected our system well." It is our position that the Committee and the public should be able to independently assess the frequency and intensity of geomagnetic disturbances using the records of ISO-New England. Production of these records should not be an undue burden as no original document creation would be required, only reproduction of existing documents.

It is our understanding that the ISO-New England operating procedures state that "Electronic Copies of Attachment A –SMD Reporting are archived for three (3) years plus the current year." Why is the archive period only three years when the solar cycle is 11 years? *It is our position that the citizens of Maine would not be well served by record retention policies that could dispose of information on potential hazards to the public.*

It is our understanding that the ISO-New England operating procedures state that GIC levels be recorded in the Control Room Event Logserver when an alarm is received from the Chester Substation. Can a record of GIC levels in the Control Room Event Logserver be provided to the

Committee and to the public? *It is our position that the Committee and the public should be able to independently assess the frequency and intensity of geomagnetic disturbances using the records of ISO-New England. The Control Room Event Logserver is an alternative source of GIC records if "Attachment A –SMD Reporting" has not been archived past three years.*

Geomagnetically Induced Current Monitoring and Data Recording

How many GIC monitoring devices does Central Maine Power/Bangor Hydro/ISO-New England currently have active? *Based on reading of the ISO-New England operating procedures, it is our understanding that ISO-New England has access to only one GIC monitoring device located at the Chester, Maine Substation and this is the entirety of real-time GIC monitoring for all of ISO-New England.*

Does ISO-New England have a sufficient number of GIC monitoring devices in New England to enable prudent operator actions during solar storms? *Based on industry discussions, it is our understanding that the single GIC monitoring station at the Chester Substation is inadequate for real-time operator decisionmaking during solar storms.*

Central Maine Power disclosed during the February 19, 2013 hearing of the Committee that it has been monitoring GIC since 1990 at its Chester location. Will Central Maine Power/Bangor Hydro/ISO-New England release this GIC data since monitoring started in 1990 to the Committee and to the public so that hazards to the citizens of Maine can be independently assessed? In particular, can Central Maine Power/Bangor Hydro/ISO-New England provide maximum GIC readings and dates of these readings for all days when the GIC met or exceeded the 5 amp criterion for a "Minor Storm," since the monitor was installed at Chester in 1990? *The Chester Substation GIC data should allow the Committee and the public to independently assess the frequency and risk of solar storms to the citizens of Maine. There is no good reason for confidentiality of the Chester Substation data, as this data has been partially released for research previously. We are already in possession of detailed GIC data for the Chester Substation for the May 4, 1998 solar storm and the January 24, 2012 solar storm. To ease the burden of producing detailed GIC data, we initially ask only for maximum GIC readings during days of solar storms.*

Are there GIC monitoring devices installed at the Generator Step Up (GSU) transformers at the Seabrook nuclear power plant? *Based on industry discussions, it is our understanding that GIC monitoring devices have been installed at Seabrook nuclear plant.*

Is GIC monitoring data from Seabrook provided to ISO-New England to enable prudent operator actions during solar storms? *Based on our reading of the ISO-New England operating procedures, it is our understanding that Seabrook GIC data is not provided in real time to ISO-New England. Because the Seabrook nuclear plant may be particularly affected by GIC, and* *because its operation is significant to State of Maine power grid reliability, it is our position that Seabrook data would be essential for prudent monitoring of geomagnetic disturbances by ISO-New England.*

Are there other GIC monitoring stations in New England where the measurements are not provided to ISO-New England? *Based on industry discussions and our reading of the ISO-New England operating procedures, it is our understanding that United Illuminating Company in Southern Connecticut has four GIC monitoring stations and that this data is not provided in real time to ISO-New England. It is also our understanding that the GIC monitoring equipment is commonly bundled with newly replaced or installed transformers.*

ISO-New England Planning for System Contingencies

Does ISO-New England planning for contingencies affecting large generators and transmission lines rely primarily on resources within the ISO-New England control area, or is there a presumption that "spinning reserves" will be available through Emergency Energy Transactions (EET) from other interconnected control areas? *At the February 29, 2013 work session of the Committee, the ISO-New England representative testified that his ISO plans for up to two system contingencies, so-called "N-2" planning. The ISO-New England planning document, "ISO-NE 2013 Operable Capacity Analysis," dated February 15, 2013, shows 600 MW of operable capacity from Real-Time Demand Response and another 400 MW of operable capacity from Real-Time Emergency Generation, for a total of 1,000 MW emergency capacity. It is our understanding that there are single generation and transmission resources within the ISO-New England control area that exceed 1,000 MW, such as the Seabrook nuclear power plant, the Chester Substation SVC, and the Phase II HVDC tie.*

If there have been previous contingencies exceeding 1,000 MW within the ISO-New England control area, how have these contingencies been managed? *An unexpected outage of the Seabrook nuclear power plant, which generates up to 1,247 MW of power, occurred on November 10, 1998. It is our understanding that an unexpected tripping of the Chester Substation Static Var Compensator (SVC), providing reactive power support for 2,700 MW of transmission, occurred in the 1990's.*

The Phase II HVDC tie consists of two poles rated at approximately 2,000 MW together. If an unexpected contingency tripped both poles at the same time, how would ISO-New England manage this contingency? Has any event ever resulted in simultaneous tripping of both Phase II HVDC poles? *It is our understanding that both poles of the Phase II HVDC tie tripped out simultaneously during at least one occasion in the 1990's.*

If a widespread natural disaster were to affect the New England control area and also affect the ability of Hydro-Quebec to supply power through the Phase II HVDC tie, or affect the ability of

New York ISO to supply power by Emergency Energy Transactions, or affect the ability of New Brunswick System Operator to supply power through the Keswick – Keene Rd and Point Lepreau – Orrington ties, what contingency plan does ISO-New England have? *It is presumable that a widespread natural disaster such as earthquake, hurricane, or solar storm could affect more than one control area simultaneously.*

Past System Contingencies Caused by Geomagnetic Disturbance

Has the Highgate HVDC tie from Quebec to Vermont tripped out during previous geomagnetic disturbances and if so, on which dates? *It is our understanding that HVDC ties have tripped during solar storms. The Committee and the public should know if the Highgate tie is particularly susceptible.*

Has the Phase II HVDC tie from Quebec to Massachusetts tripped out during previous geomagnetic disturbances and if so, on which dates? *It is our understanding that both poles of the Phase II HVDC tie tripped out simultaneously during at least one solar storm in the 1990's. The Committee and the public should know if the Phase II tie is particularly susceptible.*

Has the Static Var Compensator (SVC) in the Chester Substation tripped out during previous geomagnetic disturbances and if so, on which dates? *Based on industry discussions, it is our understanding that the Chester Substation SVC tripped out during a solar storm in the 1990's. Moreover, it is our understanding that this SVC is a critical piece of equipment for the New England power grid and its loss could result in system instability and voltage collapse.*

Did any solar storm result in an unplanned outage for the Seabrook nuclear power plant? *On November 8-9, 1998, a solar storm hit New England. On November 10, 1998, a high temperature condition was discovered in a Seabrook Generator Step Up (GSU) transformer and the plant had an unplanned outage. Subsequent examination of the transformer revealed internal melting of metal components, requiring rebuilding of the Phase A transformer equipment. It is our position that GIC and associated equipment vibrations from the solar storm may have caused failure of the Seabrook GSU transformer.*

Did any solar storm result in an unplanned outage for the now-decommissioned Maine Yankee nuclear power plant? *On April 28, 1991 a solar storm hit New England. Subsequently and within 24 hours, a GSU transformer at Maine Yankee caught fire and the plant had an unplanned outage. It is our position the GIC from the solar storm may have caused the catastrophic and disruptive failure of the Maine Yankee GSU transformer. The resulting transformer oil and generator hydrogen fire burned for 4 hours and was classified as a safety event by the Nuclear Regulatory Commission. The Associated Press article, "Maine Governor Left In Dark About Fire For More Than 12 Hours," dated May 3, 1991, gives additional background.*

Unplanned Outages and Potential Blackouts during Geomagnetic Disturbance

The February 1, 2013 revision of the ISO-New England operating procedures specifies the following actions during solar storms, as appropriate:

- "Adjust the loading on Phase II, the Cross Sound Cable and Highgate HVdc ties to be within the 40% to 90% range of nominal rating of each pole"
- "Reduce the loading on Inter-RCA/BAA ties and on other internal critical transmission lines and interfaces to 90%, or less, of their security limits"

What is the capacity and typical loading of the Phase II HVDC tie leading from Quebec into Sandy Pond, Massachusetts? *It is our understanding that the typical loading of the Phase II tie is 1,500 MW, with a maximum rated capacity of 2,000 MW. If loading were to be reduced to 40% of 2,000 MW capacity, this would result in 1,200 MW less power imported into ISO-New England. For comparison, the now decommissioned Maine Yankee nuclear plant supplied 587 MW of power, on average, over its operational lifetime.*

What is the capacity and typical loading of the Highgate HVDC tie leading from Quebec into Highgate, Vermont? *It is our understanding that the rated capacity of the Highgate tie is 200 MW. If loading were to be reduced to 40% of 200 MW, this would result in 120MW less power imported into ISO-New England.*

What is the capacity and typical loading of the Keswick – Keene Rd 345 kV transmission line from New Brunswick into Maine, which is an Inter-RCA/BAA tie? *It is our understanding that the rated capacity of the Keswick – Keene Rd tie is 700 MW. If its loading were to be reduced by 10%, this would result in 70 MW less power imported into Maine. If loading were to be reduced by 50%, this would result in 350 MW less power imported into Maine.*

What is the capacity and typical loading of the Point Lepreau - Orrington 345 kV transmission line from New Brunswick into Maine, which is an Inter-RCA/BAA tie? *It is our understanding that the rated capacity of the Point Lepreau - Orrington tie is 700 MW. If its loading were to be reduced by 10%, this would result in 70 MW less power imported into Maine. If loading were to be reduced by 50%, this would result in 350 MW less power imported into Maine.*

It is our position that reduced loading or complete loss of HVDC ties and the Inter-RCA/BAA ties into Maine could have substantial effects on reserve margins and voltage stability and could cause blackouts.

The most recent publicly available version of the ISO-New England operating procedures specifies the following action during solar storms, as appropriate:

- "Consider posturing Generators operating at their Eco Max to provide room for reserves and reactive capacity in accordance with SOP-RTMKTS.0120.0020 - Implement Capacity Remedial Action"

Has ISO-New England mathematically modeled the increase of reactive power consumption under various geomagnetic disturbance scenarios? *Metatech Corporation has modeled reactive power consumption during solar storms for New England as part of its report "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," produced by Oak Ridge National Laboratory for the Federal Energy Regulatory Commission in joint sponsorship with the Department of Energy and the Department of Homeland Security. We are not aware of whether ISO-New England has done similar analysis.*

Could "posturing generators" to provide reactive power affect reserve margins? *It is our understanding that production of "reactive power" (used for long distance transmission and electric motors) reduces real power generation due to heating limits in generators and that real power generation could be reduced by 50% or more. Therefore, posturing for reactive capacity could negatively affect reserve margins and increase the chance of load shedding and blackout.*

The Nuclear Regulatory Commission (NRC) Power Reactor Status Report for Seabrook nuclear plant in New Hampshire on July 16, 2012 reads:

> REDUCED POWER DUE TO SOLAR MAGNETIC ACTIVITY CAUSING HIGH CIRCULATING CURRENT IN UNIT 1 TRANSFORMER - POWER LIMITED TO 85% BASED ON GENERATOR STATOR COOLING DELTA T LIMIT - SWITCHYARD MAINTENANCE ON-GOING UNTIL APPROX. 7/17/12

Power for Seabrook was reduced to 68% on July 16, 2012, according to the NRC status report. If Seabrook reduces power during a future solar storm, in addition to the loading reductions specified in the ISO-New England operating procedures, could this increase the risk of blackout for New England, including the State of Maine? *Under geomagnetic disturbance procedures, nuclear plant operators in the northeast United States reduced loading of GSU transformers during solar storms on July 16, 2000 and October 30, 2003, according to Power Reactor Status Reports on the NRC website. According to a paper authored by employees of a major transformer manufacturer, some GSU transformers should be downrated by 50% with 82 amps* *of GIC and by 100% with 92 amps of GIC.*[1] *At the GMD Task Force meeting of the North American Electric Reliability Corporation on February 25-27, 2013, a major utility disclosed their transformer GIC-withstand specification of 25 amps of GIC for 15 minutes. At the Hope Creek nuclear power plant in New Jersey, a downrating threshold of 10 amps of GIC was used for an aged transformer. It is our position that GSU transformers at nuclear power plants in New England could be substantially downrated during severe solar storms or taken offline entirely.*

What are typical GIC-withstand ratings for GSU transformers and Extra High Voltage (EHV) transformers located in the ISO-New England control area and the State of Maine? *Currently, there is no recognized IEEE or other accredited standard for GIC-withstand. From industry discussions, we understand that utilities purchasing new transformers typically specify GIC withstand of 25-40 amps for short durations. For example, one utility specifies GIC withstand of 25 amps for 15 minutes.*

What levels of GIC would be expected nationwide and in Maine during a severe solar storm? *According to modeling conducted by Metatech Corporation for the Oak Ridge National Laboratory, about 10% of EHV transformers nationwide would be subjected to 90 amps of GIC. Also according to Metatech, 45% of Maine EHV capacity would be subjected to 90 amps of GIC, although this analysis was based on a transmission line configuration that may have changed. It is not clear to us how the operating procedures of ISO-New England would protect Maine transformers under severe solar storm conditions and associated high amperages.*

Excluding industrial generators which consume nearly all of their production, approximately what percentage of electric power consumption in Maine is generated outside the state? *It is our understanding that approximately one-third of Maine power is imported and therefore Maine is highly dependent on the ISO-New England control area.*

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[1] Ramsis S. Girgis and Chung-Duck KO (April 1992), "CALCULATION TECHNIQUES AND RESULTS OF EFFECTS OF GIC CURRENTS AS APPLIED TO TWO LARGE POWER TRANSFORMERS," *IEEE Transactions on Power Delivery*, Vol. 7, No. 2

Could unplanned outages during a moderate or severe solar storm exceed allowances in ISO-New England generation and transmission planning and result in a blackout? *We present the below table of potentially affected resources during solar storms:*

Resource	***Capacity***
Chester Substation Static Var Compensator (SVC)	*2,700 MW*
*Phase II HDVC Tie**	*2,000 MW*
Seabrook Nuclear Power Plant	*1,247 MW*
Pilgrim Nuclear Power Plant	*685 MW*
Highgate HDVC Tie	*200 MW*
Millstone 2 Nuclear Power Plant	*869 MW*
Millstone 3 Nuclear Power Plant	*1,233 MW*
Vermont Yankee Nuclear Power Plant	*620 MW*

** 2,000 MW Phase II HVDC capacity also contained in Chester Substation SVC capacity.*

The Chester SVC supports 700 MW of imported power from Kenswick, New Brunswick to Orrington, Maine and another 2,000 MW of imported power on the Phase II HVDC tie, as explained by promotional literature of the vendor, ABB. It is our understanding that the Chester SVC has tripped during a previous solar storm. In addition, the Phase II HVDC tie may have tripped during a solar storm, the Seabrook nuclear power plant was downrated to 68% during a small solar storm on July 16, 2012, and that the Seabrook plant was brought entirely offline on November 10, 1998 due to GSU transformer failure after a solar storm. Moreover, we believe if ISO New England were to model its control area under geomagnetic disturbance conditions, the Chester Substation, the Sandy Point terminus of the Phase II HVDC tie, the Seabrook nuclear plant, and the Pilgrim nuclear plant would rank in the top 10% of GIC exposure for approximately 100 nodes in New England. Therefore, assuming only the Chester Substation, Phase II HVDC and Seabrook would be affected in a moderate solar storm, 3,947 MW of ISO-New England resources would be at risk. Were a severe solar storm to be forecast, the Nuclear Regulatory Commission might order the remaining New England nuclear plants to be shutdown, accounting for another 3,407 MW of generation resources.

Including 200 MW for the Highgate HVDC tie, we have a plausible estimate of 7,554 MW of resources at risk for unplanned outage during a severe solar storm. According to the ISO-New England document "ISO-NE 2013 Operable Capacity Analysis," the maximum allowance for unplanned outages is 3,600 MW and the minimum allowance is 2,100 MW, depending on the time of year. In summary, the resources at risk for unplanned outage during solar storms greatly exceed the capacity planning allowances for unplanned outage, even for a moderate solar storm, and could result in load shedding and blackout.

During a moderate or severe solar storm, would real-time emergency resources be sufficient to make up for contingencies? *It is our understanding that ISO-New England maintains 600 MW of real-time demand response reserve, and another 400 MW of real-time emergency generation reserve, for a total of 1,000 MW reserve. Solar storms are widespread phenomena and would simultaneously affect other neighboring control areas, making it less likely that ISO-New England reserves could be augmented by Emergency Energy Transactions. Based on past occurrences, the Chester Substation, Phase II HVDC tie, and Seabrook nuclear plants could be taken offline by even a moderate solar storm, accounting for 3,947 MW of generation and transmission, compared with only 1,000 MW of real time emergency reserves.*

What is the forecast accuracy and warning period for solar storms? *Day-ahead forecasts of solar storm intensity have accuracy significantly below 100% and a final warning time as little as 10 minutes.*

Would the onset of a solar storm, as indicated by the Chester Substation GIC monitor, provide enough time to implement procedures in "ISO New England Operating Procedure No. 4 - Action During A Capacity Deficiency," as elaborated in "Appendix A - Estimates of Additional Generation and Load Relief From System Wide Implementation of Actions in ISO New England Operating Procedure No. 4 - Action During a Capacity Deficiency Based on a 26,462 MW System Load"? *The capacity deficiency procedures for ISO-New England appear to be designed around slow moving shortfalls, such as those caused by heat waves or cold snaps. The procedures require phone calls and coordination with large industrial customers, generation facilities, the New York ISO, and individual retail consumers. The procedures even have provisions for television appeals for conservation by State Governors. For rapid onset solar storms, these measures simply would not work. During the moderate March 1989 solar storm, the Hydro-Quebec system collapsed in only 93 seconds. A repetition of the 1859 Carrington Event solar storm would be 5 to 10 times the severity of the March 1989 Quebec storm.*

In summary, the operating procedures of ISO-New England appear inadequate to prevent blackouts during solar storms. Loss of generation and transmission resources during even moderate solar storms could result in inadequate allowance for unplanned outages, inadequate real-time emergency reserves, and resulting electric grid blackout for the citizens of Maine.

Safety Issues at Nuclear Power Plants Due to Geomagnetic Disturbance

Do GSU transformers at nuclear power plants fail due to geomagnetic disturbance? *According to a document of the Nuclear Regulatory Commission, nine GSU transformers at U.S. nuclear plants failed in the aftermath of the March 1989 storm that hit Hydro-Quebec. Additionally, according to an official report of the North American Electric Reliability Corporation, a GSU transformer at the Salem nuclear plant in New Jersey failed during the March 1989 solar storm.*

Finally, as stated above, we believe that GSU transformers at Seabrook and Maine Yankee nuclear plants may have failed due to solar storms.

If a transformer fails at Seabrook or other nuclear power plant during a solar storm, could this cause a "reactor trip" and resulting nuclear safety issue? *Nuclear plants commonly experience reactor trips after unexpected transformer failures, some of which occur due to normal aging and stress. The problem has become so acute that the Nuclear Regulatory Commission released a special bulletin, "NRC INFORMATION NOTICE 2009-10: TRANSFORMER FAILURES—RECENT OPERATING EXPERIENCE." Reactor trips are a nuclear safety issue.*

Could transformers at nuclear power plants in New England be disproportionately affected by solar storms? *New England is at high latitude and rests on igneous rock formations. These characteristics make transformers at nuclear plants in New England more susceptible to GIC from solar storms.*

Do any design characteristics of transformers at nuclear power plants make them more vulnerable to damage from solar storms? *Nuclear plants commonly have single phase transformers, including significant numbers of "shell design" transformers. Both of these design characteristics make nuclear plant transformers more susceptible to GIC from solar storms.*

Do the locations of some New England nuclear plants make them more vulnerable to solar storms? *Coastal locations are more susceptible to GIC from solar storms. The Seabrook, Pilgrim, and Millstone nuclear plants are on the Atlantic Coast.*

What work has ISO-New England and nuclear plant operators done to assure that nuclear plants will remain connected to the grid during or in the aftermath of severe geomagnetic storms and to assure continual offsite power so that reactor cooling and spent pool fuel cooling can be adequately maintained*? As events at the Fukushima Daiichi nuclear plants amply showed, backup diesel generators do not always work; reactors and spent fuel pools without power can explode or catch fire.*

Transformer Failures Caused by Geomagnetic Disturbance Resulting in Long-Term Blackout

If a severe solar storm hits New England, such as the 1859 Carrington Event, could transformers overheat and fail, causing long-term blackout? *The report "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," produced by Oak Ridge National Laboratory for the Federal Energy Regulatory Commission in joint sponsorship with the Department of Energy and the Department of Homeland Security, showed that transformer failures and long-term blackouts are potential results of severe solar storms.*

How long would it take to replace failed transmission transformers? Are spare transformers commonly available for high voltage transmission lines or are these transformers of specialized design with spares requiring custom manufacture? *Replacement high voltage transformers take 1-2 years to manufacture because of their specialized design. Very limited spares are available. A U.S. Department of Energy report on this subject, "Large Power Transformers and the U.S. Electric Grid" (2012) can be found at:*

http://energy.gov/oe/downloads/large-power-transformers-and-us-electric-grid-report-june-2012

Ratepayer Costs Incurred Due to Geomagnetic Disturbance

Do State of Maine utilities incur extra costs due to altered generator settings, uneconomic dispatch, or reduced transmission line loading during solar storms? Who pays these extra costs, the utilities or the ratepayers? *A recently published paper by Kevin Forbes & O.C. St Cyr of Catholic University and NASA*[2] *showed a relationship between off-cost economic dispatch of power in the PJM market and minor solar storms. Central Maine Power testified that solar storms occur several times each month, so transmission line congestion and uneconomic dispatch may be substantial for the citizens of Maine. Ultimately, ratepayers bear the burden, through increased regulated rates or increased prices in the competitive power market.*

Hardware Protective Devices for Geomagnetic Disturbance

Are there hardware protective devices that could be installed by Central Maine Power and Bangor Hydro that would protect transformers and other equipment from damage and tripping during solar storms? *Hardware protective devices include series capacitors and neutral current blocking devices. These devices are available from commercial vendors.*

Could hardware protective devices better protect the citizens of Maine than "operating procedures"? *Operating procedures are designed mostly to bolster reactive power reserves. Operating procedures are likely to be overwhelmed by severe solar storms. Moreover, operating procedures do not reduce the GIC flows that cause transformer heating and harmonic production, two of the most serious geomagnetic disturbance effects.*

How much do neutral blocking devices cost? *According to Emprimus, a vendor of neutral blocking devices, a set of devices for a transformer neutral would cost approximately $250,000 to $300,000.*

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[2] Kevin Forbes & O.C. St Cyr (2012), "Did geomagnetic activity challenge electric power reliability during solar cycle 23? Evidence from the PJM regional transmission organization in North America," *SPACE WEATHER: THE INTERNATIONAL JOURNAL OF RESEARCH AND APPLICATIONS,* VOL. 10, S05001, 14 PP., 2012

What would be the additional charge per ratepayer per year to use hardware protective devices for vulnerable transformers? *According to a study by the Oak Ridge National Laboratory, "Electromagnetic Pulse: Effects on the U.S. Power Grid," the cost of installing neutral blocking devices would be approximately 20 cents per ratepayer, per year. According to a study recently presented to the GMD Task Force of the North American Electric Reliability Corporation by the Foundation for Resilient Societies, the cost of installing neutral blocking devices would be approximately 50 cents per U.S resident, per year.*

Could hardware protective devices save utilities and ratepayers money? *According to a study recently presented to the GMD Task Force of the North American Electric Reliability Corporation by the Foundation for Resilient Societies, the benefits of installing neutral blocking devices would exceed the costs, even using an optimistic blackout scenario.*

Conclusion

We encourage the Maine legislature to inquire as to the types and cost-effectiveness of hardware protective equipment that Maine electric utilities have considered or are now considering to protect critical electric grid infrastructure against solar geomagnetic disturbances. Hardware protective equipment specified during the planning stage for new transmission lines, such as the Maine Power Reliability Program for Central Maine Power, would be more cost-effective than retrofits.

Past experience amply shows that solar storms are a clear and present danger to the Maine electric grid and to the citizens of Maine. Electric utilities need to be asked tough questions and to give clear and forthright answers on the public record. The Committee has within its power to shed light on solar storm hazards that have been hidden from public view for far too long.

We testify neither for nor against the Act, but only to offer additional information and to highlight research findings. Thank you for the opportunity to suggest questions pertinent to the reliability of electric power in the State of Maine, and for the opportunity to present our research.

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