Federal Energy Regulatory Commission

Geomagnetic Disturbance Technical Conference

Written Comments by

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Significant Deficiencies in the Draft NERC TPL – 007 Standard

A. Intentionally letting the grid collapse and attempting to restart it.

1. **This proposition has been used anecdotally in recognition that proposed TPL-007 cannot prevent a system wide blackout for a Carrington type event. This is an acknowledgement that the grid is susceptible** for such events and is further coupled with the assumption that the grid will collapse quickly and will cause minimal or no damage to the system.

2. **This proposition implies there is no type of meaningful system remediation**, and therefore can be linked to performance of only procedural actions during a geo-magnetic Disturbance (GMD) event. Grid studies have demonstrated that present procedural actions, which are not implemented until the onset of the GMD event, are ineffective to keep the grid stable [1].

3. FERC Docket no. RMI-22-000 has directed NERC, during the second phase of the GMD Standard development, to develop a standard which prevents the loss of the power grid. The present draft NERC GMD standard does not meet this FERC directive.

4. **For a Carrington level GMD event [2] which is known to last 10 or more days, this translates into the North American Grid (or major section of the grid) being out of service for many days because the grid is fragile and will collapse quickly**! **Is a many day outage with equipment damage acceptable to FERC, DOE, DHS, NRC, and DOD for national security and public health and welfare in today's society?** Utilities favoring a much smaller Benchmark GMD event will suggest that a solar storm will only last a few hours, not 10 days, and therefore the outage will be short.

5. **During recorded GMD events less than one tenth the size of a Carrington GMD event**, the grid went down in 92 seconds, yet damaged a large transformer at the Salem Nuclear plant, and in Canada and South Africa multiple transformers were damaged [3, 4]. And recently Dr. Luis Marti published a paper that shows generator rotor damage may occur when a GMD event results in GSU transformer GIC currents which exceed 50 Amps per phase [5]. Power flow modeling of the grid which includes geo-magnetic disturbances show there will be many locations of GIC in excess of 50 Amps per phase [1]. This means for a Carrington level event, the recovery from a grid outage will be more difficult and protracted due to equipment damage.

6. **Two insurance studies (Zurich, NOAA and Lockheed Martin) in 2014 and 2015** correlated billions of dollars of annual damage suffered by customers from the harmonics generated in the grid from even low level solar storms (GMDs) [6,7]. The proposition of no remediation, and allowing the grid to collapse, completely ignores and does nothing to prevent the costly damage that is already occurring every year on the grid.

B. Recorded data shows NERC GMD Benchmark Standard latitude adjustment factor understates the electric field by more than 95 percent middle and lower latitudes :

The latitude adjustment factor which lowers the geo-electric field strength for geo-magnetic latitudes below 60 degrees is flawed for several reasons.

1. First it is based on the assumption that the electro-jets for a one in one hundred year will be centered over northern Canada just like every day moderate solar storms. There is clear evidence that that will not be the case when the next extreme (one in one hundred year) storm hits again. The recorded experience shows that the extreme storms are typically centered at much lower latitudes (i.e. possibly below a 40 degree magnetic latitude) [11].

2. Additionally, a recently published paper shows recorded data at a geo-magnetic latitude of 12.7 degrees in China experienced a geo-electric field strength which was twenty two (22) times (i.e. 2,200%) larger than that which is predicted by the draft NERC GMD standard for an extreme event [12]. Therefore, the latitude adjustment needs to be re-evaluated and revised significantly in order to be consistent with actual recorded data.

3. Furthermore, magnetometers in Bombay India, at a 10 degree geo-magnetic latitude, recorded a large change in Earth's magnetic field (about 1,700 nano-Tesla) during the Carrington GMD event of 1859 [23]. This again indicates that the latitude adjustment factor in the NERC GMD standard is not appropriate nor accurate for an extreme Carrington GMD event.

C. Recorded data shows NERC Benchmark model understates "hot spot size" by a multiple factor of 28 and the NERC Benchmark model which applies Spatial Averaging is invalid

Actual data from India shows a simultaneous peak covering a distance of 2800 Km. This invalidates the assumption of a 100 Km "hot spot" and the entire theory of using spatial averaging to model solar storms. Spatial averaging becomes invalid with such a large area experiencing a simultaneous peak. The NERC assumptions are based upon data from lower level solar storms. This actual data shown in Appendix A from India comes from a latitude of 10 degrees north of the magnetic equator, and so is even more powerful as compared to the NERC formula.

Additionally, the spatial averaging approach applied to the calculation of the geo-electric field is based on assumptions which cannot be justified based on recorded data nor on the physics of GMD induced electro-jets.

1. First of all extreme CMEs ejected from the sun are many thousands (10,000 to 20,000) of times larger than the diameter of the Earth [8].

2. Electro-jets associated with everyday solar storms are known to have very large horizontal dimensions on the order of 500 km to over 1,500 km. The induced geo-electric fields at the Earth surface will likewise cover large areas (i.e. larger than 500 km by 500 km) [9]. Therefore the spatial averaging approached assumed in the NERC GMD standard development is not appropriate. This spatial averaging concept cannot be justified for every day solar storm events and therefore it cannot be justified for a much larger extreme solar storm event.

3. A paper published by R. G. Rastogi in 1999 (See Appendix A) describes the on solar storm effects of a solar storm at multiple observatories at low latitudes. The recordings span a distance of 31 °N, or a linear distance of 1800 miles (2880 km). The graph (2a) shows that the H field disturbance is uniform and occurs almost simultaneously at all stations, which strongly argues against a hot spot of only 100 km [24].

D. NERC Benchmark Standard Completely Ignores Coastal GMD Multiplier

1. The NERC GMD Benchmark Standard does not include a coastal multiplier factor for the geo-electric field. This multiplier can easily be two or as high as 7. This enhancement factor was presented in several NERC GMD task force meetings and has been published in several papers by leading GMD scientists [23, 24].

2. This enhancement factor is important for several reasons. First of all this enhancement factor can range from a multiplier of two (2) to seven (7) depending on specific parameters and conditions [23, 24].

3. And secondly this is an important factor since a large portion of our eastern population resides along our Atlantic and Pacific coastline.

E. The NERC Benchmark Standard completely fails to address harmonics in any meaningful way and fails to address the FERC wholesale contract requirement that power delivered should not Exceed IEEE 519 Harmonic Standard for Low and high Level Solar Storms:

The GMD standard should require an analysis of potentially harmful GIC induced harmonic generation.

1. A recent EPRI paper by R. Walling (See Appendix B) clearly shows that large harmonic components are generated at even low GIC current levels (i.e. 10 Amps of GIC neutral current) in HV and EHV power transformers [19]. Measurements performed at the Idaho National Laboratories (INL) in 2012 show high harmonic levels when a simulated GIC DC current was injected into a power transformer (See Appendix B) [19, 20]. These harmonic levels are significantly above the IEEE 519 Harmonic standard.

2. Furthermore, a published paper finds a correlation between several billions of dollars of insurance claims annually for equipment damage that can be attributed to GIC induced harmonics in the North American power grid [6]. Therefore a harmonic analysis should be a requirement and included in the NERC GMD standard. And the NERC GMD standard should require that generation interconnection agreements adhere to the IEEE 519 standard.

3. Since 2003, FERC has had a pro-forma Large Generation Interconnection Agreement (LGIA) used to define the relationship between the Generator and Transmission Owners. Section 9.7.6 of the LGIA defines the obligation that neither Transmission Owner nor the Generation Owner shall not cause voltage distortion at the point of interconnection that exceed IEEE 519 standard, the industry accepted harmonic standard. The Idaho National Lab transformer tests demonstrated that as little as 10 amps in the neutral can cause the transformer to generate harmonics that exceed IEEE 519 standard, the industry accepted standard. EPRI analysis also confirmed this. Based on the INL tests any Generator Step-up Transformer (GSU) or nearby Transmission transformer that have 10 amps of greater neutral GIC, they will be violating their Interconnection Agreement.

F. NERC Benchmark standard completely ignores likelihood of and criteria for Generator Rotor Damage.

Additional criteria for studying the potential for generator rotor damage should be added to the draft NERC GMD Standard.

1. A recently published paper by Dr. L. Marti shows that generator rotor damage by GIC induced harmonics can be expected at GIC currents of 50 Amps per phase [5].

2. An earlier IEEE paper by Gish et.al. concluded "Damage to a generator rotor is possible from GIC activity." Discussion by Walling states "This paper describes a potentially grave consequence of GIC that is under-appreciated by the industry. Although GIC-related damage of generators has not been documented, our analyses lead us to concur with the authors that stator current harmonics during severe geomagnetic disturbances can lead to rotor heating duty more severe than caused by operating at the maximum fundamental-frequency negative-sequence current imbalance as defined by ANSI" [17].

G. Evidence of Numerous GMD Peak Field Reversals has been Ignored:

There is also evidence that there are a large number of reversals of the electric field from a positive field to a negative field and vice versa. This reversal will change the direction of the GIC flow into and out of the transformer. Regardless of the direction of GIC the excessive transformer MVAR losses are always positive. There are at least 10 transitions from 50% positive field to 50% negative field in a minute or less the NERC Benchmark waveform[10]. There are many more if considering a longer period between the peak conditions.

When the electric field transitions through zero there is zero GIC thus zero excessive transformer MVAR losses. The voltage collapse from excessive MVAR losses may be arrested by switching shunt reactive devices (capacitors). When the electric field transitions through zero, the transmission voltage will, in most cases, enter into the emergency range due the capacitors still in service and the absence of the excessive transformer MVAR losses. If this high voltage does not damage any of the capacitors, most of the capacitors should switch out due to the high voltage. This should return the voltage to the normal range.

The problem is most switchable capacitors have a 5 minute timer preventing re-insertion. Preventing re-insertion is necessary to allow any trap charges on the capacitor to drain off and prevent damage on re-insertion, a common design. So when the field transitions through zero to a subsequent peak, any capacitor previously in service will not be available to arrest the next voltage collapse risk. Under a Carrington type event, that will be hundreds of electric field transitions. The first risk of voltage collapse may be arrested with capacitors, but every subsequent peak is at risk of voltage collapse based on capacitor unavailability.

To protect Bulk Electric System reliability GMD must be studied operationally over an extend period of time to account for the electric field transitions the determine the ability to prevent voltage collapse for each transition.

H. NERC GMD Benchmark Standard Storm duration period 8 times shorter than actual record data:

The selection of solar storm duration of only thirty two (32) hours for a one in one hundred year event is far shorter than that recorded and experienced during the 1859 Carrington storm. The storm data for the 1859 event shows the storm impacted the Earth with three CMEs which started on August 27th and lasted until September 6th, a total of ten (10) days or a duration of 240 hours not 32 hours. This change represents a significantly large period for which the power grid transformers and generators will be under stress when an extreme storm hits again.

I. GMD Standard Lacks a Factor of Safety

1. Normal Engineering practices usually apply a factor of safety especially when human safety is a concern. In this case the Drafting Team has ignored the need for a factor of safety.

2. A typical safety factor used in by the electrical power industry typically varies from a multiplier in the range from 2 to 4. Therefore, a safety of factor in this range should be applied to the anticipated geo-electric field for an extreme geo-magnetic (GMD) impact.

J. Flawed Approach for Developing the NERC GMD Standard:

1. **The approach used by the NERC Standard drafting team does not address the real and potentially devastating impact of a future extreme geomagnetic disturbance (GMD) event.**
   NERC's approach is based on a short sighted engineering approach, using inappropriate and limited recorded data, to a multi-disciplinary issue which could cause extremely catastrophic consequences.

2. The approach used to develop the Standard is based only on recorded data from the late 1980's which does not include any of the major and extreme coronal mass ejection (CME) or GMD events that are known in our history before power grid were developed [10]. The real issue that the standard should address is the extreme events such as the 1859 Carrington, 1921 NY Railway storms (GMDs) and also the July 2012 CME (which missed the Earth) [8] which could result in prolonged power outages and the subsequent lack of water, food, fuel, and medical supplies. The development approach selected therefore neglects the real issue that should be addressed; namely, a standard which is aimed at protection against the largest GMDs/ CMEs that are known to mankind. NERC's approach is flawed since it clearly ignores and side steps the real issue which potentially could be a super catastrophe and a loss of thousands if not millions of lives.

K. NERC's Probability of the Next Extreme GMD Event Ignores Three Published Papers:

1. The NERC GMD standard states that the probability of an extreme Carrington event is a one (1) in 70 to 600 year event based on a paper published by one author [10]. This statement needs to be modified significantly since there are three other independent published papers that conclude an extreme Carrington event has a one in two (1 in 2 or a 50%) chance of impacting the Earth within the next fifty (50) years [13,14,15]. Without this clarification the GMD standard minimizes the chances that we will experience an extreme storm again in lifetimes. However, the findings, of the other totally independent scientists which have been ignored, show that solar storm phenomena truly needs to be taken seriously.

L. NERC GMD Standard Procedures are Ineffective for Moderate and Extreme GMD Events:

The NERC operating procedures to mitigate the consequences of large GIC currents are flawed for several reasons.

1. First, the initial coronal mass ejection (CME) from an extreme solar flare travels away from the sun at greater than five (5) million miles per hour. The initial impact can be described as a Solar Tsunami when it impacts the Earth. As a result there are no initial low level indications in the power grid of the impact until the frontal CME wave hits the Earth. The only warning that the CME is imminent are the NOAA satellite warnings which give the ISO and utility teams about a 5 – 10 minutes warning before impact [18].

2. For example, on March 17, 2015 a solar storm impacted the earth at 7:00 AM EST. A warning of this storm was not issued by NOAA until 7:49 AM or 49 minutes after the impact. And a second example is the warning for the solar storm in June of 2015. NOAA satellites detected this storm at 1:15 PM on June 22nd and broadcasted a warning to the ISO's. The Midwest ISO (MISO) then sent out a warning to the utilities at 1:30 PM which was only 4 minutes before the storm impacted the Earth at 1:34 PM. This is clear evidence that operators will not have enough advanced warning time to allow readjustments of generation and transmission in an attempt to mitigate the system against a large geomagnetic disturbance (GMD). It should be noted that most ISO procedures are not implemented until the onset of the GMD event.

    a. Numerous recordings of GMD impacts show that the first impact is usually the largest. However, in some cases multiple CMEs have been observed during a prolonged GMD event in which several large impacts have been recorded over multiple days. In fact, the Carrington event consisted of three CMEs that occurred over a twelve (12) day period.

b. The size of an extreme CME is has been shown to be much larger than the Earth. Extreme CME data recorded in July of 2012 by NOAA, for a storm that missed the Earth, clearly shows that an extreme CME can be 10,000 times or larger than Earths diameter [8].

c. Power World modeling of the Maine power grid (See appendix D)clearly shows that the NERC prescribed operating procedure to combat the reactive demand caused by geo-magnetically induced currents (GICs) does **not** reduce the reactive power demand and does **not** prevent voltage collapse of the grid [1].

M. GMD Standard does not Mention an Option for Installing a Hardware Mitigation Solution:

The draft NERC GMD standard does not mention nor consider the option of installing a GIC mitigation hardware solution. Several such effective solutions have been demonstrated, fully tested and are operational in several locations both in the USA and Canada. For example, the Quebec power grid implemented a series capacitor mitigation after experiencing a GMD blackout in March of 1989. However, these solutions are not mentioned nor suggested by this draft GMD standard.

N. Criteria for Transformer Thermal Modeling:

The Transformer thermal model criteria are not based on engineering data.

1. The criteria for completing a thermal analysis of a transformer is stated as 75 Amps per phase, for which there is no basis. These criteria should clearly be much lower, as data indicates that transformers have been damaged at levels at or below 15 Amps per phase [416].

2. The first draft GMD standard applied the more appropriate 15 Amps per phase for this criteria for utilities to perform a transformer thermal analysis. However, the utilities would not agree nor approve the standard because of this criteria. So the drafting team was urged to increase this parameter to get approval by the utilities.

O. GMD Standard does not Require System Studies at Peak Geo-Electric Field conditions:

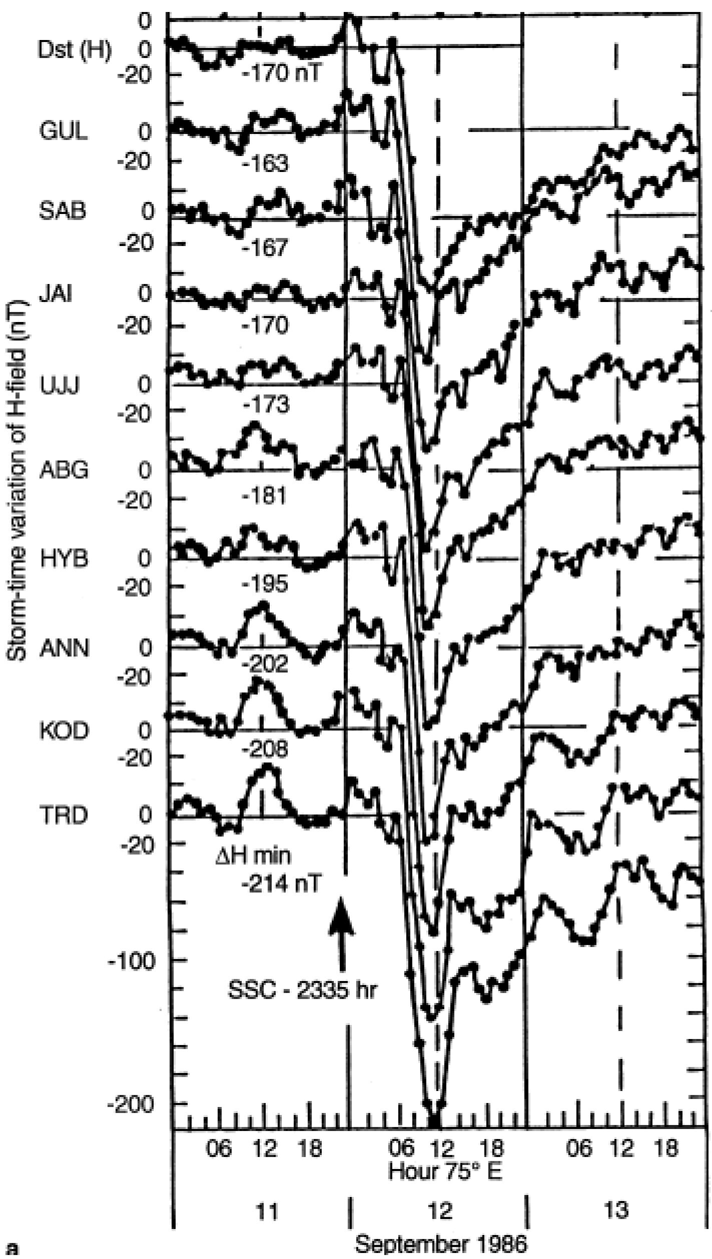
1. The draft NERC GMD standard does not require system GMD studies at peak electric field conditions, such that the most vulnerable generation and transmission sub-

stations can be identified. The power flow modeling offered by several suppliers now includes GIC modules that provides this important capability. The knowledge provided by such studies will be important for determining which transformers and generators should be considered for active protection.

2. Additionally GMD power flow studies are also useful to determine substations which are hot spots for GIC currents. For example, recorded data at the Chester substation in Maine shows that large GIC currents can be expected for moderate level storms. And when extrapolated to an extreme level GMD event, alarmingly high GIC currents of over 1,000 amps can be expected. These results are shown in Appendix C.

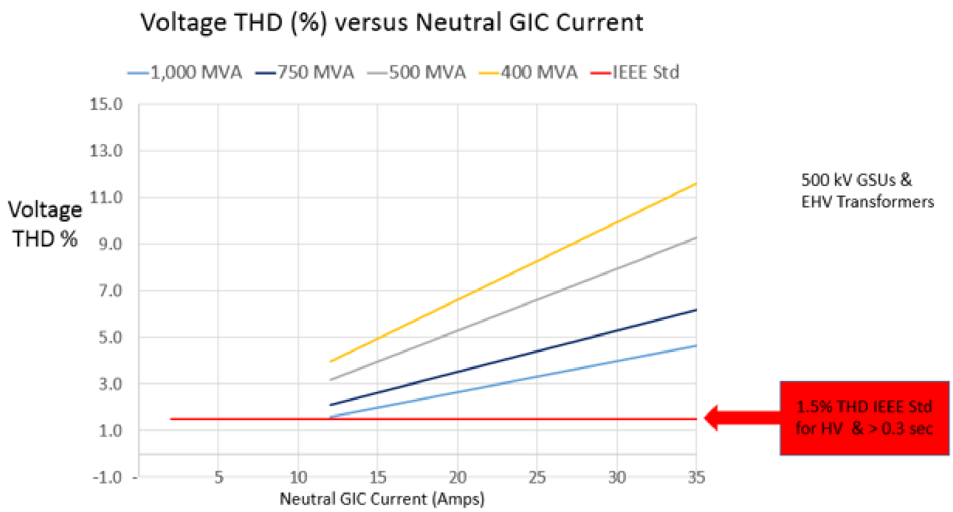
Appendix A:

Geomagnetic storm effects at low latitudes
R. G. Rastogi
Ann. Geophysicae 17, 438 - 441, 1999

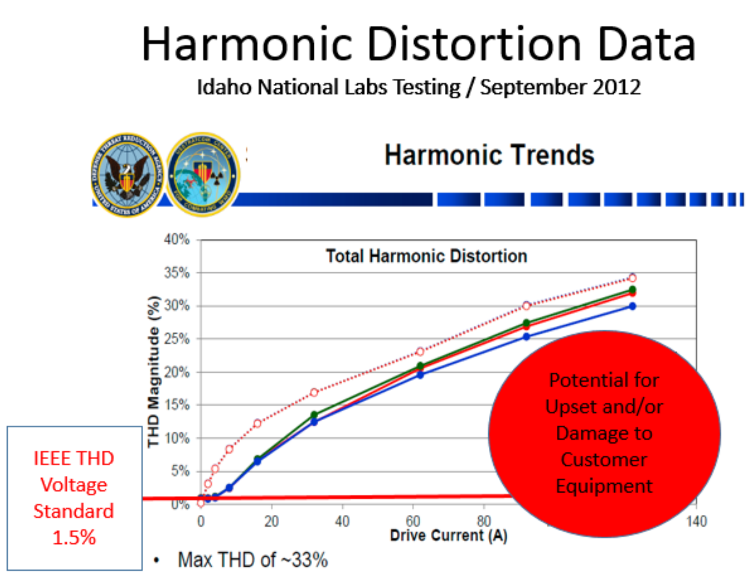


Appendix B:

R. Walling, EPRI Report

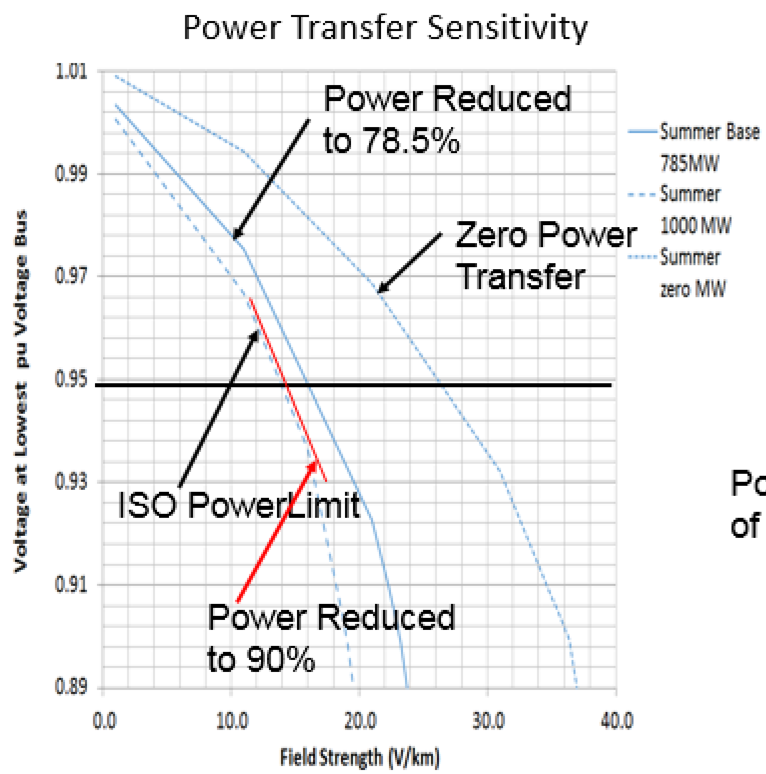


Department of Home Land Security (DHS) Testing at Idaho National Laboratories 2012



Appendix C:

NERC GMD Mitigation Procedures do not Reduce Reactive Power Demand and do not Protect System from Voltage Collapse



Power World Modeling of Maine Grid

Appendix D:

Chester Substation Data and Projection for an Extreme Storm

Chester Maine Geo-magnetically Induced Currents (GIC) Storm Data

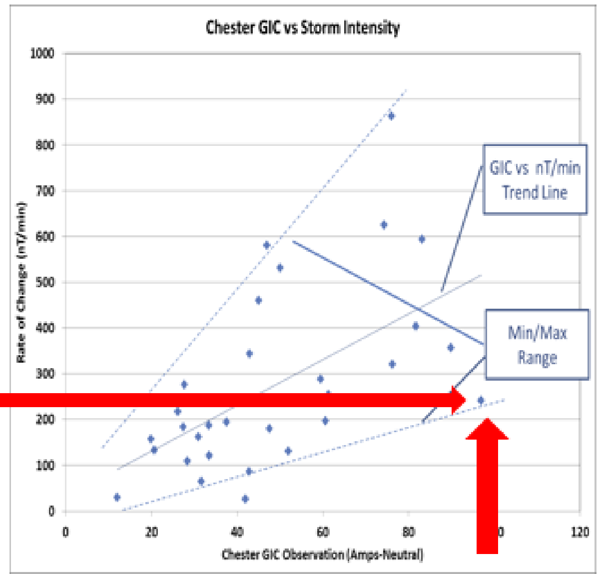
Linear Projection to 100 Year Storm (5,000 nT/min) gives neutral GIC current of:

Minimum = 500 Amps

Mean = 1,000 Amps

Max = 2,000 Amps

250 nT/min



~ 100 Amperes

Data taken from EIS submission to Maine PUC, Oct 4, 2013

Very Large GIC currents are consistent with Power World modeling of the Maine and Wisconsin power grids and a recent EPRI paper by R. Walling

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