Meeting Notes
Project 2013-03 Geomagnetic Disturbance Mitigation Standard Drafting Team Meeting

January 17, 2017 | noon - 5:00 p.m. Eastern
January 18, 2017 | 8:30 a.m. - 5:00 p.m. Eastern
January 19, 2017 | 8:30 a.m. - noon Eastern

NextEra
Juno Beach, FL

Webex Meeting Number 731 660 682

Administrative

1. **Introductions**
   The meeting was brought to order by the Chair at noon Eastern on January 17, 2017. Jow Ortiz, NextEra Energy, provided the team with building and safety information/logistics. Participants were introduced and those in attendance were:

First Name	Last Name	Company	Member/ Observer	In-person (Y/N)	Webex
Scott	Barfield-McGinnis	NERC	O	Y	
Emanuel	Bernabeu	PJM Interconnection LLC	M	Y	
Ken	Fleischer	Fleischer Consultants	O	Y	
Louis	Gibson	Hydro-Quebec	M	Y	
Ian	Grant	TVA	O	Y	
Justin	Kelly	FERC	O	Y	
Philip	Kleckley	South Carolina Electric & Gas	O	Y	
Ruth	Kloecker	ITC Holdings	O	Y	

First Name	Last Name	Company	Member/ Observer	In-person (Y/N)	Webex
Frank	Koza	PJM Interconnection LLC	M	Y	
Per-Anders	Lof	National Grid	M	Y	
Luis	Marti	Hydro One	M	Y	
Mark	Olson	NERC	O	Y	
Jow	Ortiz	FPL	M	Y	
Ralph	Painter	Tampa Electric Co.	M	Y	
Lauren	Perotti	NERC	O	Y	
Antti	Pulkkinen	NASA Goddard	M	Y	
Qun	Qiu	AEP	M	Y	
Mike	Steckelberg	Great River Energy	M	Y	
Rui	Sun	Dominion Virginia Power	M	Y	
Christopher	Szmodis	PPL Electric Utilities	O	Y	
Berhanu	Tesema	Bonneville Power Administration	M	Y	
Guy V.	Zito	Northeast Power Coordinating Council "NPCC"	O	Y	
Various Web Participants (See attached)					

2. Determination of Quorum

The rule for NERC Standard Drafting Team (SDT or team) states that a quorum requires two-thirds of the voting members of the SDT. Quorum was achieved as 12 of 13 members were present.

3. **NERC Antitrust Compliance Guidelines and Public Announcement**

   NERC Antitrust Compliance Guidelines and public announcement were reviewed by Mark Olson. There were no questions raised.

4. **FERC Order No. 830 and the project Standards Authorization Request (SAR) was reviewed by Mark Olson.** Participants discussed each directive in the SAR. The SDT agreed that the SAR covered the Order No. 830 directives for revising TPL-007. **The SDT will consider all comments submitted on the SAR at a future SDT meeting following the end of the informal comment period (ending January 20, 2017).**

5. **An overview of TPL-007-1 and Benchmark GMD Event was presented by Luis Marti.**

   a. Background, considerations, and the rationale for spatial averaging and scaling factors was discussed. Antti Pulkkinen stated that no significant new research into spatial averaging has been completed for consideration by the SDT. Ground conductivity data is being collected and analyzed by researchers. Some utilities may be able to use this data to obtain improved ground models however new models to replace the one-dimensional defaults used in the standard are not available. Mark Olson stated that NERC has included spatial averaging, latitude scaling, and earth conductivity model and coastal effect research in its Order No. 830 proposed research plan.

   b. Participants reviewed the GMD Vulnerability Assessment process including various studies and considerations that are taken into account. Participants discussed approaches to conducting transformer thermal impact assessments described in the thermal impact assessment white paper. They discussed IEEE Std C57.163 and the parameters of the GIC signature that must be considered to perform a transformer thermal impact assessment for the benchmark GMD event as required by approved TPL-007-1.

6. **Discuss approaches to revise Benchmark GMD Event so that it is not solely based on spatial averaging (Order No. 830 P 44-47)**

   a. Participants discussed approaches to meet the directive.

      i. Participants considered **using a non-spatially averaged geoelectric field value** (e.g. 20 V/km from the 2012 GMD report or the 16 V/km from the 2015 Los Alamos National Labs white paper) over an entire planning area. Participants agreed that this is excessively pessimistic in light of data. Louis Gibson (HQ) stated that such a pessimistic benchmark negatively impacts entities with very large planning areas, and that in actuality the impact of local enhancements is distributed over the large area. **The SDT is not currently developing a requirement to implement this approach.**

      ii. Participants considered **providing further justification in support of spatial averaging to FERC**. The SDT agreed that new information was not available that had not been considered in TPL-007-1 NOPR commenting and the FERC technical conference. Mark Olson stated that the deadline in Order No. 830 for revising TPL-007 is not conducive to performing and applying new research to this revision of the standard. However the proposed NERC GMD research plan includes this type of research, and outcomes could drive future changes to the standard. **The SDT is not actively working toward this approach.**

iii. Participants discussed **modeling local geoelectric field enhancements**. Antti Pulkkinen presented plots of geoelectric fields from published papers depicting spatial scales of enhancements. He stated that enhancements could be generally represented as a 300 km X 100 km rectangle oriented east-west. Data suggests that enhancement durations are in the range of 2 to 5 minutes. The SDT agreed that tools are not available to perform GIC analysis with a moving geoelectric field enhancement box. **The SDT will consider how the approach could be implemented in future meetings.**

iv. Participants discussed requiring entities to assess the system to determine the highest geoelectric field that can be withstood without voltage collapse **(breaking point)** as alternative to meet the directive. SDT agreed that the approach could be challenging to implement for thermal impact assessments. **The SDT did not reject the approach but is not actively following up.**

v. The SDT discussed developing a **benchmark geomagnetic waveshape with a localized enhancement**. The enhancement would be based on data. **The SDT agreed to continue to analyze and develop this approach.**

b. Participants discussed how assessments with localized enhancements should be incorporated into the standard.

i. First option considered involves using the localized enhancement for **thermal impact assessment only**. Load flow studies would be based on the approved (spatially averaged) peak of 8 v/km only and no additional load flow study would be required. The option could be implemented by modifying approved R6 (thermal impact assessment) to require the enhanced study. **The SDT agreed that the approach may not meet the directive without further analysis and justification**.

ii. Second option considered is to **add requirements for entities to conduct a localized enhancement event scenario** in addition to the approved benchmark and GMD VA. When performance issues are identified, the entity would be required to consider mitigation options but not necessarily include them in a Corrective Action Plan (CAP), in the same way that extreme events are handled in TPL-001-4. The assessment would include:

1. Voltage study that accounts for localized enhancement to a specified peak geoelectric field
    a. example: enhanced box, sectionalized assessment, wide area
2. Thermal assessment
    a. On transformers identified by a new criterion (xx A/phase) determined from analysis of thermal models using enhanced signature

i. The SDT discussed developing screening criteria based on transformer core construction and transformer type. Technically justified thermal models would be needed to support such criteria. **Jow Ortiz will research availability of additional modeling information that could be used to develop criteria and discuss with the SDT at a future SDT meeting.**

b. use GIC based on local enhancement

i. SDT develop an enhanced signature (with localized peak)

ii. Multiplier for peaks for a certain duration (factor of ~2)

iii. Duration on order of 3-5 min?

iv. Generally east-west

iii. The SDT agreed to continue to develop the second option by examining data to develop a potential enhanced geomagnetic waveshape; and begin analyzing thermal response on the available transformer thermal models. Luis Marti, Emanuel Bernabeu, and Antti Pulkinnen will initiate the effort.

iv. Frank Koza, Pers-Anders Lof, and Mark Olson will develop draft requirements to implement the second option for discussion at the next SDT meeting.

7. **Discuss approaches to new requirement(s) for GIC and magnetometer data collection (Order No. 830 P 88 - 92).** Participants discussed technical and practical issues associated with the directive including entity responsibilities, thresholds for collection, technical criteria, use of GIC and magnetometer data. Some participants suggested that the requirements would be better placed in a different standard such as EOP-010. Emanual Bernabeu and Luis Marti discussed how data can be used to validate ground conductivity models, but it is very challenging. **Frank Koza, Pers-Anders Lof, and Mark Olson will develop draft requirements for discussion at the next SDT meeting.**

8. **Discuss revising TPL-007 Requirement R7 to establish deadlines for Corrective Action Plans and mitigation measures (Order No. 830 P 101 - 103). Frank Koza, Pers-Anders Lof, and Mark Olson will develop draft requirements for discussion at the next SDT meeting.**

9. **Future meeting(s)**

   a. The SDT agreed to meet February 27 - March 1, 2017. Mark Olson will propose a meeting location and coordinate by email.

   b. A conference call will be coordinated for February to discuss progress on action items.

10. The meeting adjourned at 10:15 am eastern on January 19, 2017

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GMD Planning Standard

Overview of TPL-007-1 for SDT

January 2017

RELIABILITY | ACCOUNTABILITY




GMD Planning Standard

- TPL-007-1 addresses risks of voltage collapse and equipment damage in the Bulk Electric System (BES) caused by GMD events

- Entities involved:
  - Planning Coordinators and Transmission Planners
  - Transmission Owners
  - Generator Owners

GMD Planning Standard

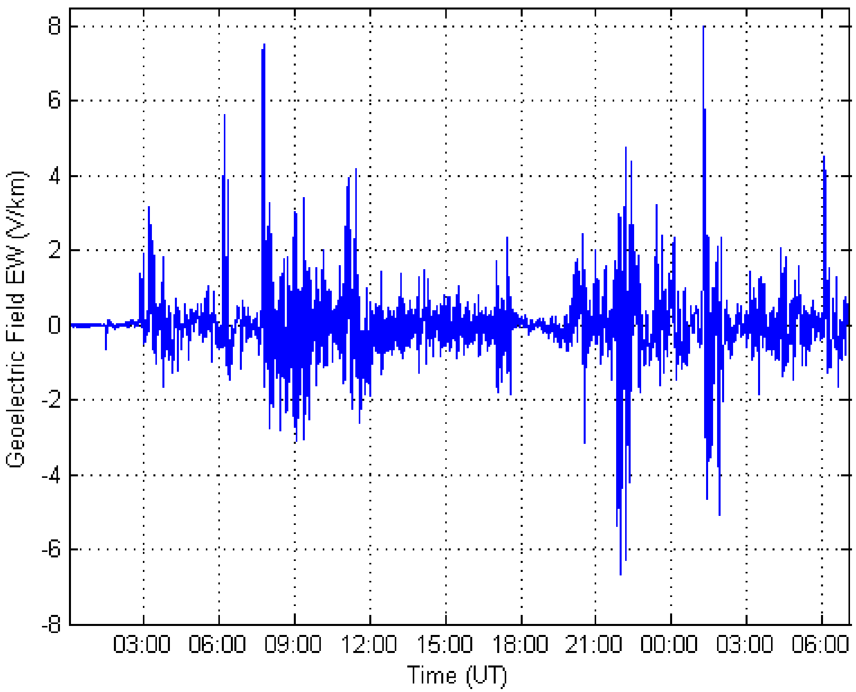
- Components of TPL-007-1
  - Benchmark GMD event
  - GMD Vulnerability Assessment
  - Corrective Action Plan (CAP)

Defining the Benchmark—what was done

- Space weather:
  - K-index, Dst index, nT/min, etc
  - Power Systems: Geoelectric Field
- Objective: characterize the occurrence rates of geoelectric field
- The SDT considered the following key characteristics of the extreme geoelectric fields:
  - Amplitude
  - Spatial structure: directionality and appropriate spatial scale lengths
  - Temporal waveform
- NERC interim report 2012:
  - Localized peak geo-electric field ⟶ wide area geo-electric field
  - Same data source: 1993-2012 IMAGE 10-sec resolution

Benchmark GMD Event

- Assessments are based on a severe 1-in-100 year GMD event. Two components for analysis:
  - **Magnitude of 8 V/km scaled to the entity's planning area**
  - Wave shape for assessing transformer hot-spot heating



Source: NERC Benchmark GMD Event Description, May 2016

Why 8 V/km

Statistical occurrence of extreme geoelectric field amplitudes is characterized considering spatial scales:

- Same data source as NERC interim report.
- Spatially local geoelectric field enhancements do not characterize wide area effects.
  - Localized peak 20 V/km
  - Wide area averages of 8 V/km.

White paper includes SDT's analysis of:

- Localized geomagnetic activity on a representative system
- Reference storm wave shape comparison

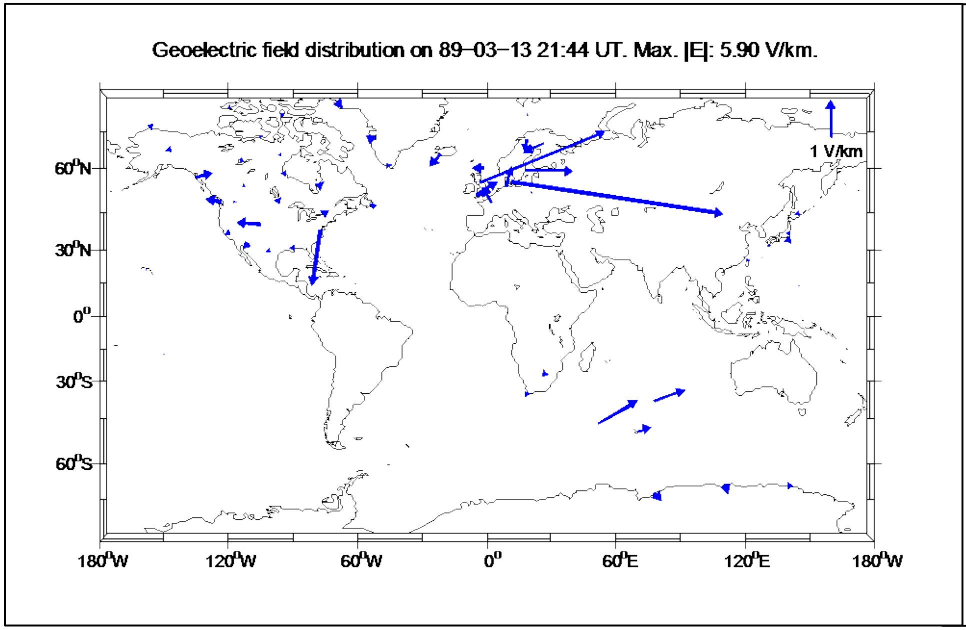
Geoelectric Fields

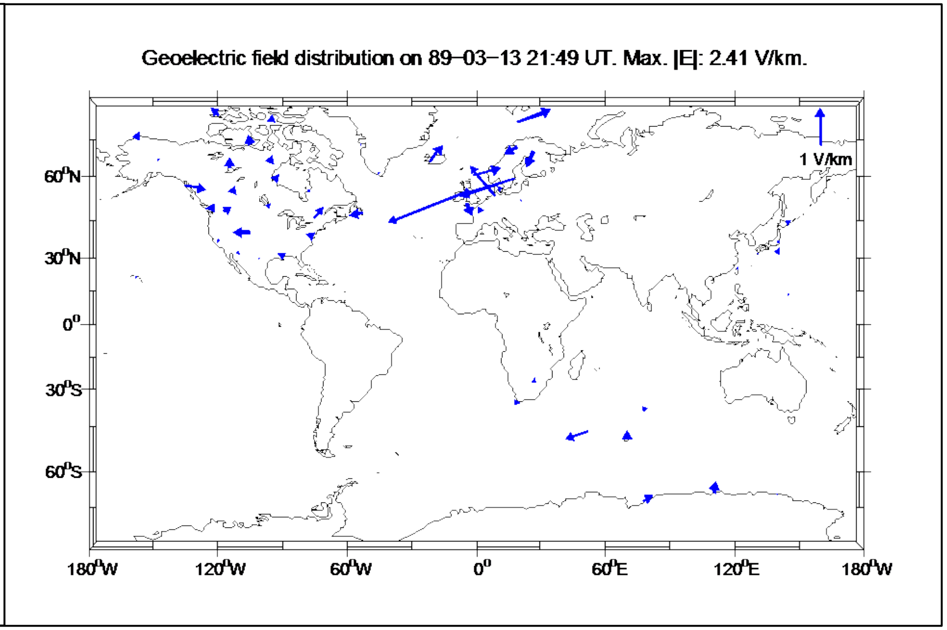
Key Insight:

- Engineers utilize uniform geoelectric fields across hundreds of kilometers

"Local enhancement" of the Geoelectric Field.

1989 GMD Storm





Spatial Averaging

- Storm-time geoelectric fields are spatially complex which can bias statistical analysis
  - Localized e-field enhancements occur in small (~100 km) regions
- Benchmark analysis examined spatially-averaged data to address wide-area GMD effects

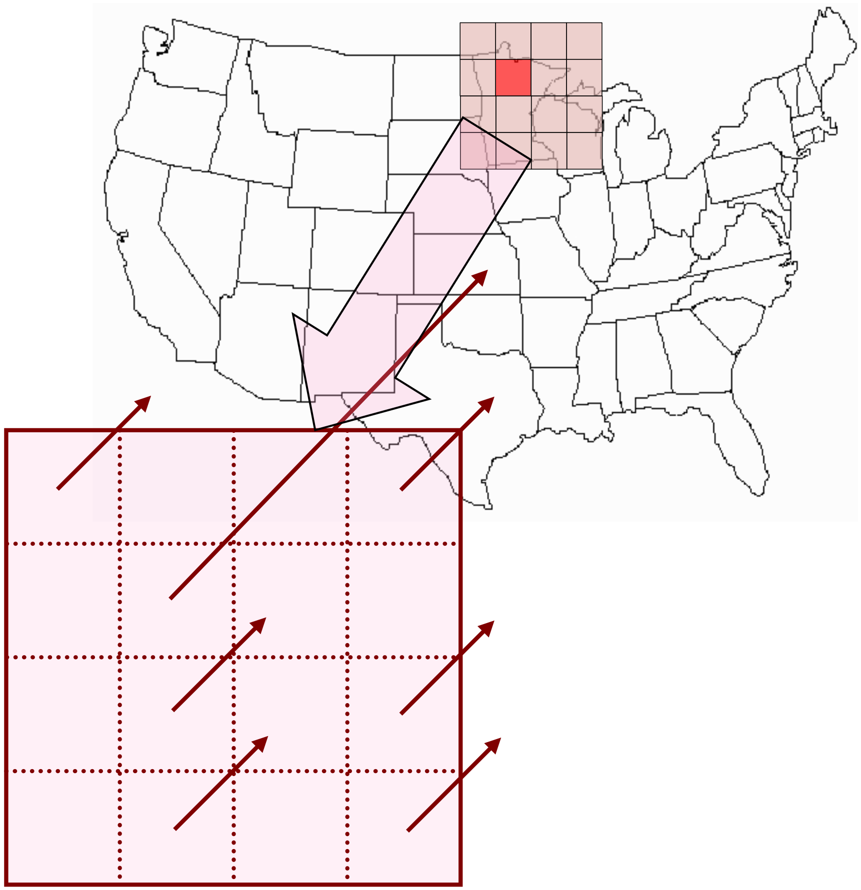
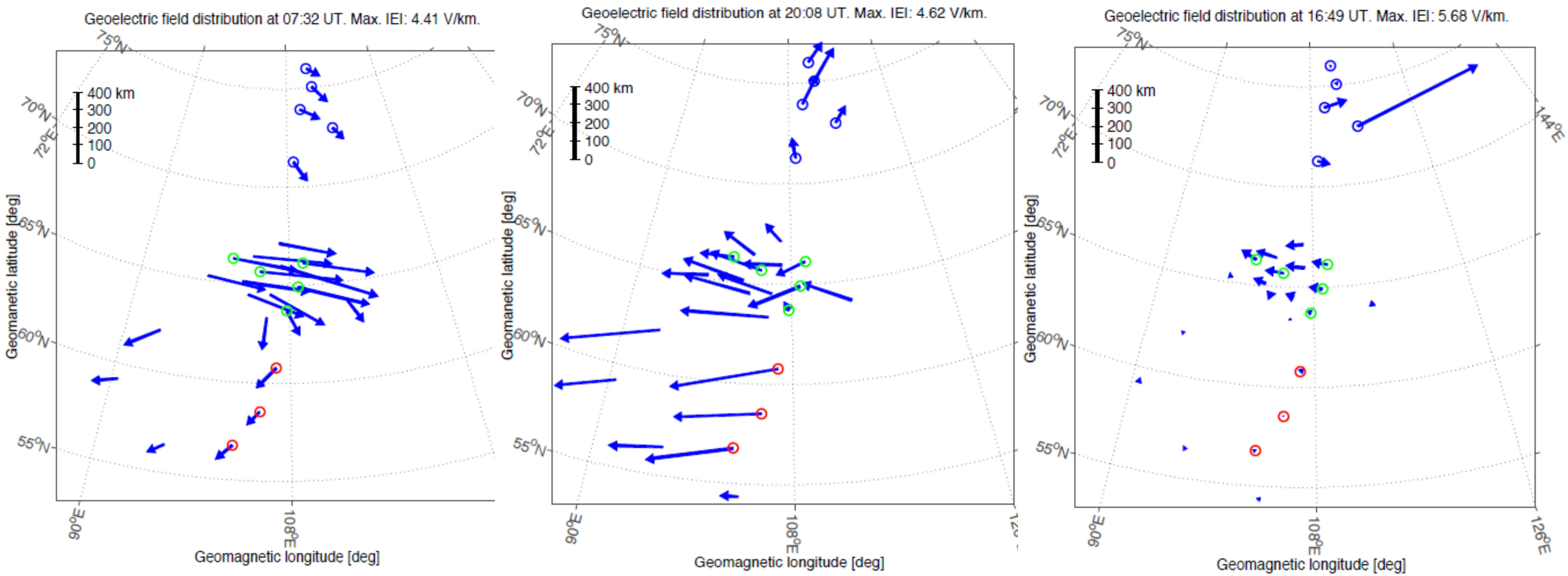


Illustration of Localized Geoelectric Field Enhancement

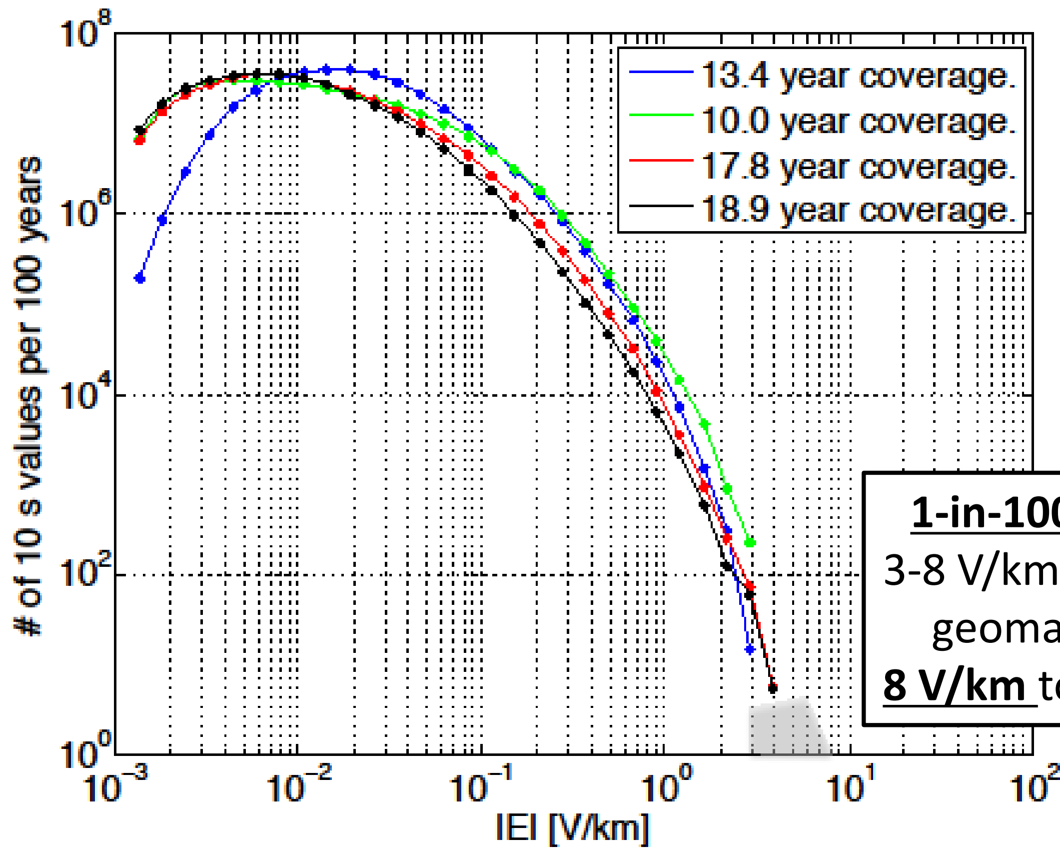
Spatially Coherent Geoelectric Fields

Three groups:

- Spatial average on each group
- Extreme value statistics: maximum over all groups



Reference Geoelectric Field Amplitude



1-in-100 Year Occurrence

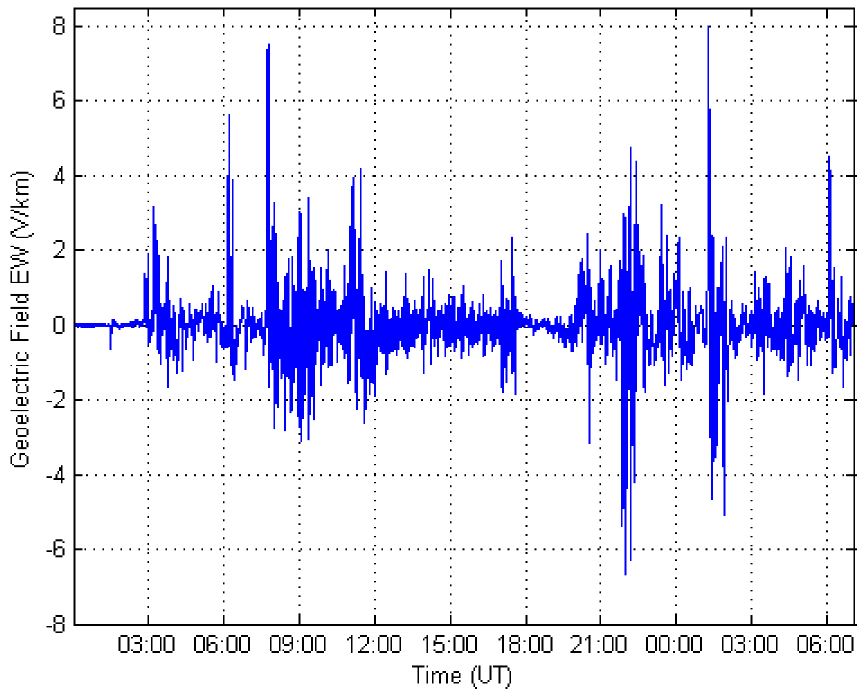
3-8 V/km at 60° N geomagnetic latitude

8 V/km to be conservative

Statistical occurrence of spatially averaged high-latitude geoelectric field amplitudes from IMAGE magnetometer data (1993 – 2013)

Benchmark GMD Event

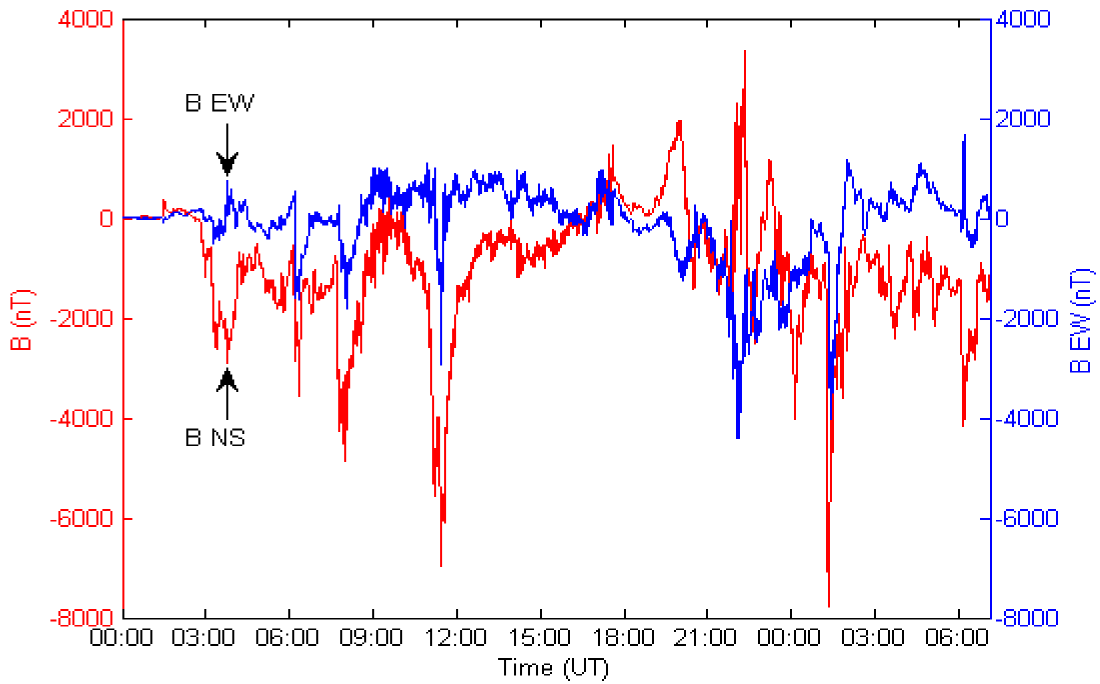
- Assessments are based on a severe 1-in-100 year GMD event. Two components for analysis:
  - Magnitude of 8 V/km scaled to the entity's planning area
  - **Wave shape for assessing transformer hot-spot heating**



Source: NERC Benchmark GMD Event Description, May 2016

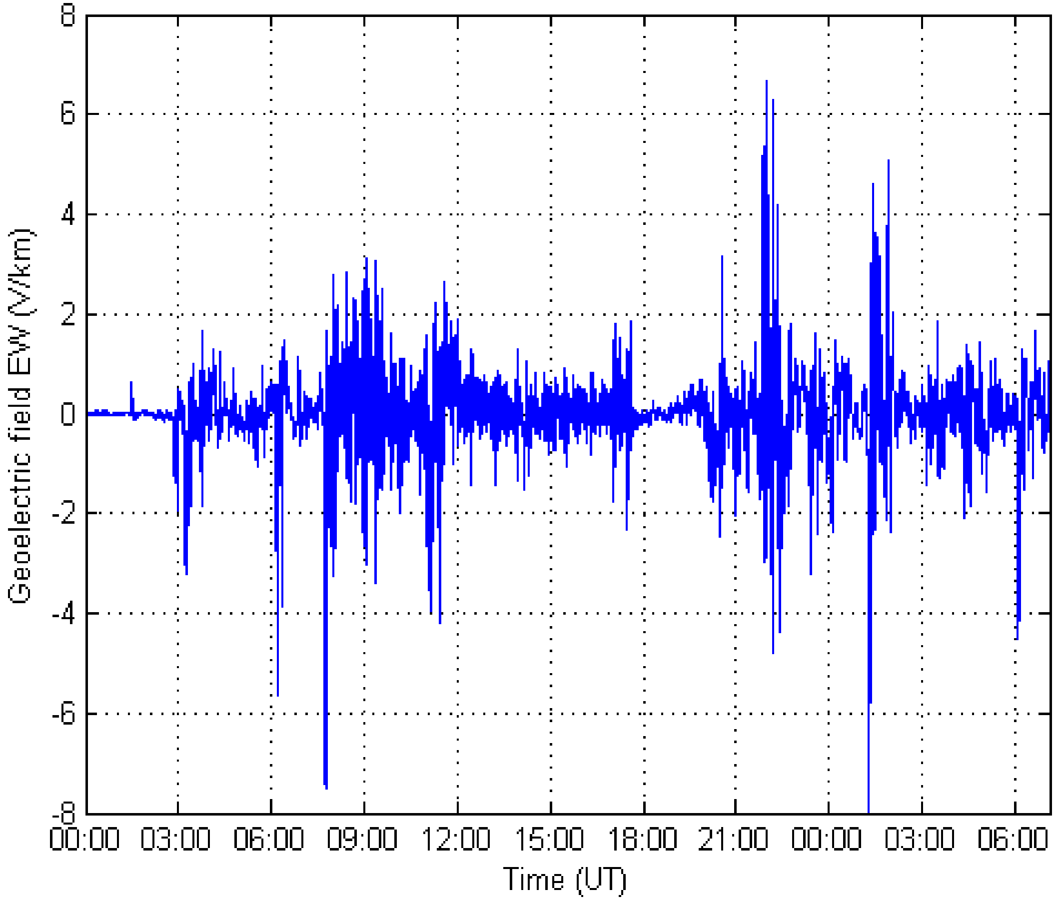
Benchmark GMD Event

- Reference geomagnetic field waveshape
  - Frequency content of March 1989 GMD event provides a conservative approach for thermal assessment of transformers



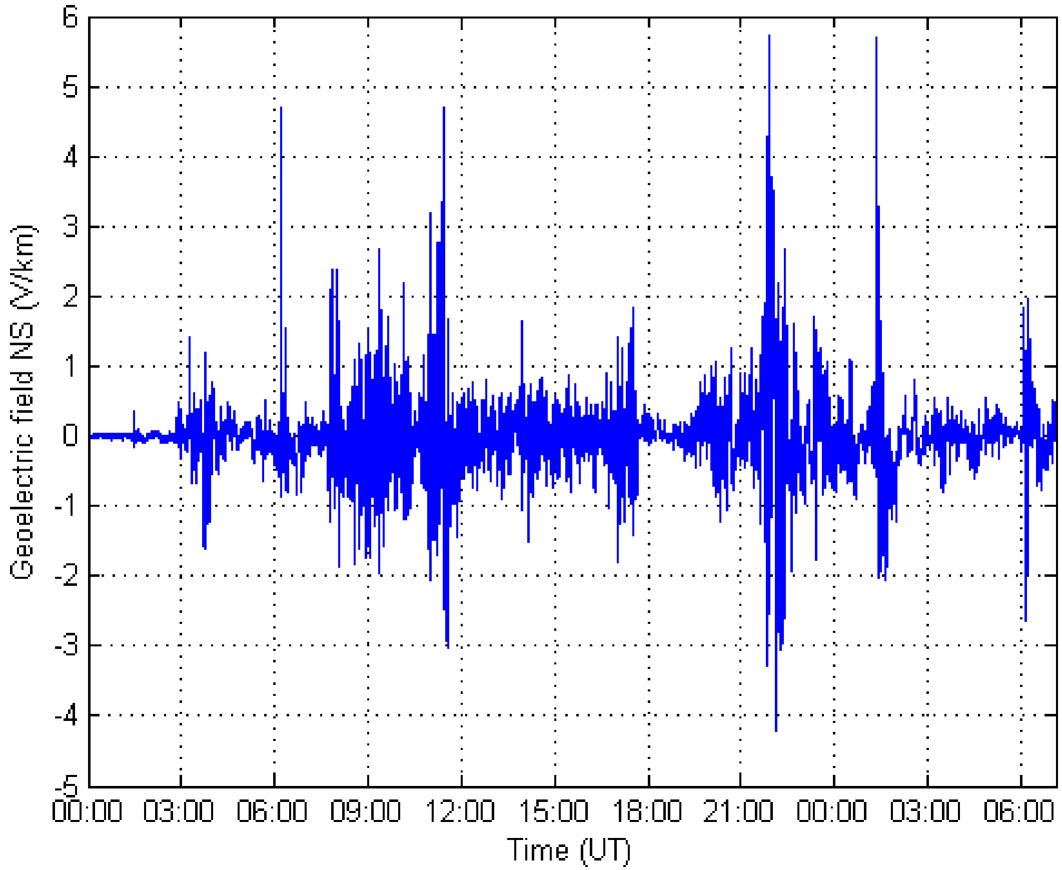
Reference Geomagnetic Field Waveshape

Reference Geoelectric Field Waveshape



Benchmark geoelectric field waveshape at 60° North. Calculated using the reference Quebec ground model. E_E (Eastward).

Reference Geoelectric Field Waveshape



Benchmark geoelectric field waveshape at 60° North Calculated using the reference Quebec ground model. E_N (Northward).

Calculated Peak Geoelectric Field

$$E_{peak} = 8 \times \alpha \times \beta \text{ (in V/km)}$$

where,

E_{peak} =	Benchmark geoelectric field amplitude at System location
α =	Factor adjustment for geomagnetic latitude
β =	Factor adjustment for regional Earth conductivity model

8 V/km is the peak geoelectric field amplitude at reference location (60° N geomagnetic latitude, resistive ground model)

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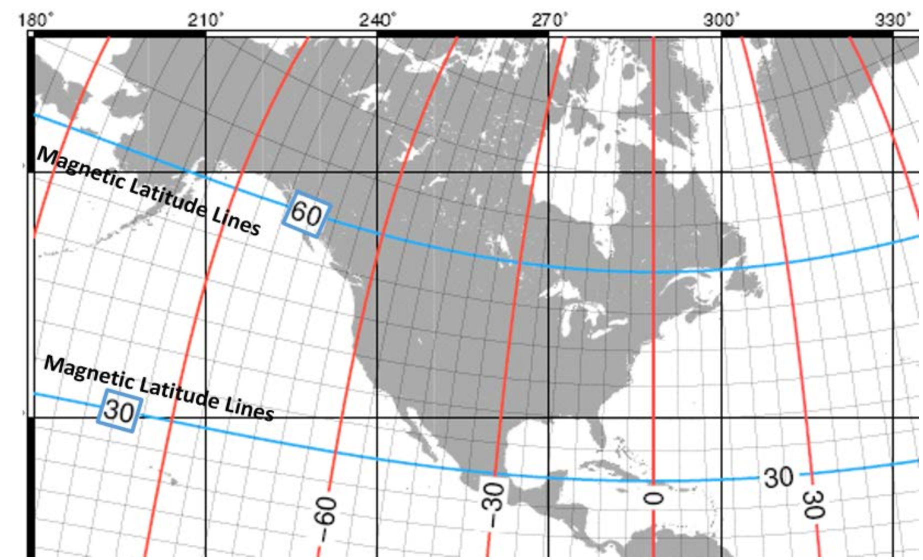
Geomagnetic Latitude Scaling

- Determination of α scaling factors described in NERC GMD TF Application Guide for Computing GIC
- Table provided in TPL-007-1 Attachment 1 and Benchmark white paper

1.0 at 60° N	Juneau; Winnipeg; Churchill Falls, NL
0.3 at 50° N	New York ; St Louis; Salt Lake City
0.1 at 40° N	Jacksonville; New Orleans; Tucson

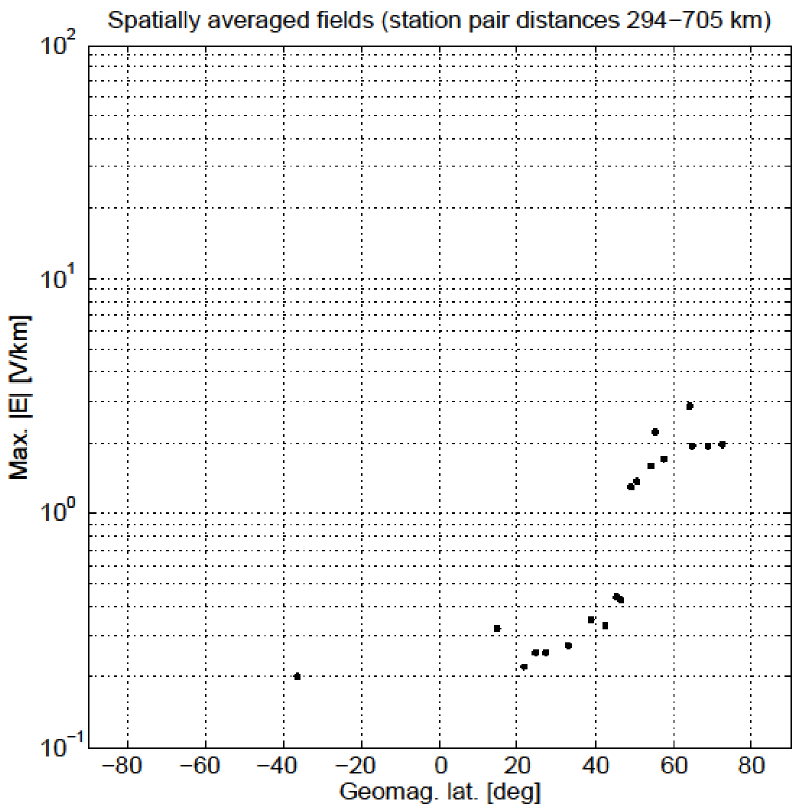


Geomagnetic Latitude Chart

$$E_{peak} = 8 \times \alpha \times \beta \text{ (in V/km)}$$

Geomagnetic Latitude Scaling Factor

- Plot shows the latitude distribution of spatially averaged geoelectric field amplitudes
- Averaging was done for station pairs
  - Distances varied between 300 km to about 700 km
- Order of magnitude drop across 40-60 deg is similar to results obtained from analysis of peak e-fields

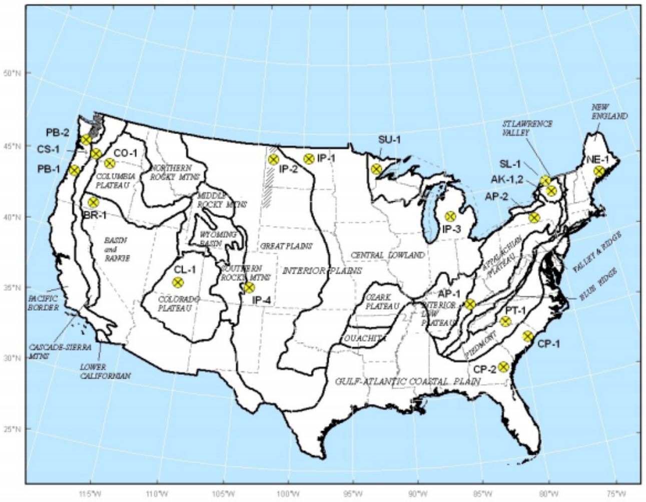


Geomagnetic Latitude Distribution of Maximum Spatially Averaged Geoelectric Fields

Earth conductivity model factor (β)

0.81	Atlantic Coastal (CP-1)	0.67	British Columbia (BC)
0.27	Columbia Plateau (CO-1)	0.79	Prairies

- Table provided in TPL-007-1 Attachment 1 and Benchmark white paper
- A utility can use a technically-justified earth model and calculate its own β

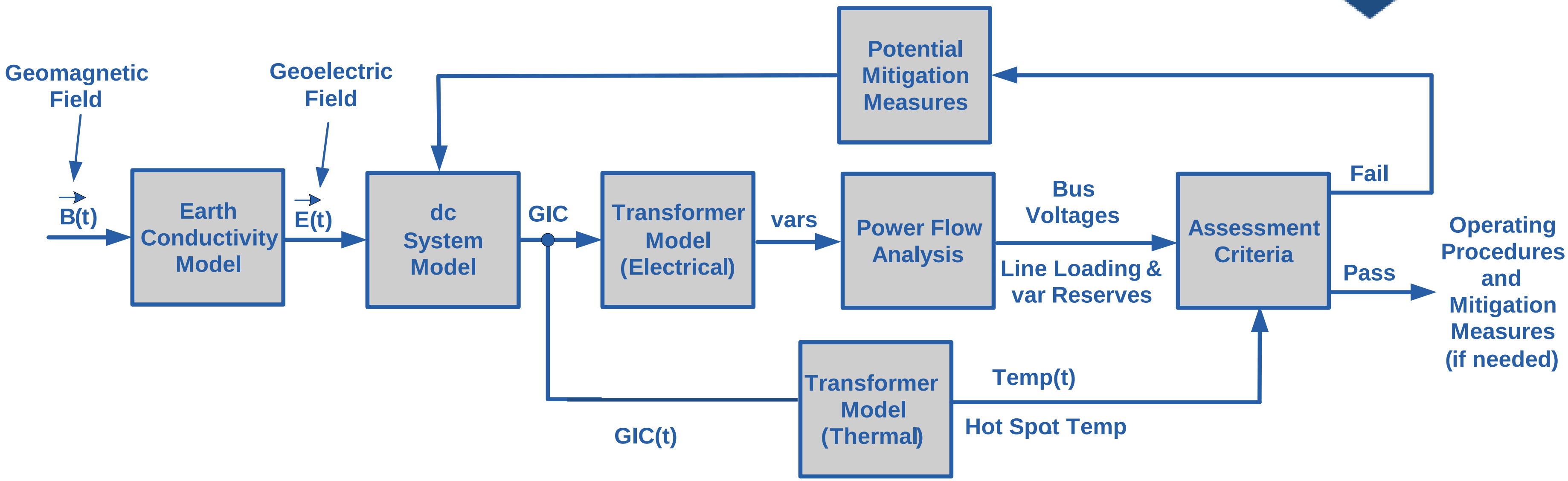


Based on information from US Geological Survey (USGS) and NRCan

GMD Vulnerability Assessment

- Documented evaluation of potential susceptibility to voltage collapse, Cascading, or localized damage of equipment due to geomagnetic disturbances
- Requirements are contained in TPL-007-1
- Responsible Entities (PCs/TPs) perform the assessment of the Near-Term Transmission Planning Horizon **every 60 months**
  - Examine On-Peak Load and Off-Peak Load

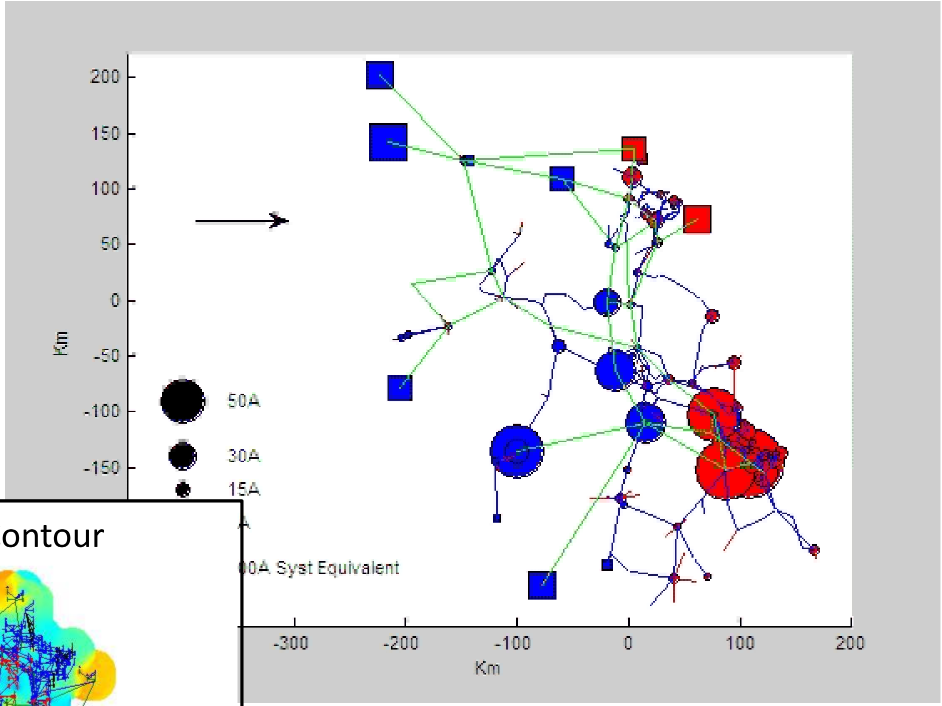
GMD Vulnerability Assessment



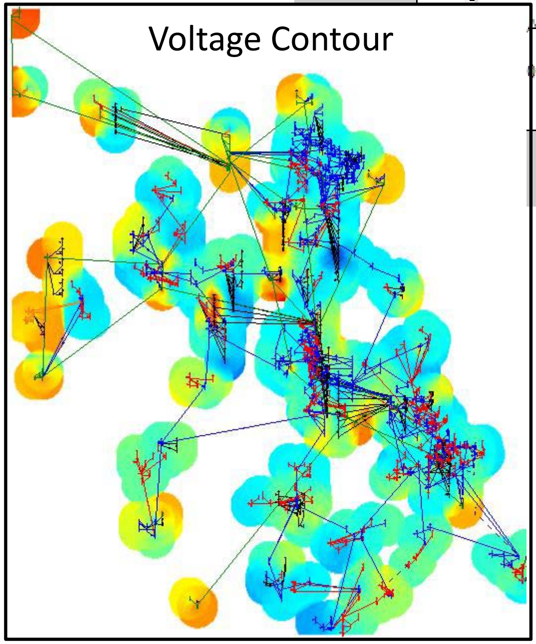
- The objective of the GMD vulnerability assessment is to prevent instability, uncontrolled separation, or cascading failure of the System during a GMD event
- System performance is evaluated based on
  - System steady-state voltage criteria established by the planning entity
  - Cascading and uncontrolled islanding shall not occur

GIC and Load Flow

- Assessment accounts for transformer reactive power loss due to GIC
- Commercial software options are available to perform integrated GIC and load flow simulations



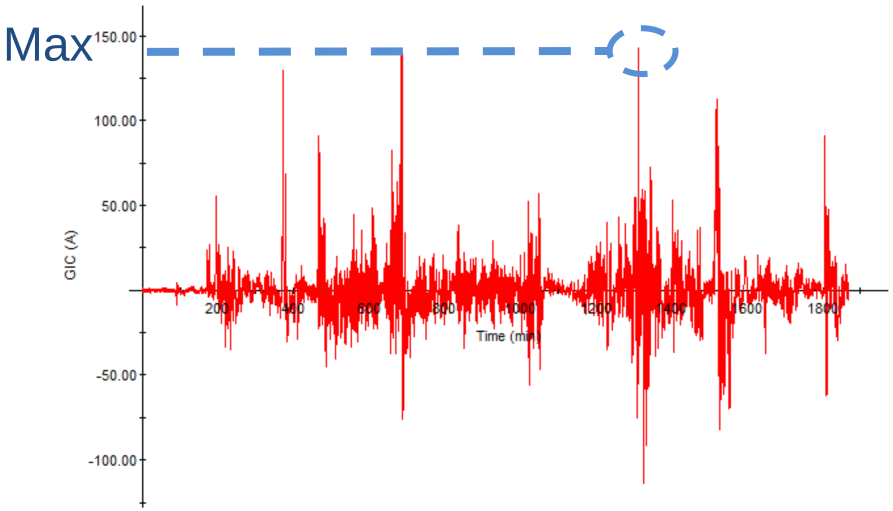
GIC from simulation



Voltage Contour

Provide GIC Information (R5)

- Responsible Entities (PCs/TPs) provide GIC flow information to Transmission Owners (TOs) and Generator Owners (GOs)
  - Maximum value (Amps per phase)
  - GIC(t) time series, if requested



Calculated GIC(t) (Amps per phase) at a transformer

- GIC flow information is used by TOs and GOs to perform transformer thermal impact assessment

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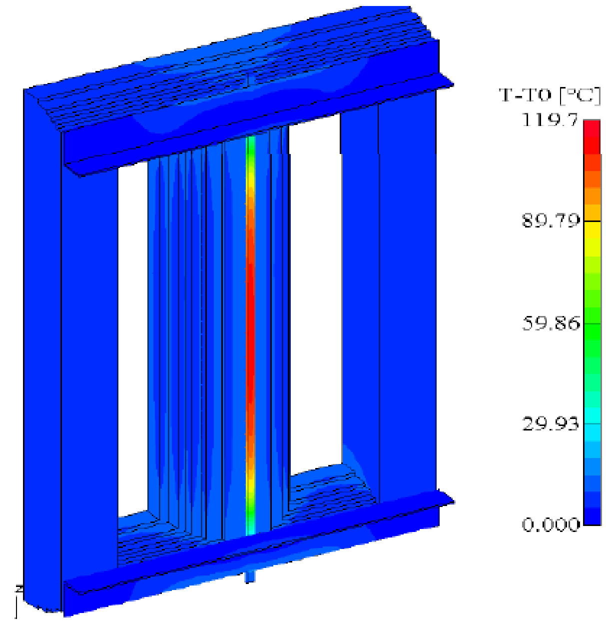
Perform Thermal Assessments (R6)

- TOs and GOs conduct thermal impact assessment of BES power transformers
- Provide results within 24 months
- Techniques:
  - Manufacturer performance curves
  - Thermal response simulation
  - Thermal impact screening



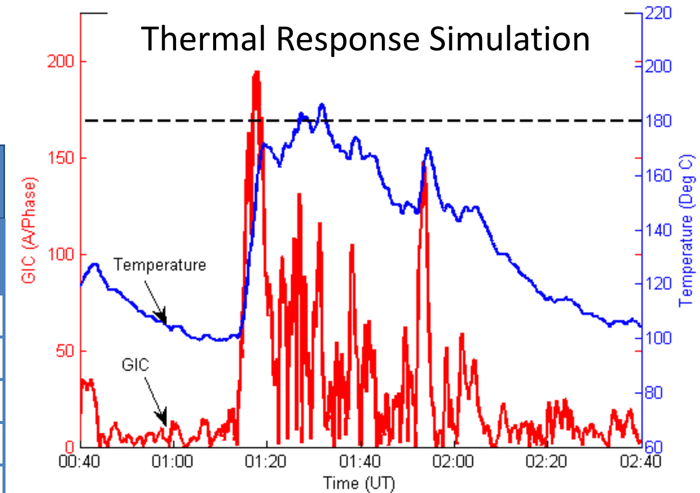
- Assessment is **not required** for transformers < 75 A per phase peak GIC for the Benchmark

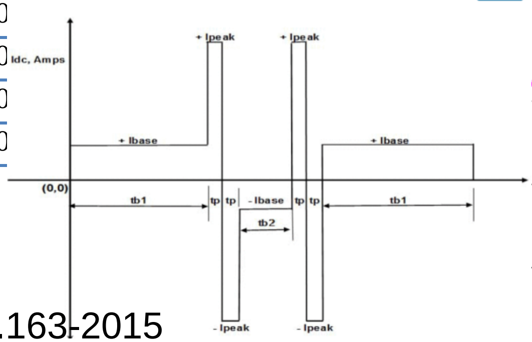
Perform Thermal Assessments (R6)

- Technical guidance developed by the standard drafting team describes techniques

Table 1: Upper Bound of Peak Metallic Hot Spot Temperatures Calculated Using the Benchmark GMD Event			
Effective GIC (A/phase)	Metallic hot spot Temperature (°C)	Effective GIC(A/phase)	Metallic hot spot Temperature (°C)
0	80	100	182
10	107	110	186
20	128	120	190
30	139	130	193
40	148	140	204
50	157	150	213
60	169	160	
70	170	170	
75	172	180	
80	175	190	
90	179	200	

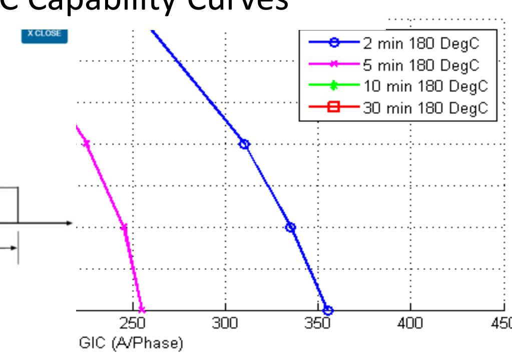
Screening Table





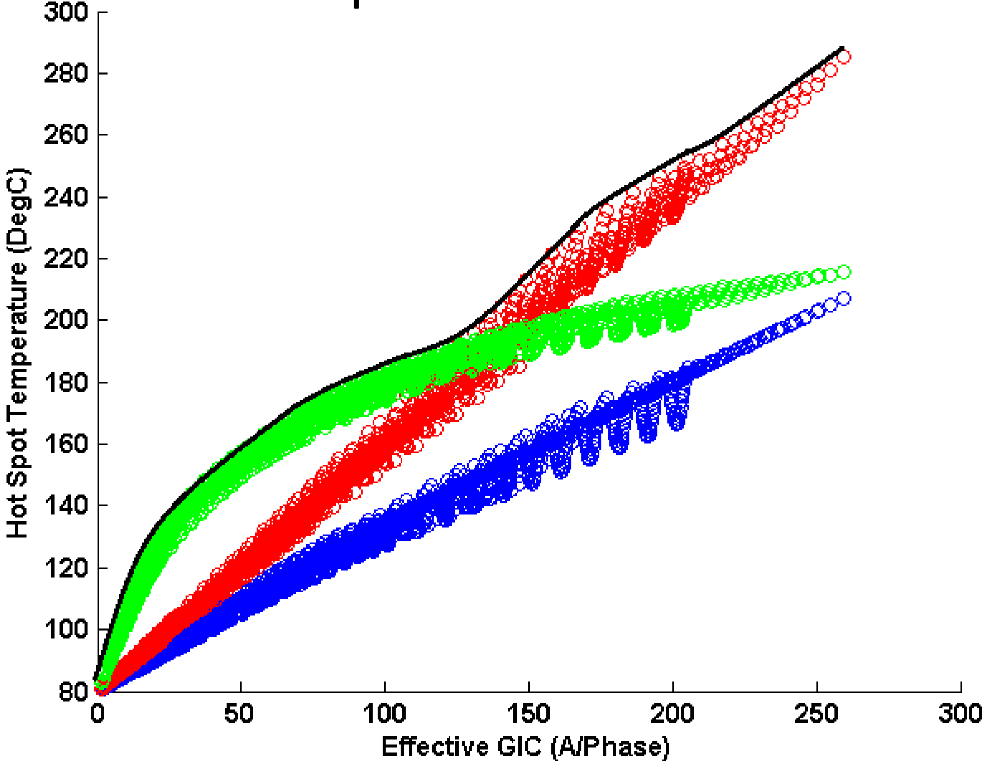
C57.163-2015

GIC Capability Curves



Screening table

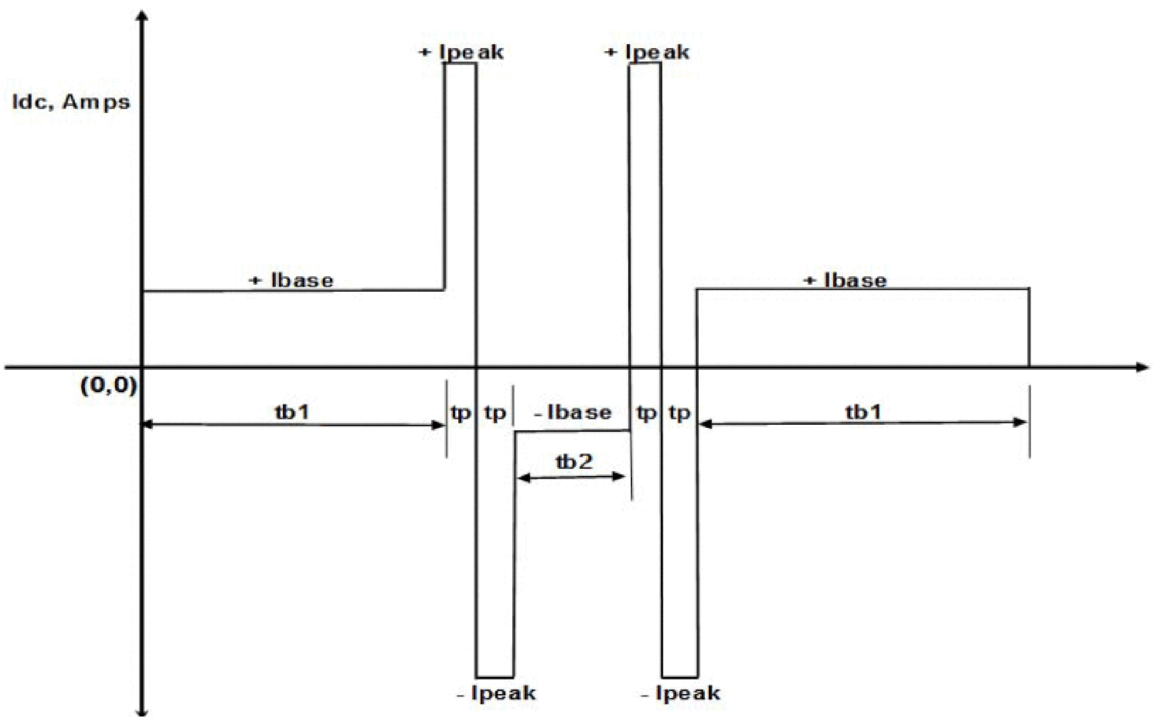
- Screening table generated with the most conservative thermal model known at the time.
- Hundreds of simulations with all possible combinations of circuit orientation



Screening Table

IEEE Std. C57.163.2015

- Was not issued when TPL-007-1 was prepared.
- Not a game changer



hydro one

Corrective Action Plans (CAP)

- TPL-007 requires CAP when the GMD Vulnerability Assessment indicates system performance requirements are not met
- Options include
  - Hardening the system
  - Installing monitors
  - Operating procedures

Mitigation Strategies

- Mitigation options include:
  - Operating Procedures (if supported by system study)
  - GIC reduction or blocking devices
  - Protection upgrades
  - Equipment replacement
- Mitigating measures will introduce changes to GIC flow in the System and can have unintended consequences
  - Planners may need to take an iterative approach
  - Additional technical studies (insulation coordination, system protection, resonance, etc.) may be required depending on the type of mitigation that is employed
- Technical considerations are available in Chapter 5 of the GMD Planning Guide and in the 2012 GMD Report

Listed Requirements

- R1 – Determine responsibilities
- R2 – Develop models
- R3 – Establish performance criteria
- R4 – Perform GMD Vulnerability Assessment
- R5 – Provide GIC flow information
- R6 – Perform transformer thermal assessments
- R7 – Develop Corrective Action Plan

TPL-007 Implementation Plan

January 1, 2017*

July 2017

- R1
- Identify Responsibilities

July 2018

- R2
- System Models

January 2019

- R5
- GIC Flow Information

January 2021

- R6
- Thermal Assessment

January 2022

- R3, R4, and R7
- GMD Assessment
- Corrective Action Plan

*January 1, 2017 is the first day of the calendar quarter after Order No. 830 becomes effective. For more info see the Implementation Plan posted on the project page.

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Discussion

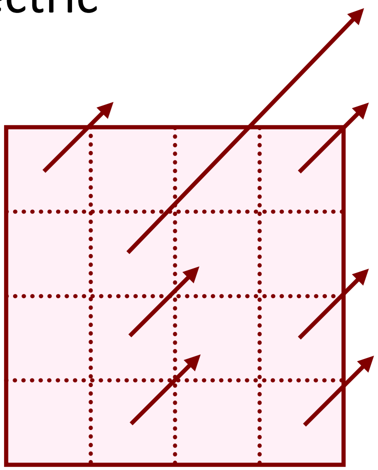
Back-up Slides

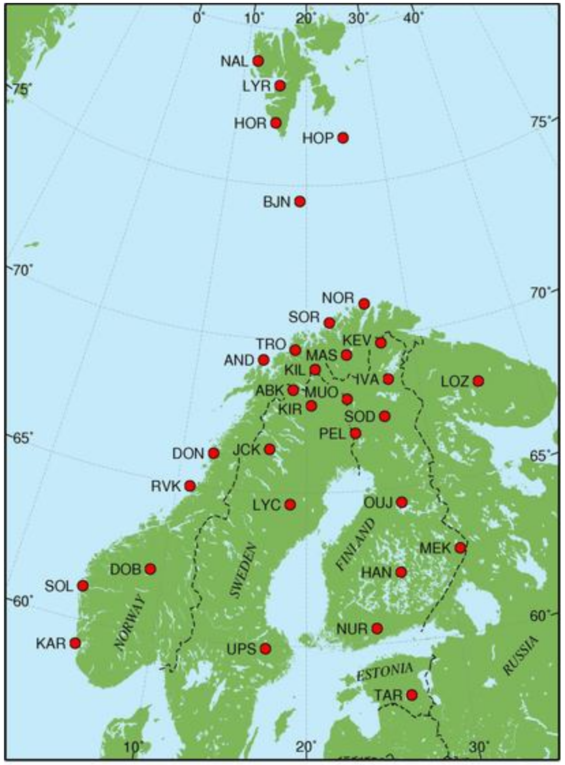
Spatially Coherent Geoelectric Fields

Power System: apply geoelectric field across hundreds of kilometers

Extreme 100-year geoelectric field should be characterized across the same relevant scale

- Solution: spatially averaged geoelectric fields.
- 500 km area was chosen:
  - Intended application
  - Available data granularity
  - Patterns exhibited by the data



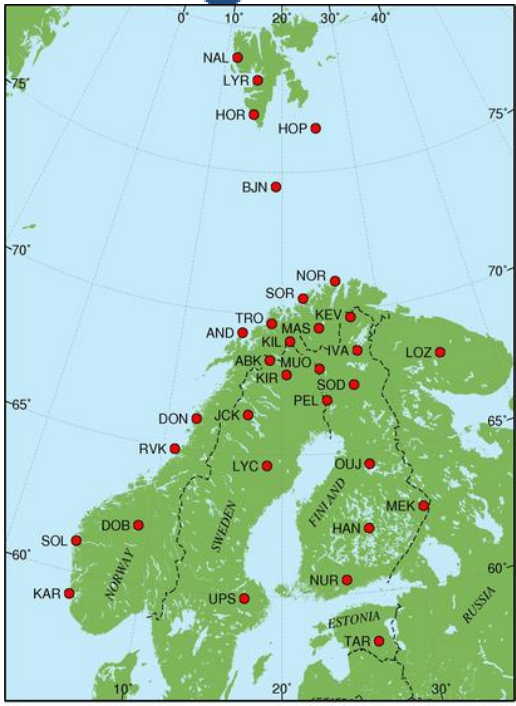


Spatially Coherent Geoelectric Fields

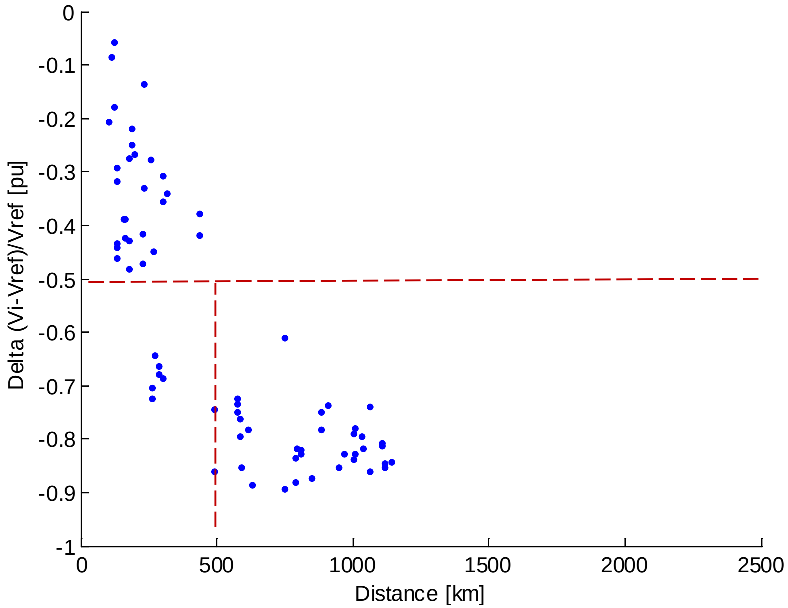
- Delta E-field for pair of stations:
  - Delta = 0: no E-field decay
  - Delta = -1: E-field decayed to 0

$$Delta = \frac{E_i - E_{ref}}{E_{ref}}$$

- Conclusions:
  - Larger E-field appear to decay faster
  - Spatial coherence decreases significantly after 500 km

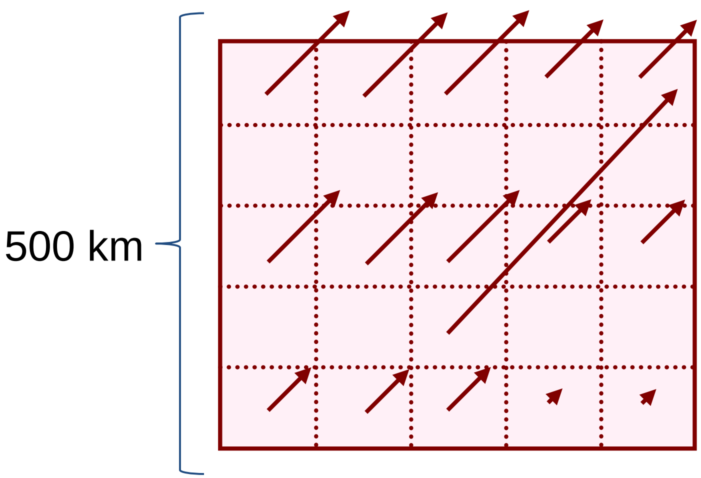


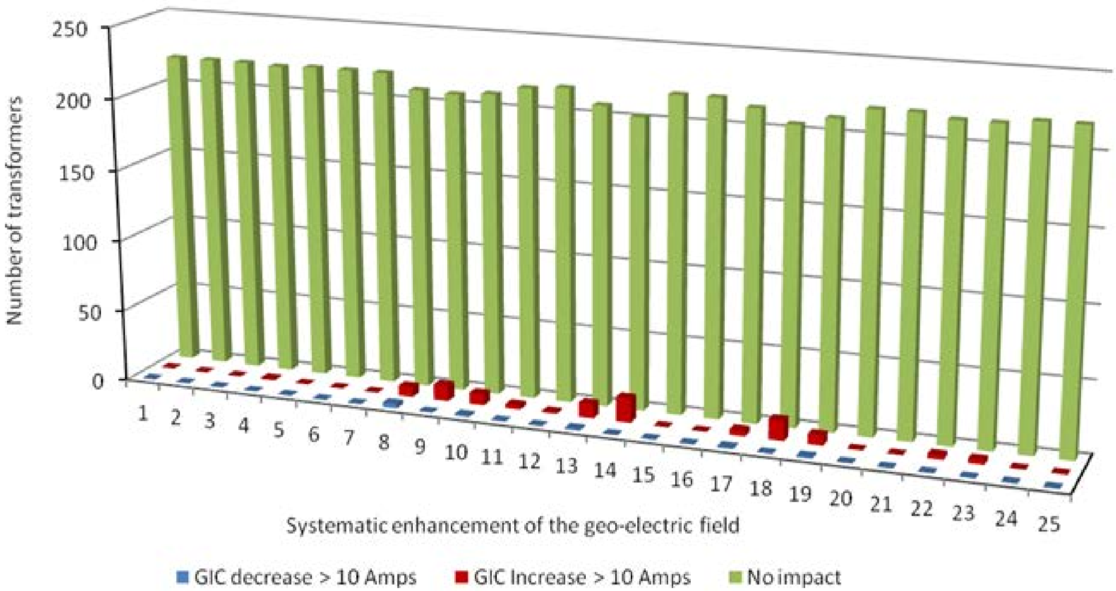
June 2011



GMD: Wide-area nature

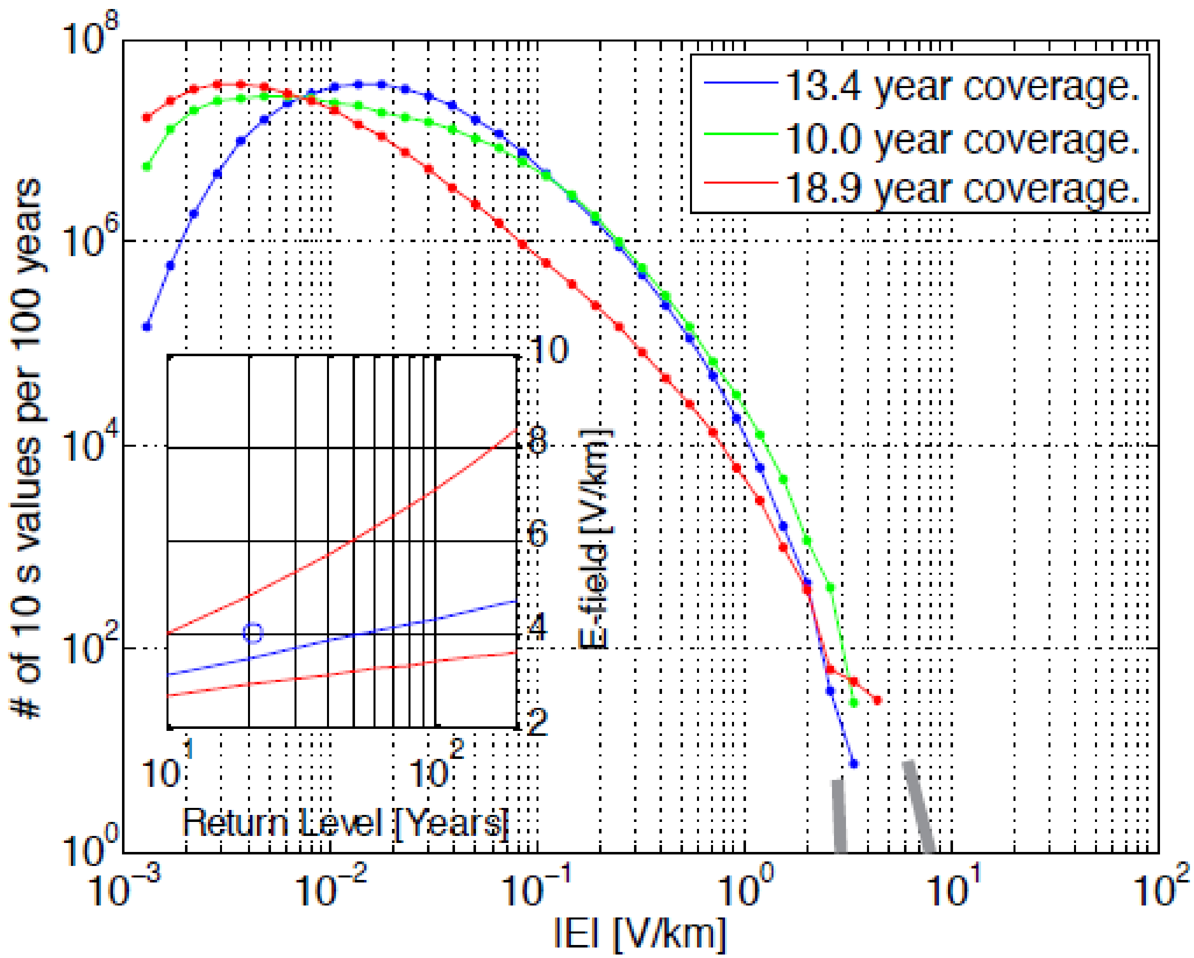
- Distinctive characteristic of GMD: wide-area
- Power grid by design is resilient to localized problems:
  - N-1 and N-1-1 criteria
- "Local enhancement" does not cause wide-area GIC flows





Number of transformers that experience a GIC increase greater than 10 Amps (in red). Reduction in GIC of more than 10 Amps (in blue). Essentially the same (in green)

100-year Extreme Geoelectric Field



Identify Responsibilities (R1)

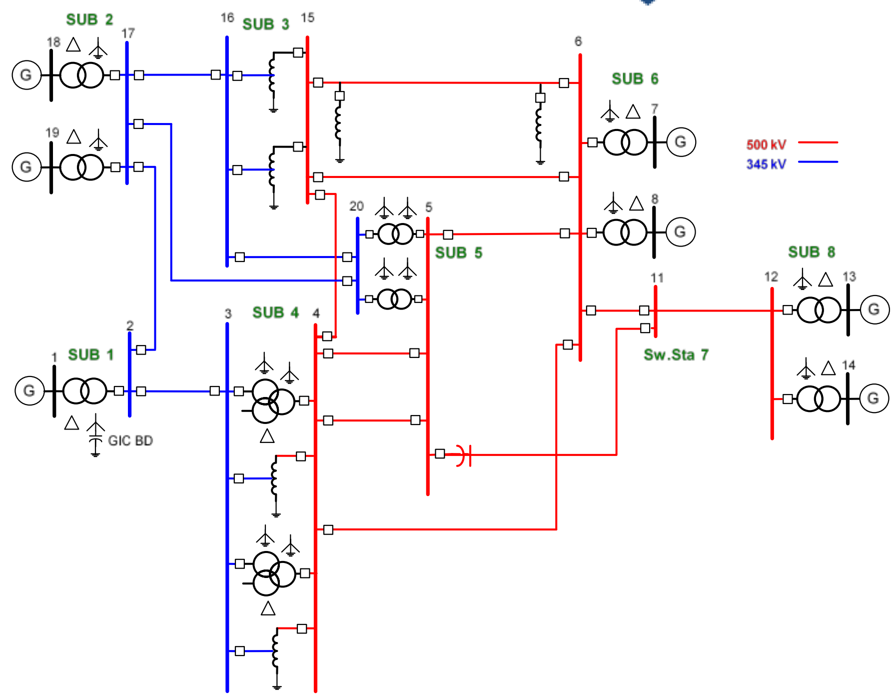
- Planning Coordinators (PC) and Transmission Planners (TP) determine individual and joint responsibilities for:
  - Maintaining models
  - Performing studies

- These determinations affect the responsibilities of the PC and TP in subsequent Requirements
  - Referred to as ***Responsible Entities***

Maintain Models (R2)

- Responsible Entities (PCs/TPs) are required to maintain models of the planning area for performing the GMD Vulnerability Assessment
  - dc models for GIC calculations
  - ac System models for load flow simulations

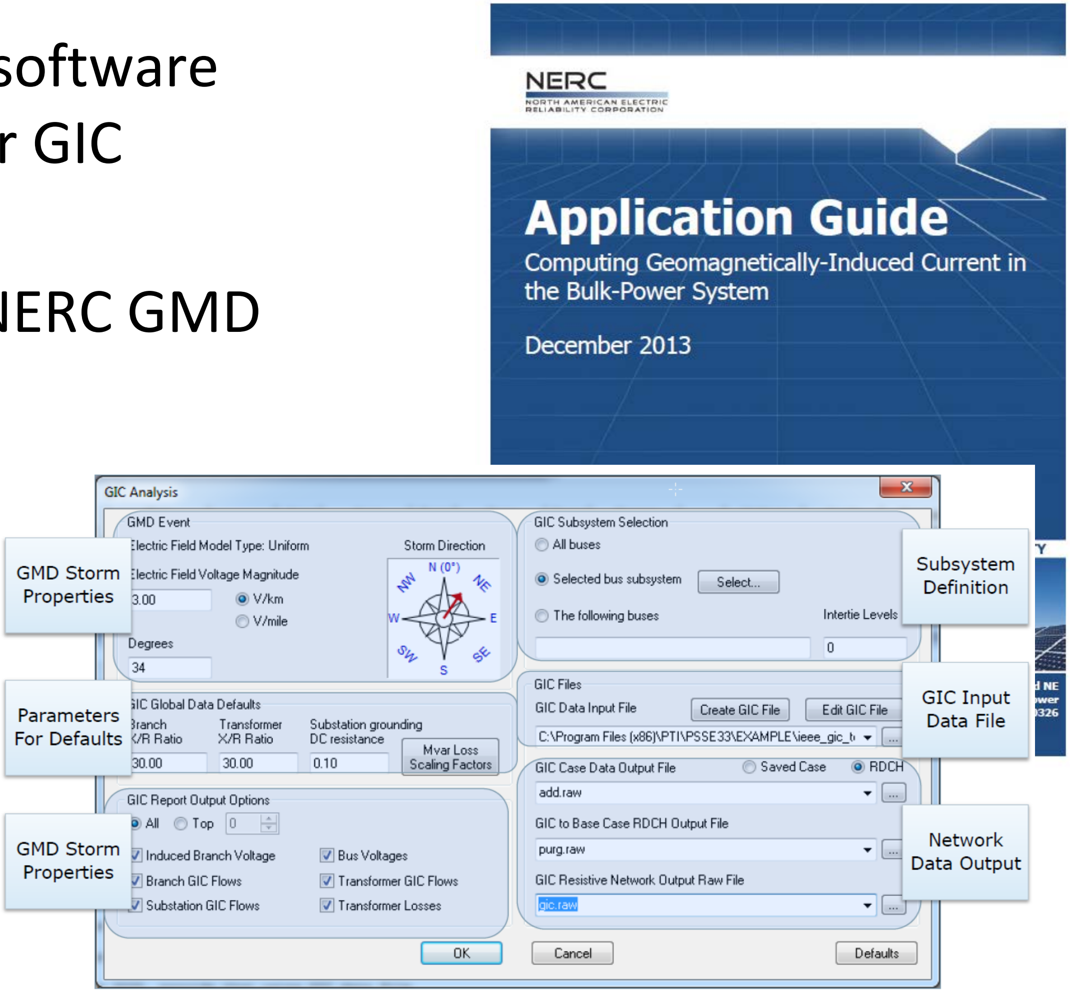
- Models cover all transformers with **high side wye-grounded terminals >200 kV**



Example power system from NERC GIC Application Guide, December 2013

Maintain Models (R2)

- Commercial and custom software packages are available for GIC calculation
- Guidance developed by NERC GMD Task Force

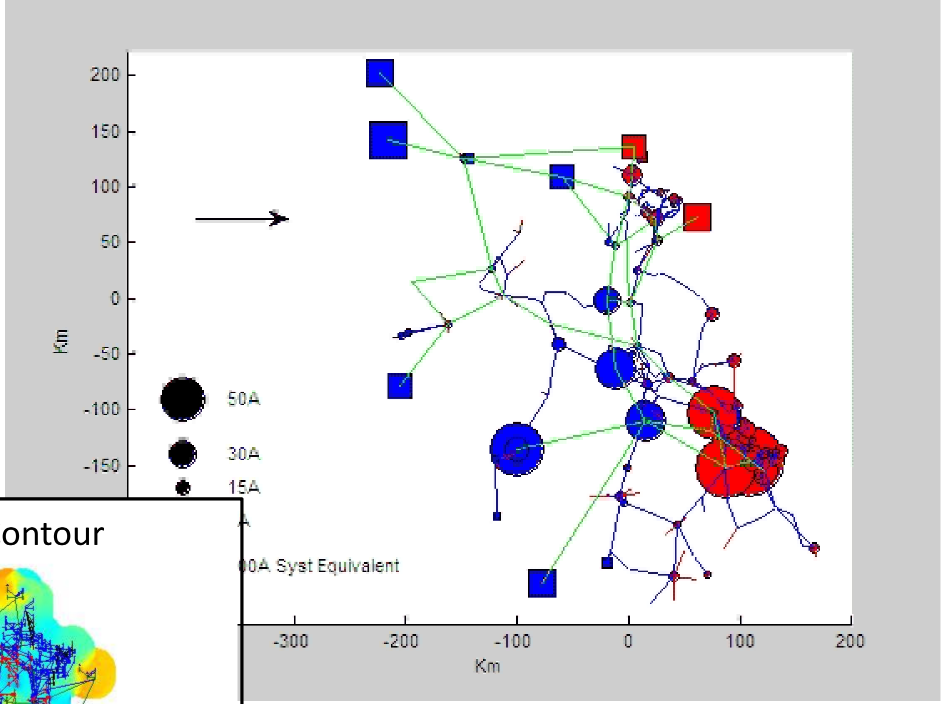


Performance Criteria (R3)

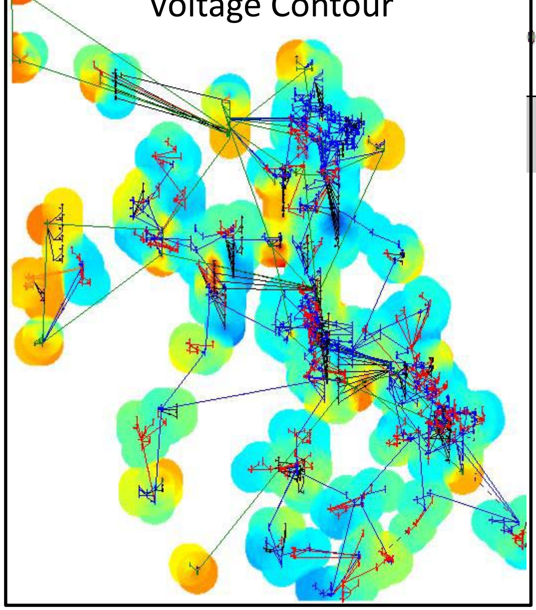
- Responsible Entities (PCs/TPs) determine voltage performance criteria to be used in the GMD Vulnerability Assessment
  - e.g., steady state voltage limit
  - Cascading and uncontrolled islanding shall not occur

GIC and Load Flow

- Assessment accounts for transformer reactive power loss due to GIC
- Commercial software options are available to perform integrated GIC and load flow simulations

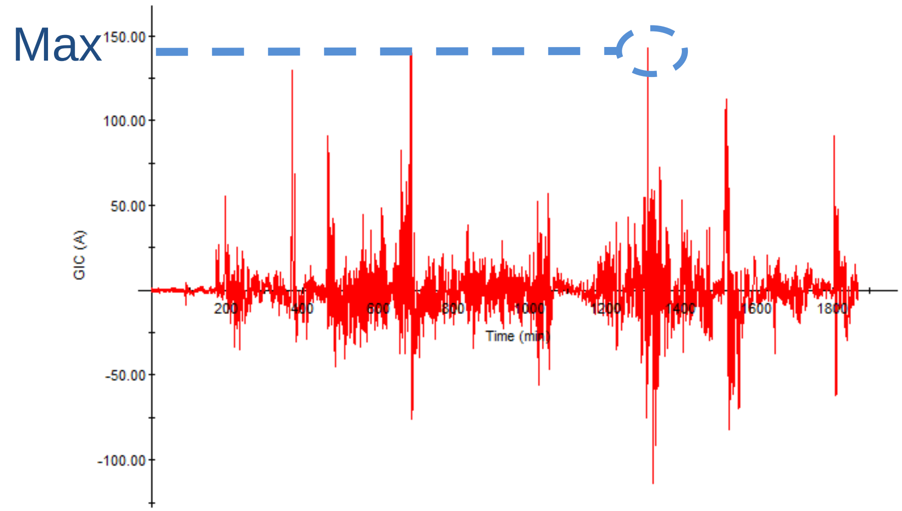


GIC from simulation

Voltage Contour


Provide GIC Information (R5)

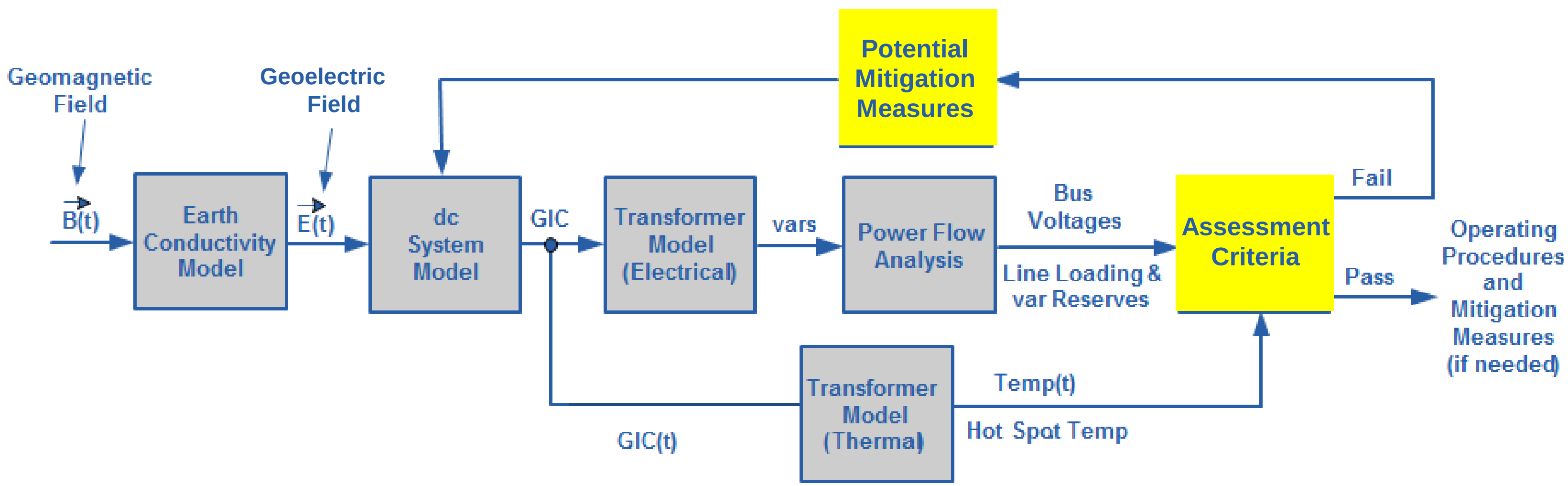
- Responsible Entities (PCs/TPs) provide GIC flow information to Transmission Owners (TOs) and Generator Owners (GOs)
  - Maximum value (Amps per phase)
  - GIC(t) time series, if requested



Calculated GIC(t) (Amps per phase) at a transformer

- GIC flow information is used by TOs and GOs to perform transformer thermal impact assessment

Corrective Action Plans (R7)



- Responsible Entities (PC/TP) must develop a CAP when results indicate performance requirements are not met

Mitigation

- Mitigation options include:
  - Operating procedures identified through studies
  - GIC reduction or blocking devices
  - Equipment upgrades or replacement
- NERC GMD Task Force Planning Guide and the 2012 GMD Report provide some considerations

Assessment Results

- Responsible Entities are required to provide assessments and CAPs to:
  - Reliability Coordinator (RC)
  - Adjacent PCs and TPs
  - Entities identified in the CAP

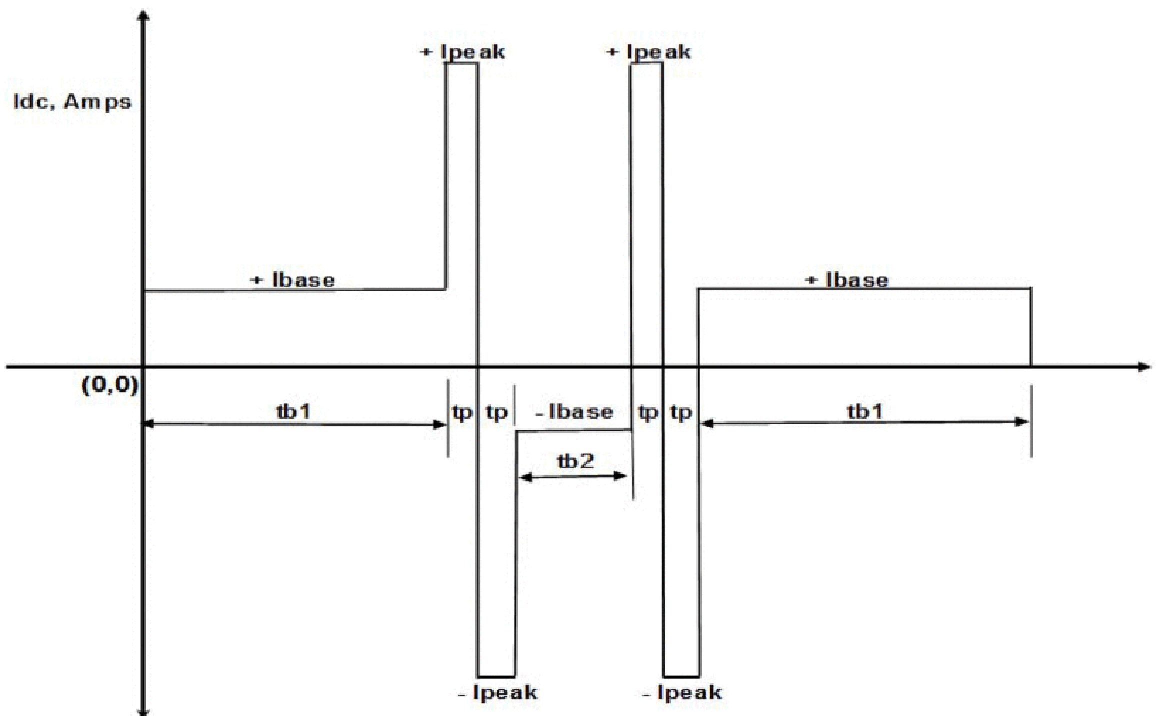
Transformer thermal assessment

- Steady-state GIC flows is not adequate.
- The behaviour depends on GIC(t)
- GIC(t) is event and system dependent
- There are three ways to carry out a thermal assessment

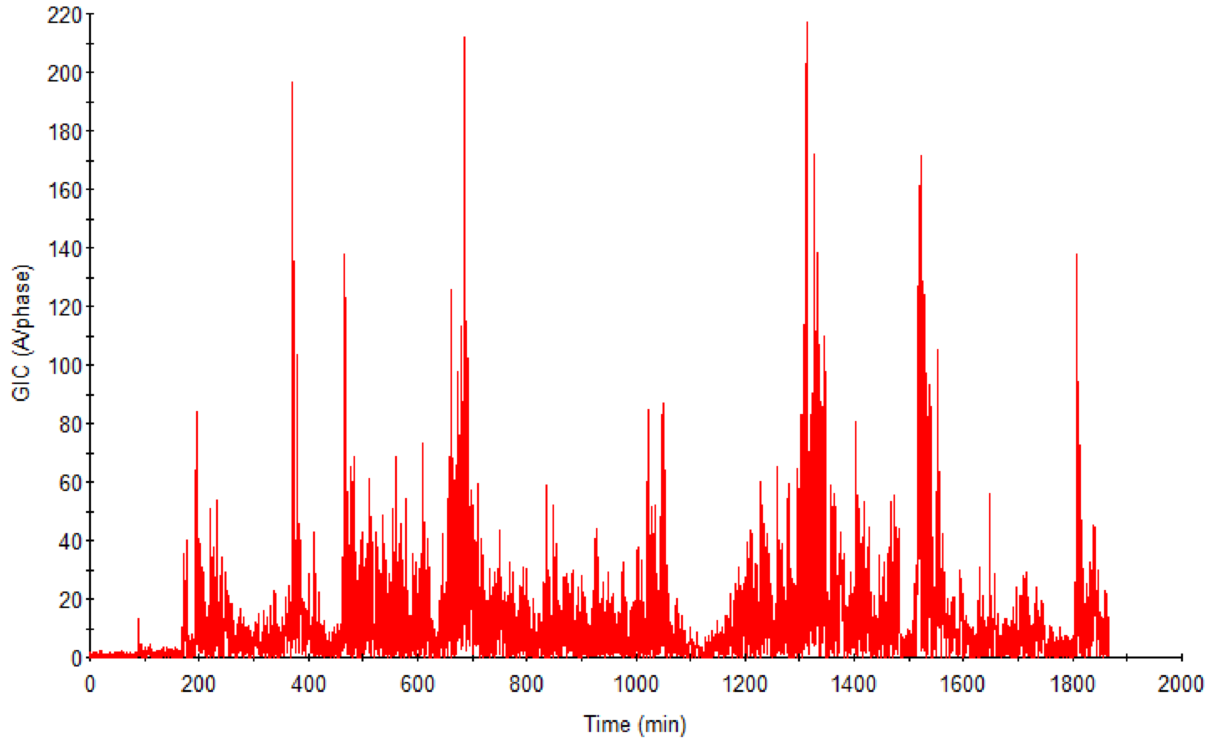
1. Thermal transfer functions allows the calculation of Temp(t) so long as the thermal step response of a transformer is known
   - From measurements
   - Theoretical calculations from manufacturers
2. Manufacturer's capability curves
3. Manufacturer's application of C57.163-2015 - IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances with a manufacturer or user-defined "signature"

Using a manufacturer or user-defined "signature"

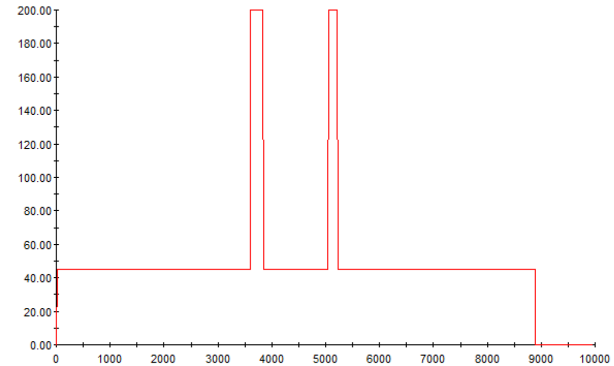
- As with capability curves, the challenge is to match GIC(t) to a signature as suggested in C57.163-2015



For example, Ibase 45 A, Ipeak 200 A

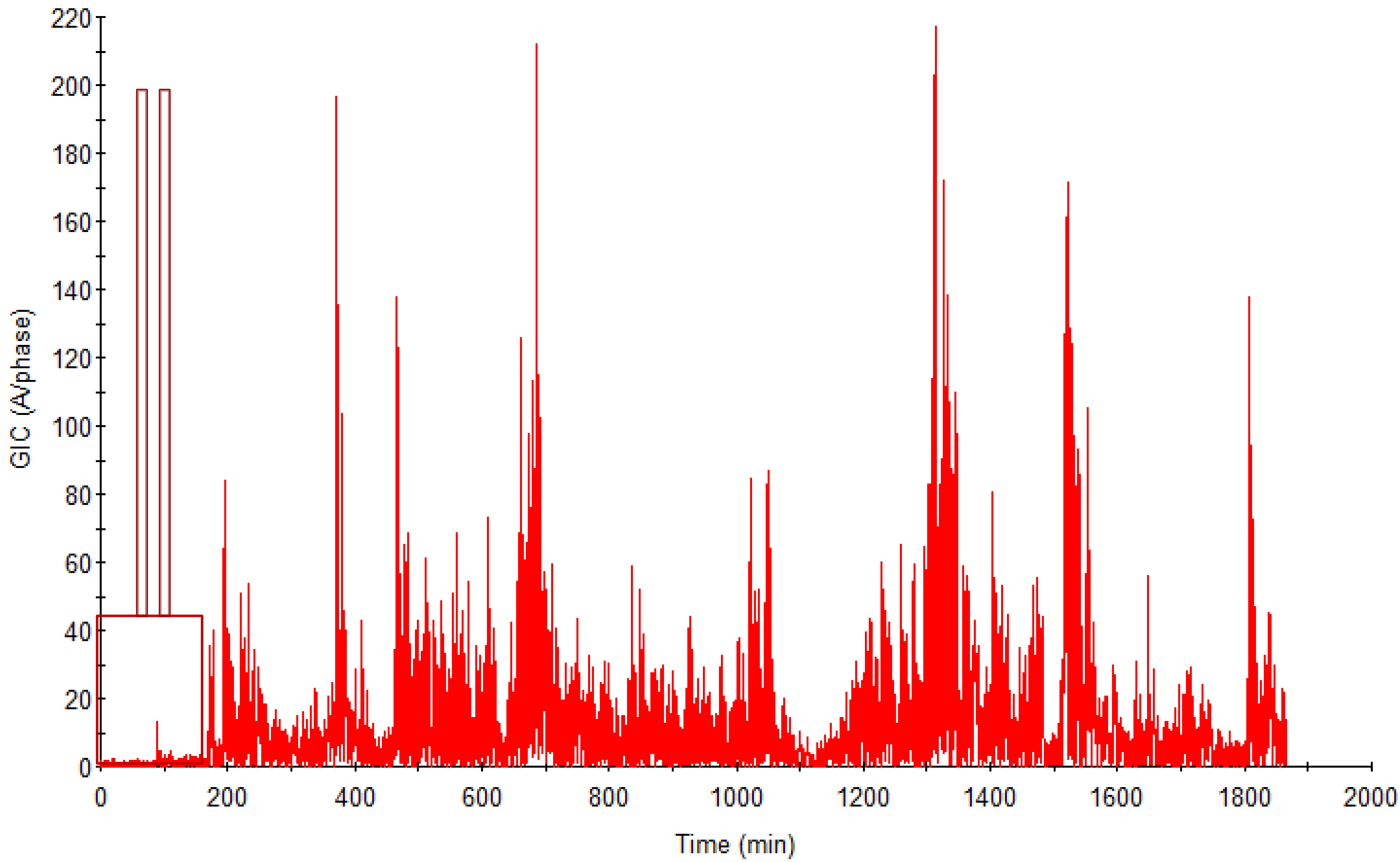


Using recommended tb1=60min,tp=2 min, tb2=20 min
Tb is effectively 4 min

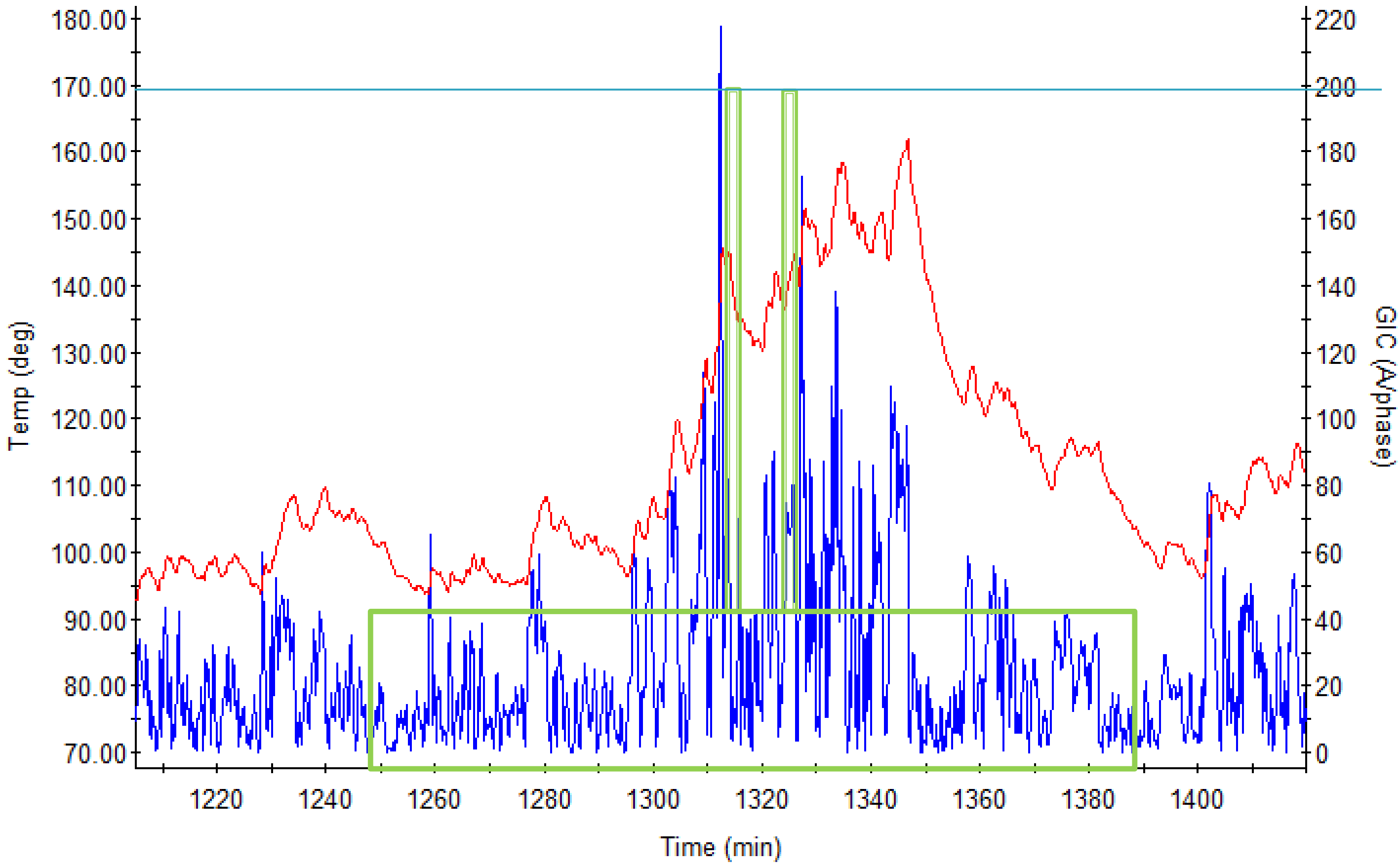


For example, Ibase 45 A, Ipeak 200 A

Scaling the signature

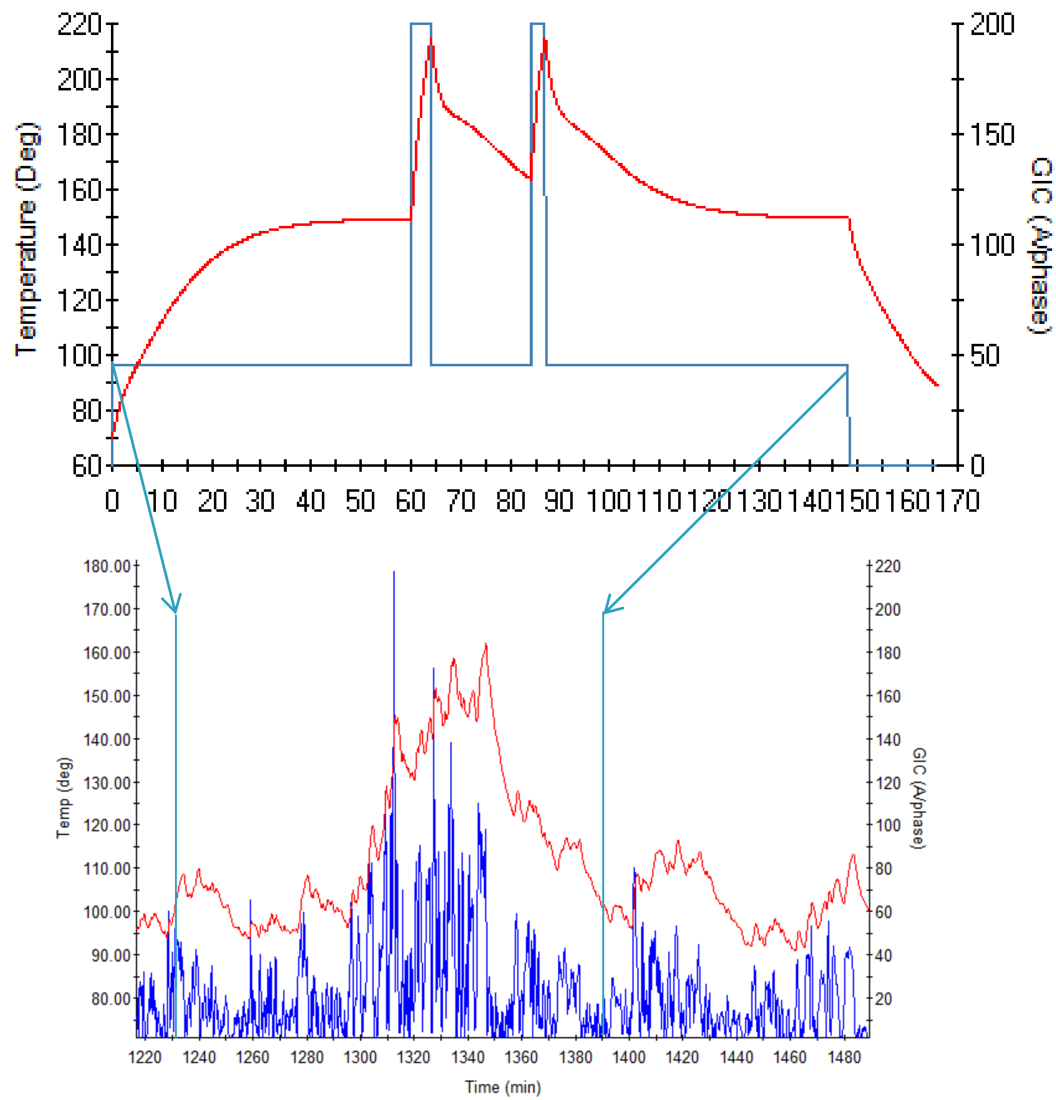


For example, Ibase 45 A, Ipeak 200 A



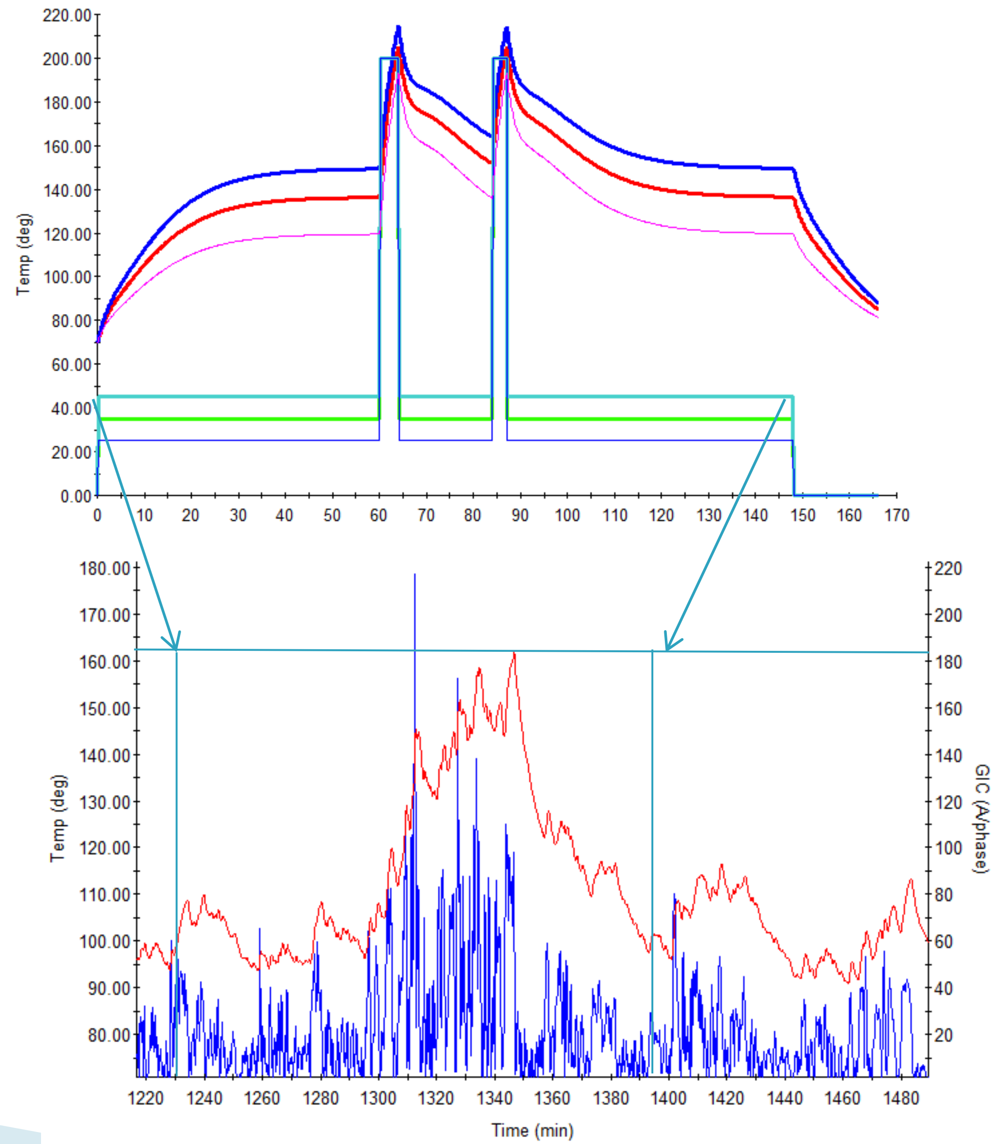
For example, Ibase 45 A, Ipeak 200 A

- Not easy to determine What Ibase could be.
- C57.163-2015 provides no guidance in this respect.
- Every system configuration has a different GIC(t) waveshape



For example, comparing Ibase 25 A, 35A and 45A, Ipeak 200 A

- With additional trial and error one could match peak temperatures. Long term temperatures are more challenging because the signature does not allow for cooling and temperatures will continue to creep up.
- Same transformer with different circuit configuration/orientation one would have to do this again with another GIC(t) waveshape.



All sessions in Eastern Standard Time (New York, GMT-05:00)
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