Description of document: Idaho Public Utilities Commission (PUC) records concerning the risks to the electric power grid from geomagnetic storms, 2014-2015

Requested date: 02-February-2016

Released date: 05-February-2016

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Source of document: Idaho Public Utilities Commission
Public Records Request
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From: Jean Jewell
Date: Feb 5, 2016 11:47:24 AM
Subject: Your Public Records Request to the Idaho PUC

The Idaho Public Utilities Commission (PUC) received your public records request on February 2, 2016, requesting any memos, studies or reports (internal Commission documents and/or contractor reports) concerning the risks to the electric power grid from geomagnetic storms. A search of our records located two documents related to your request.

As the PUC's records custodian, I am forwarding these documents to you as attachments to this email. There is no charge for providing these documents to you.

Jean Jewell
Commission Secretary
Idaho Public Utilities Commission

An Introduction to Geomagnetic Disturbances (GMDs)

Bruno Leonardi
9/8/14

Imagination at work.

Outline

Session 1 – Solar Flares & GMDs

Session 2 – Geomagnetic Induced Current (GIC) in Bulk Power System

Session 3 – GIC Calculation

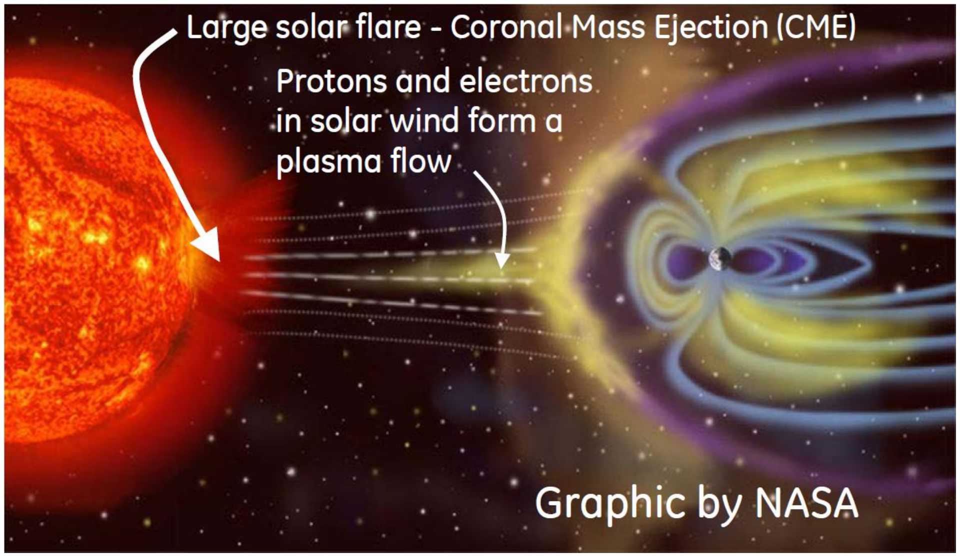
Session 4 – GIC Effects on Power System Equipment

Session 5 – The NERC GMD standards

Session 6 – PSLF GMD Capabilities

Solar Flares & GMDs

Solar Flare

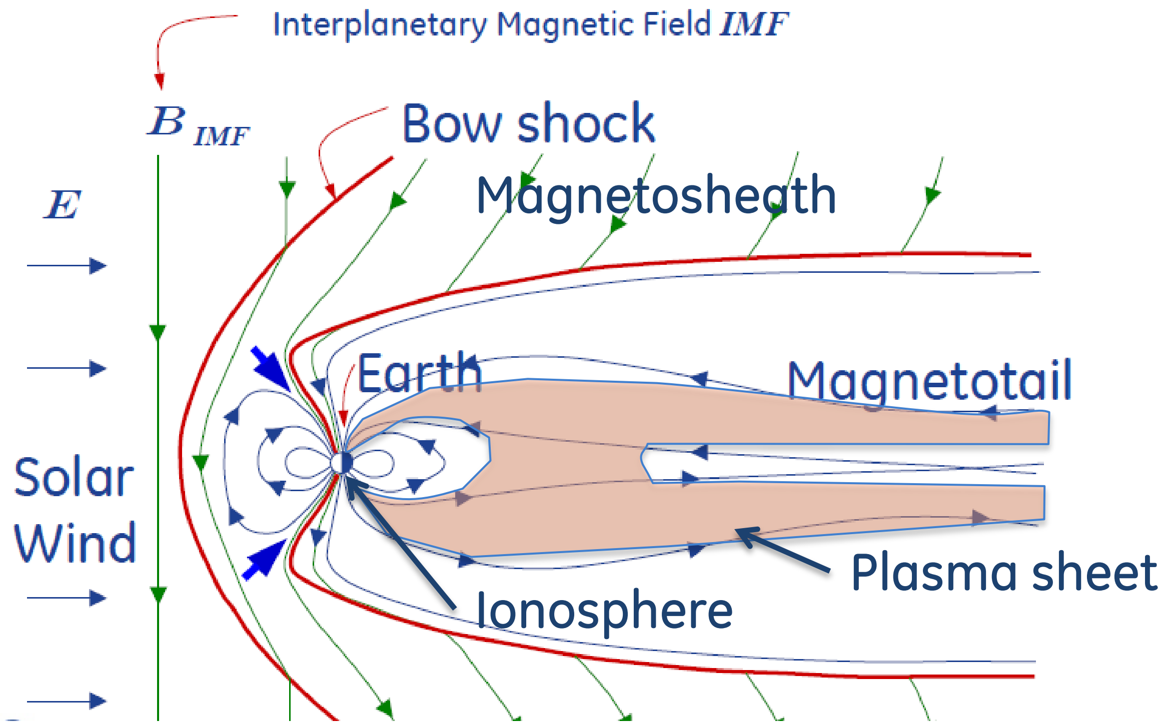


Aurora

Sunspots

- The Sun continuously emits solar particles through solar winds
- Occasionally, large masses of energized particles (electrons and solar wind ions) escape from Sun's corona and travels across space
- These masses of energized particles are called coronal mass ejections (CMEs)
- The interaction between these energized particles and earth's ionosphere causes GMDs

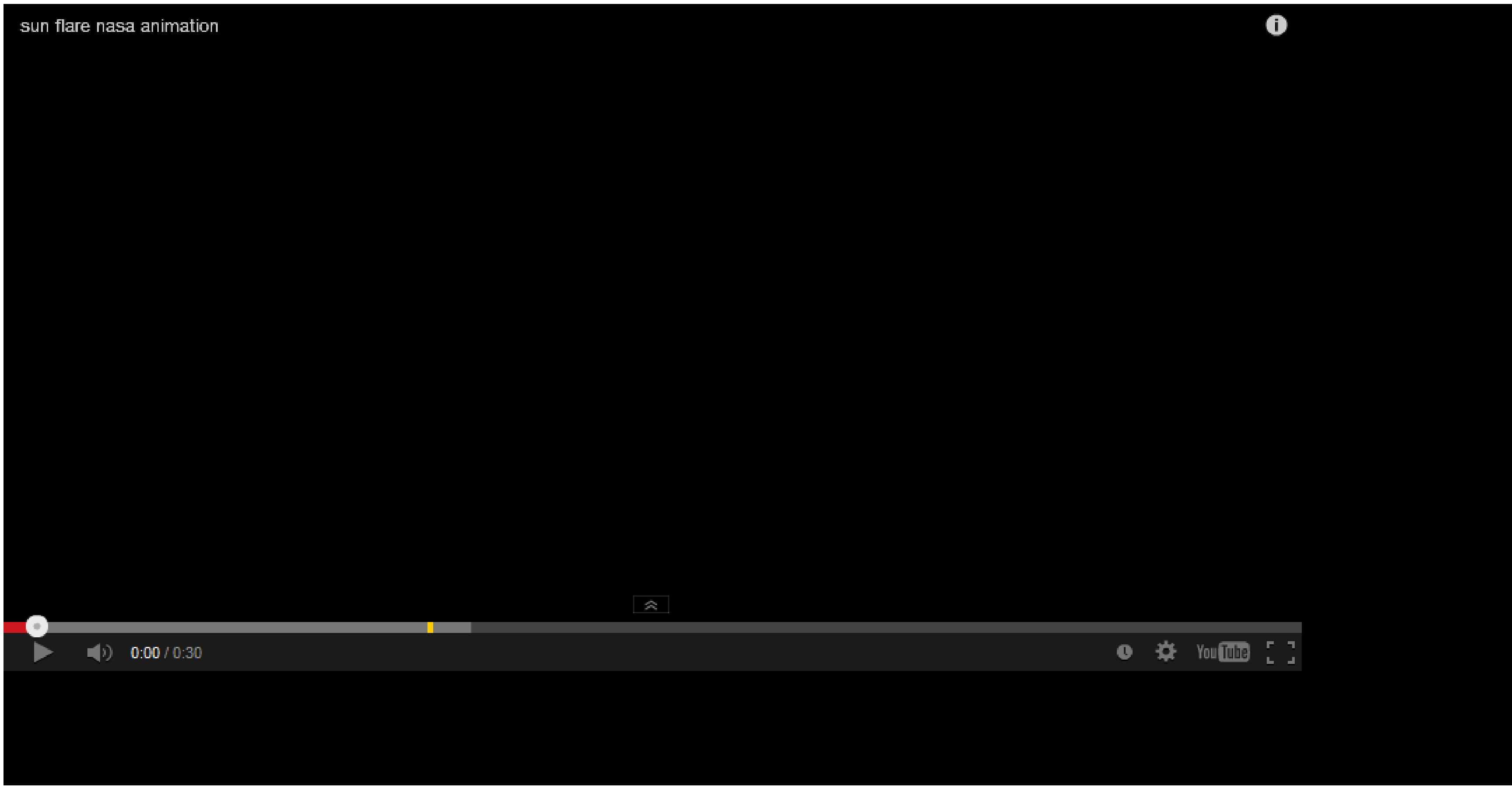
Charged Particles Travel through Space and Interact with Earth's Magnetic Field



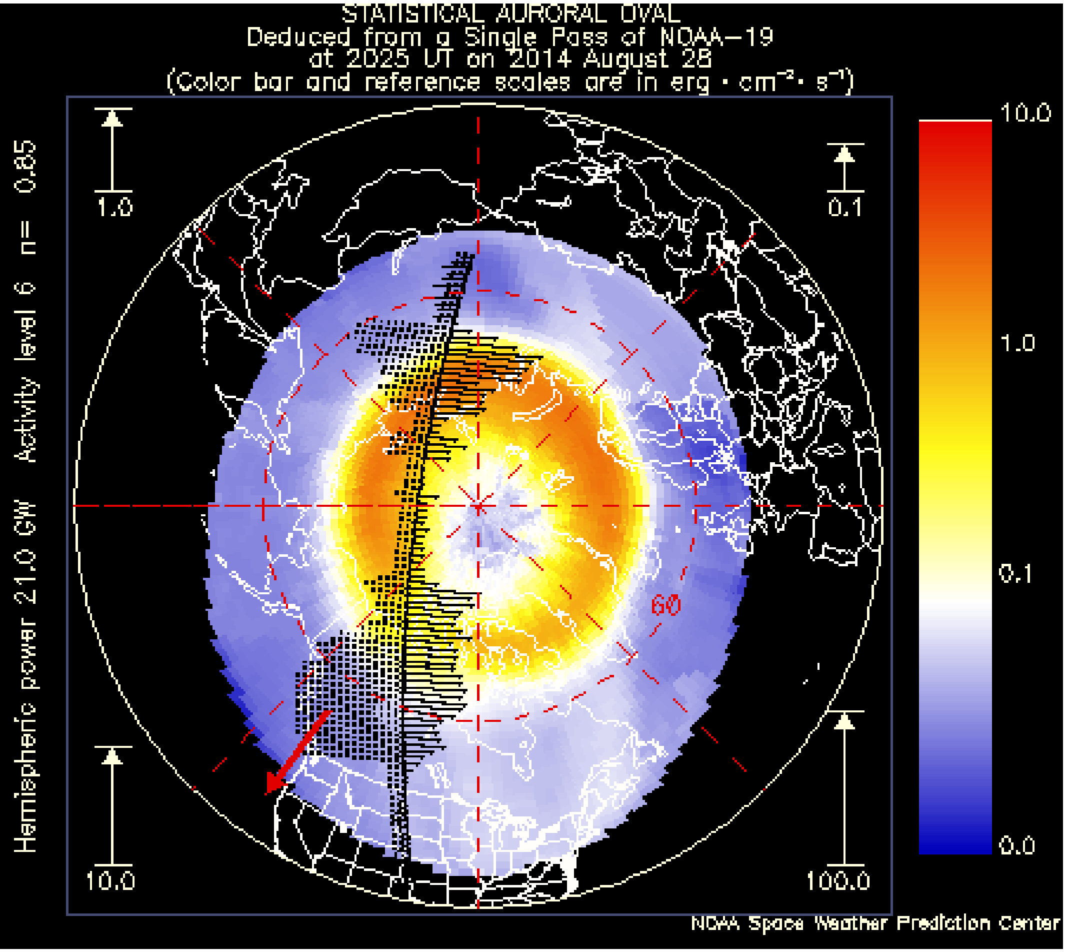
The interaction of CMEs with earths magnetosphere-ionosphere produces ionospheric currents called **electrojets**

Injection of Highly Energized Particles in the Poles

https://www.youtube.com/watch?v=9Mv6xfeHY9E

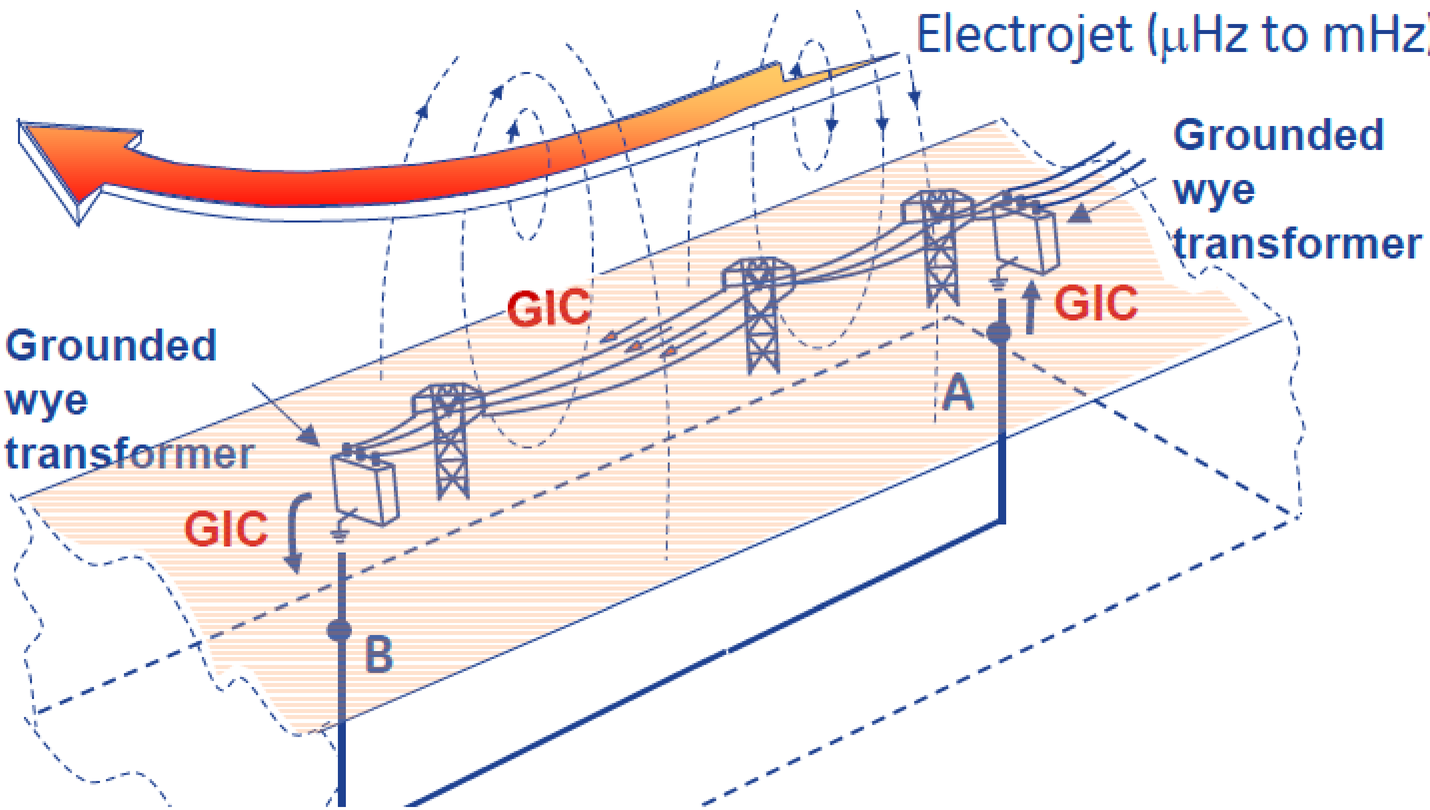


Aurora borealis and australis are also caused by solar winds



- In average intensity storms, the aurora oval is mostly contained to higher latitudes
- This is not true for stronger solar storms, which causes electrojets to flow over lower latitudes causing GICs in the power grid

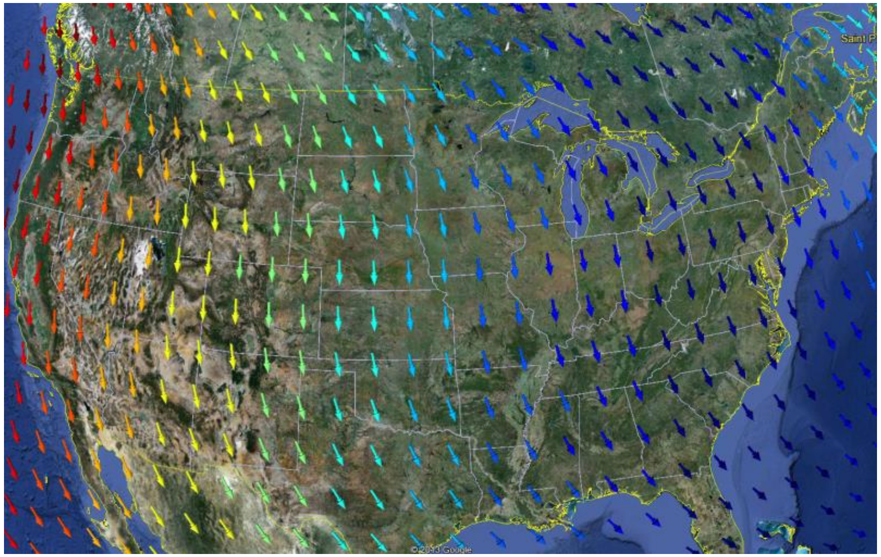
Electrojets induce Electric Field Near Surface of the Earth

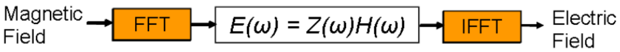


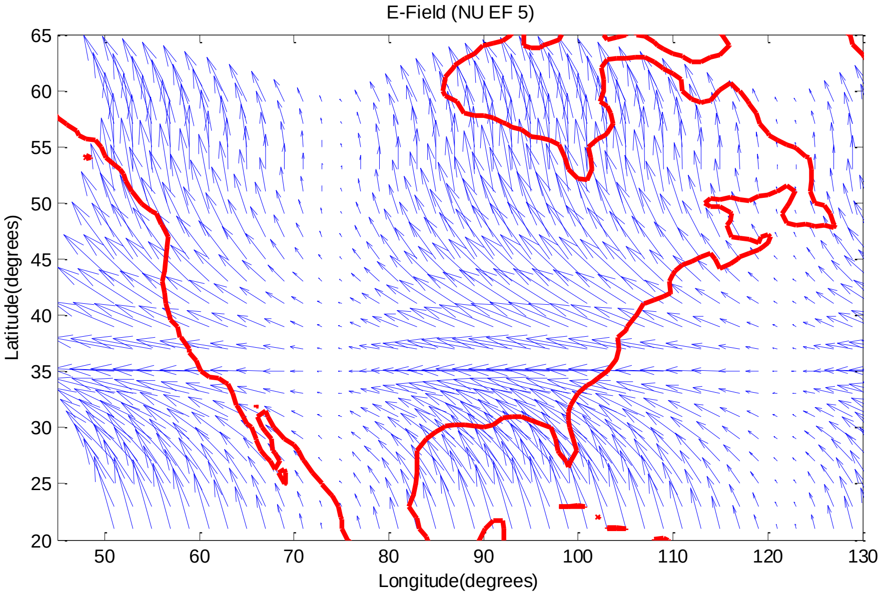
What is a Geomagnetic Disturbance (GMD)?

- A Geomagnetic Disturbance is a perturbation of earth's magnetic field density $\frac{\partial \vec{B}}{\partial t}$ due to energized solar particles
- This variation of the **magnetic field** produce an **electric field** near the earth's surface, which will then induce a DC voltage along the length of a transmission line in accordance to Faraday's Law

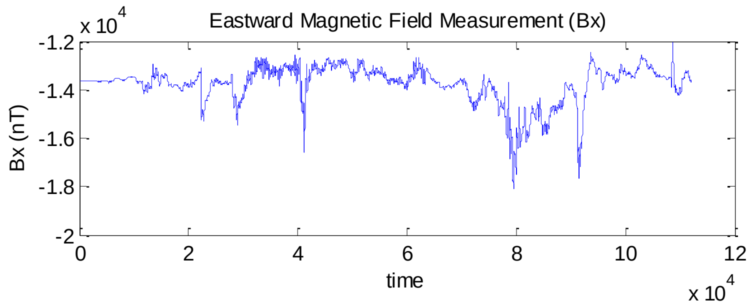
Non-Uniform, Time-Varying Electric Fields Will Induce DC Voltages on Transmission Lines

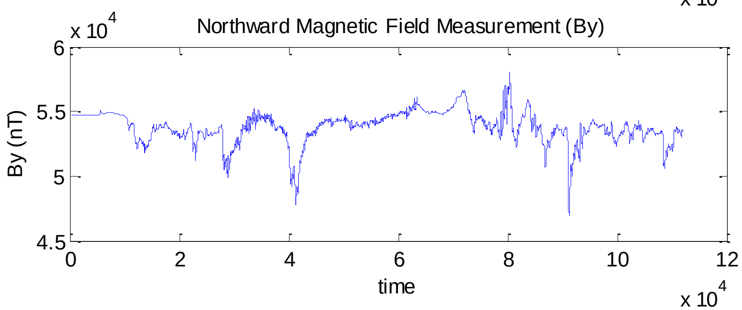


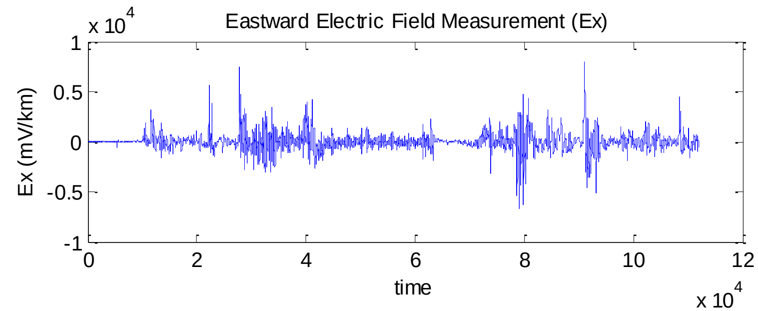


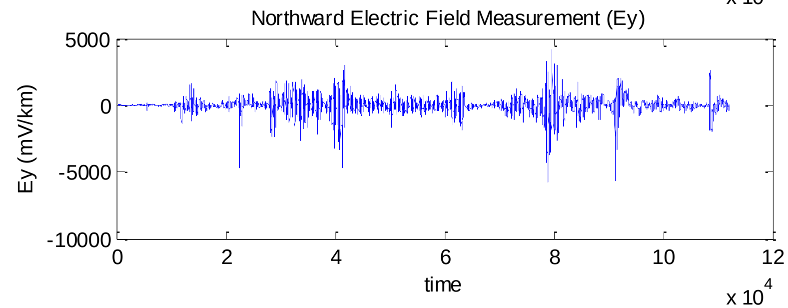


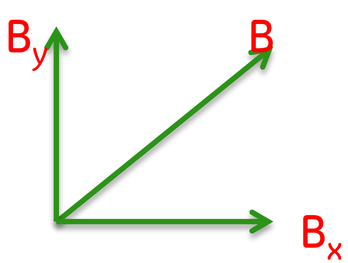
Geomagnetic and Geoelectric fields in the 1989 solar storm (Ottawa observatory)

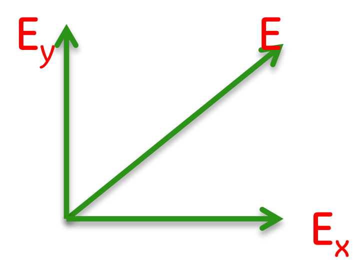




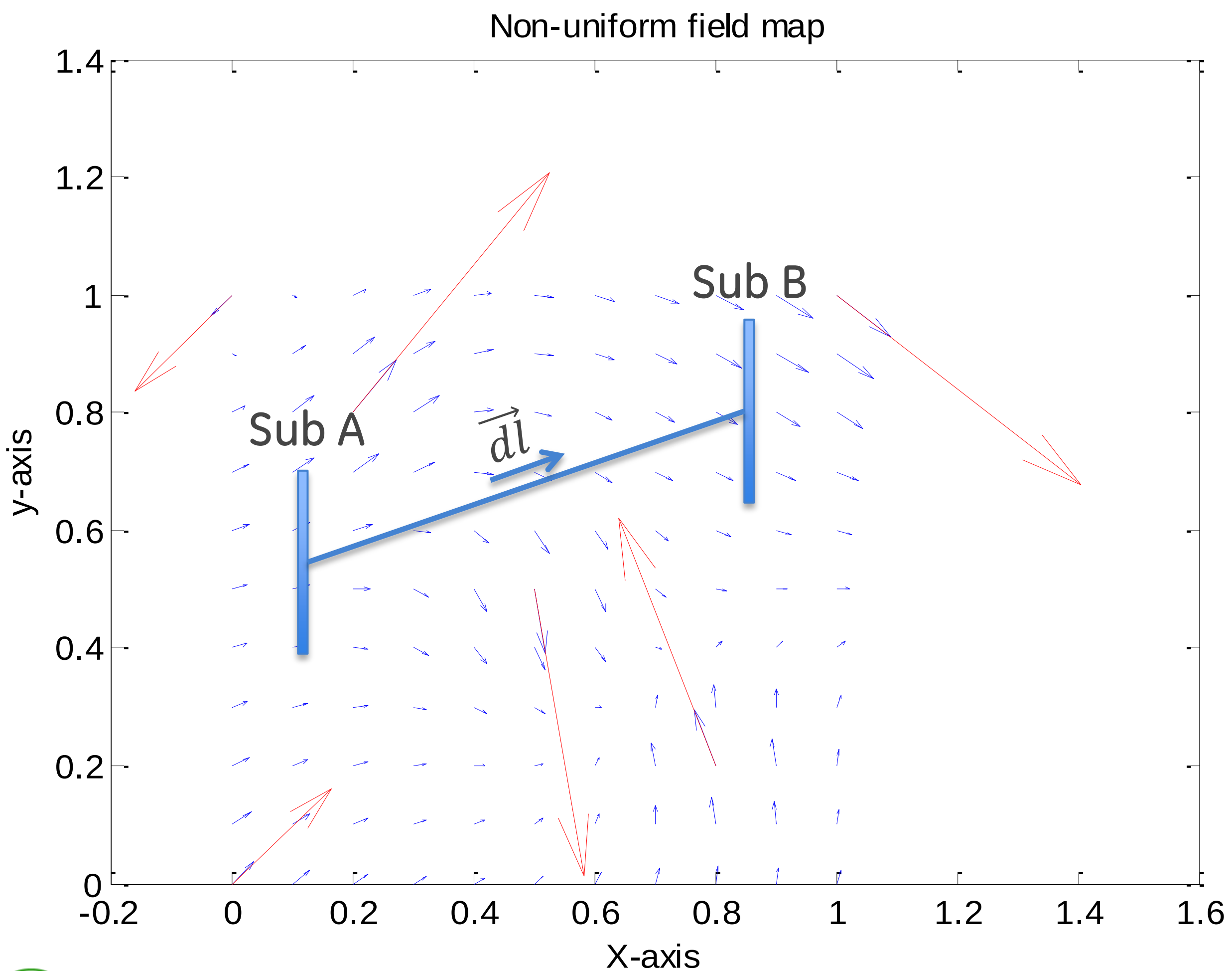






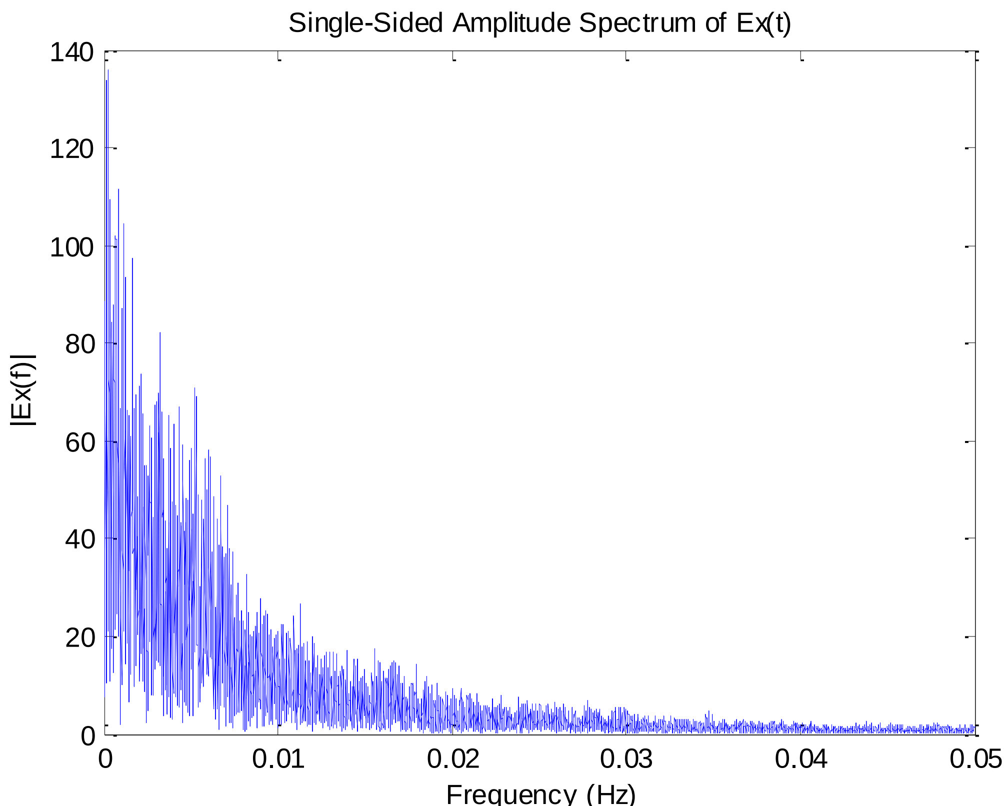


V_{DC} Calculation Via Faraday's Law



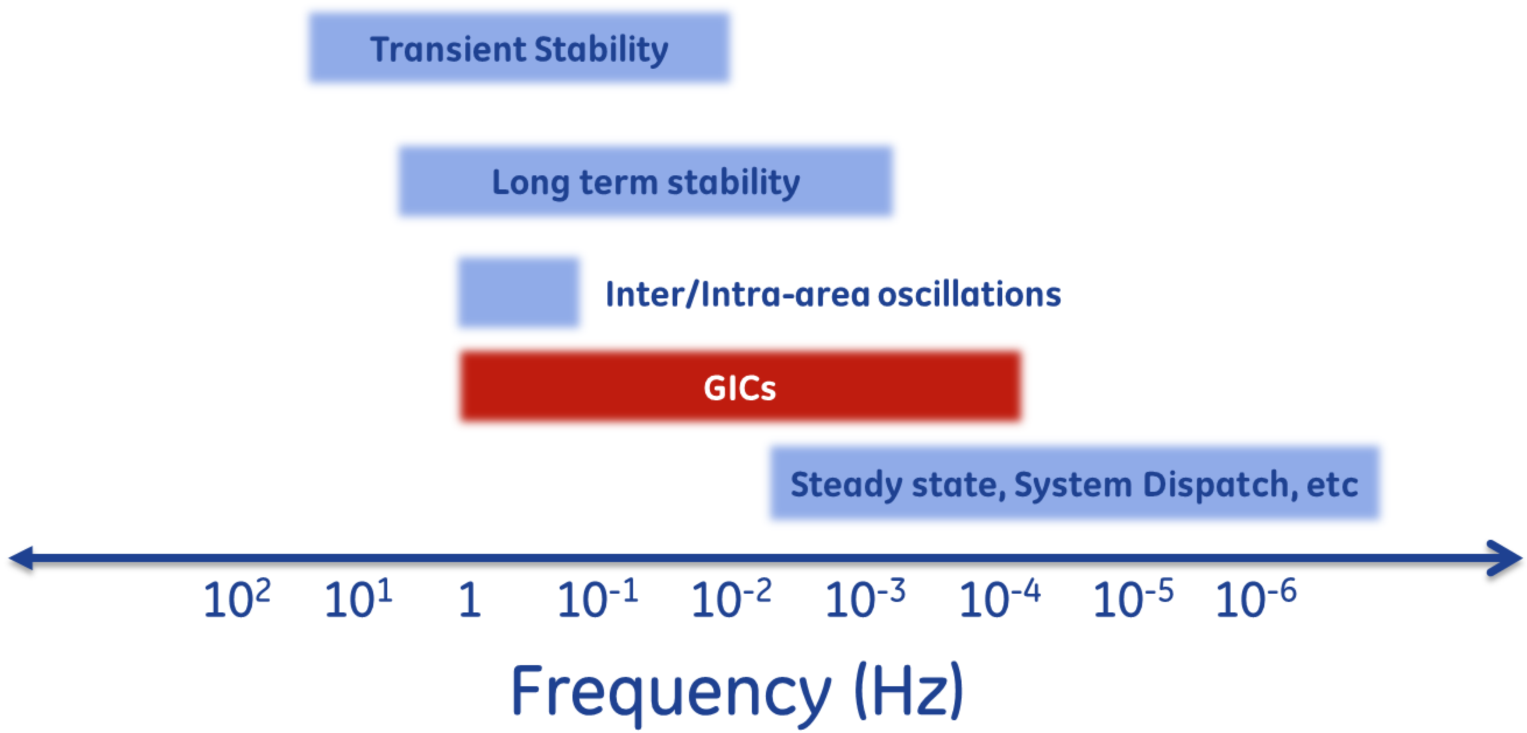
$$V_{DC} = \oint_L \vec{E} \cdot \partial \vec{l}$$

Spectral Composition of 1989 Storm Electric Field Sample

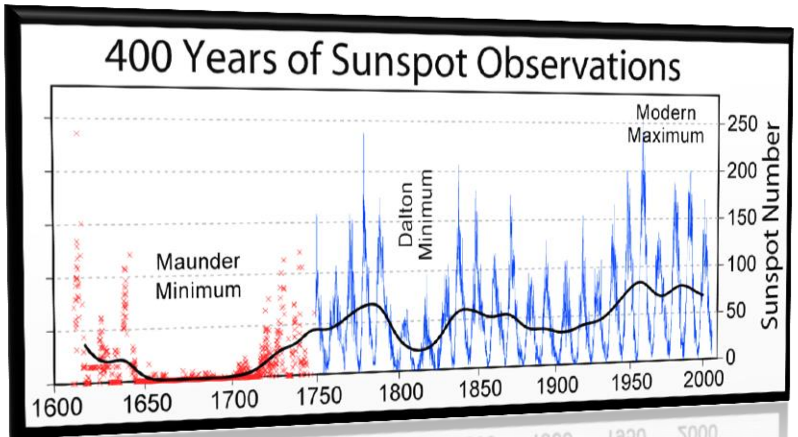


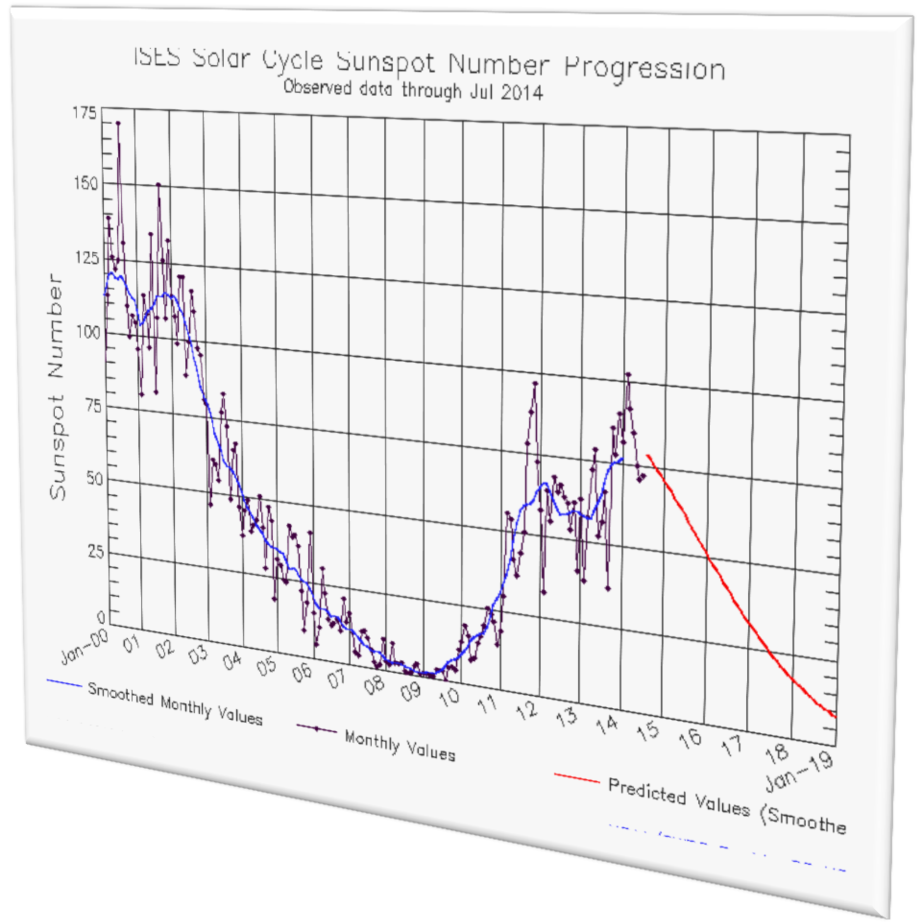
Traditionally, GICs frequencies are assumed to vary between **0.0001Hz and 1Hz,** with lower frequency components being predominant

GMD phenomena time scale



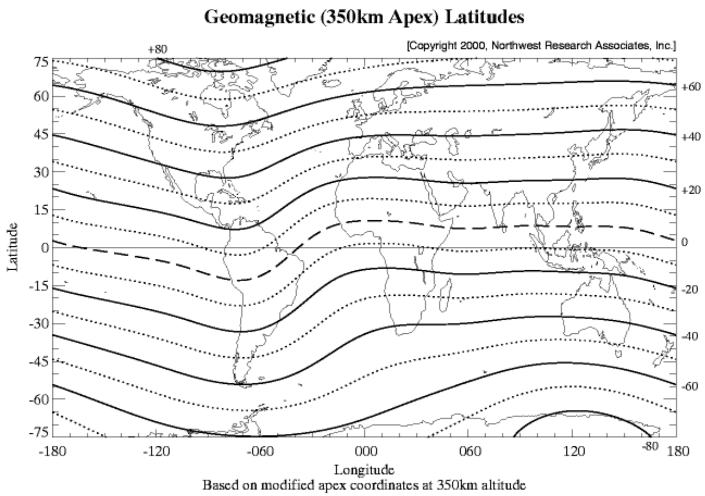
Solar cycle has a period of approximately 11 years

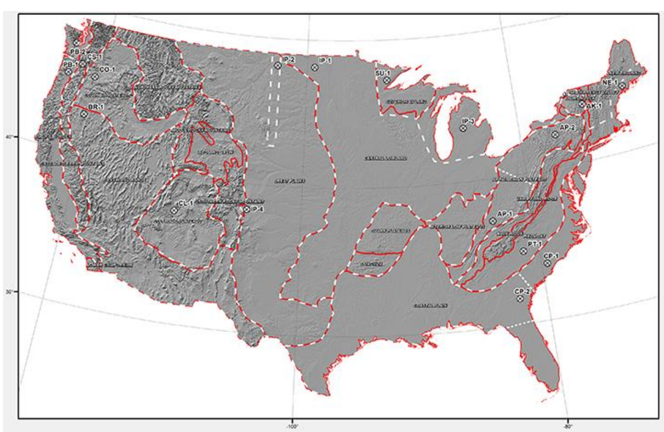


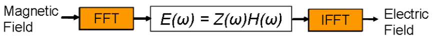


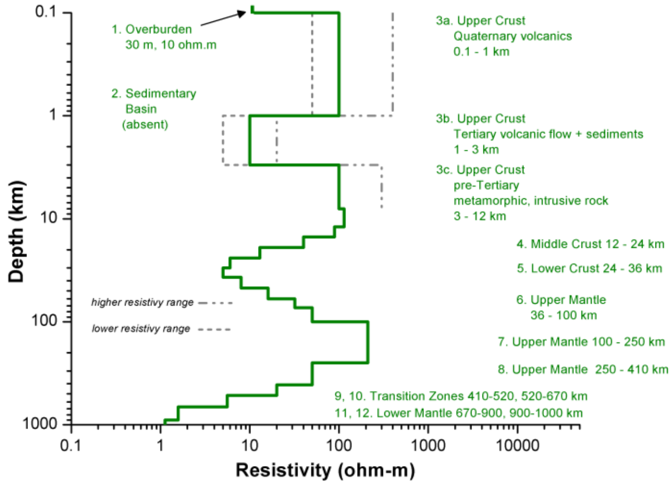
* Graphs are property of NOAA

GIC intensity depends on the geomagnetic latitude and soil conductivity profile

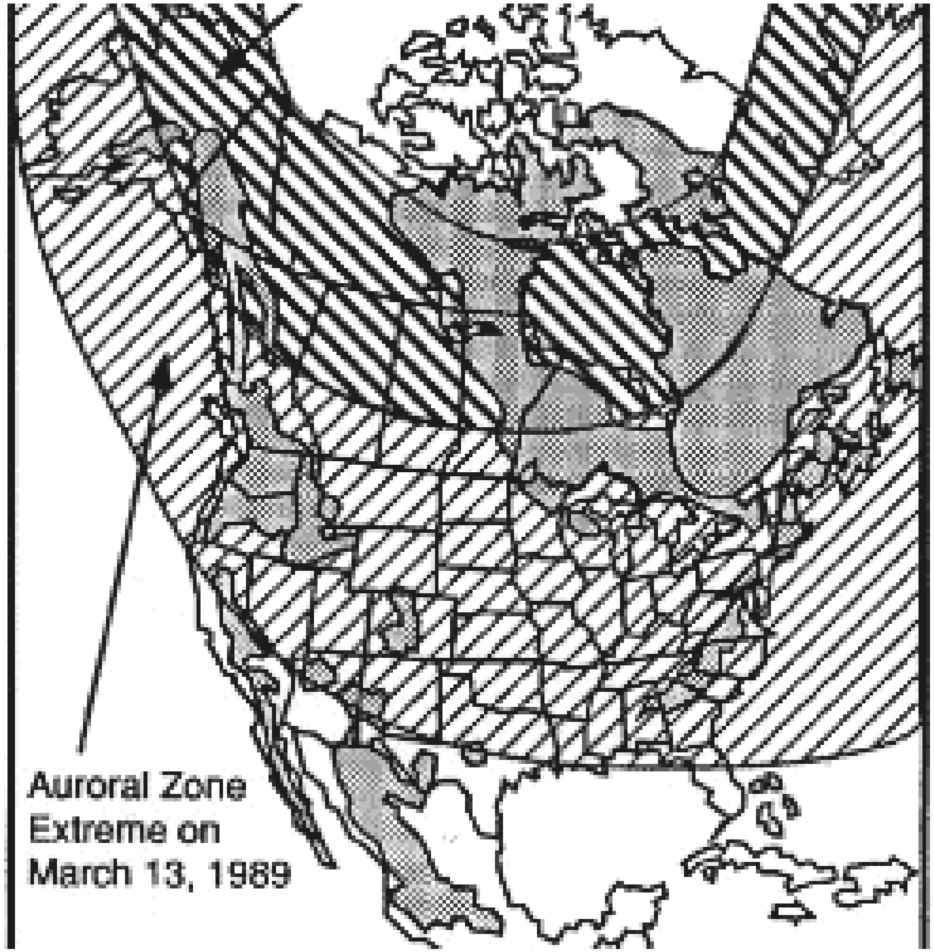








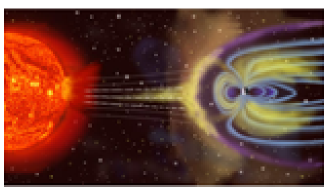
Auroral Zones and Igneous Rock Regions



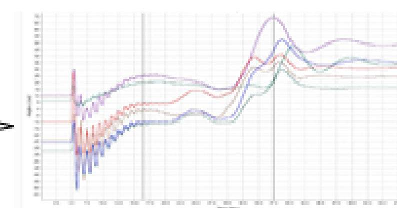
- Areas of igneous rock (show in gray) prone to higher GICs
- This happens because the induced electric field is higher is areas of low soil conductivity
- Coastal areas can also be under higher E-field intensities due high conductivity seawater bodies

GMD Phenomena – from Sun to PSLF simulator

Science component				Power systems engineering component		
Solar flare	Earth magnetic field variation	Soil conductivity model	Induced E-field and voltage near earth's surface	DC voltage and GIC calculation	Additional VAR demand due to transformer saturation	Power systems steady state and dynamic analysis

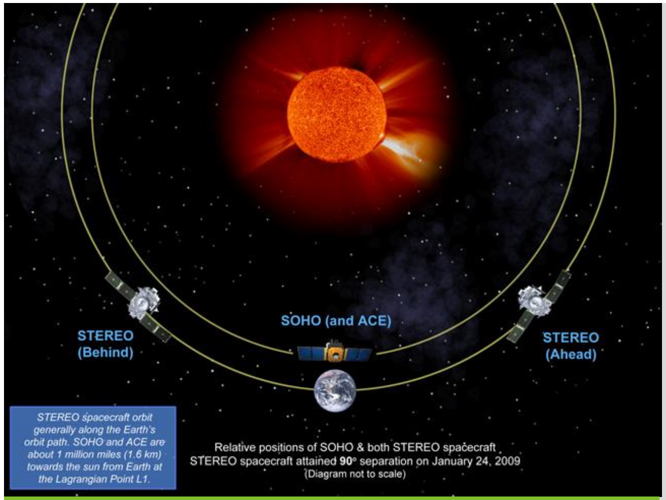


$\frac{\partial \vec{B}}{\partial t}$ ρ $\vec{E}(t,s)$ $Y_{bus} \cdot V = I$ $Q = f(GIC)$



Space weather monitoring

- Forecasters can determine if CME is earth directed
- Warnings regarding solar storms can be issues 14 to 96 hours before the effects are felt on earth
- Indices are used to determine intensity of solar storm (A index and K index)



* NASA Goddard Space Flight Center: http://stereo.gsfc.nasa.gov/img/sciencevisuals/preview/ST_orbit1.jpg

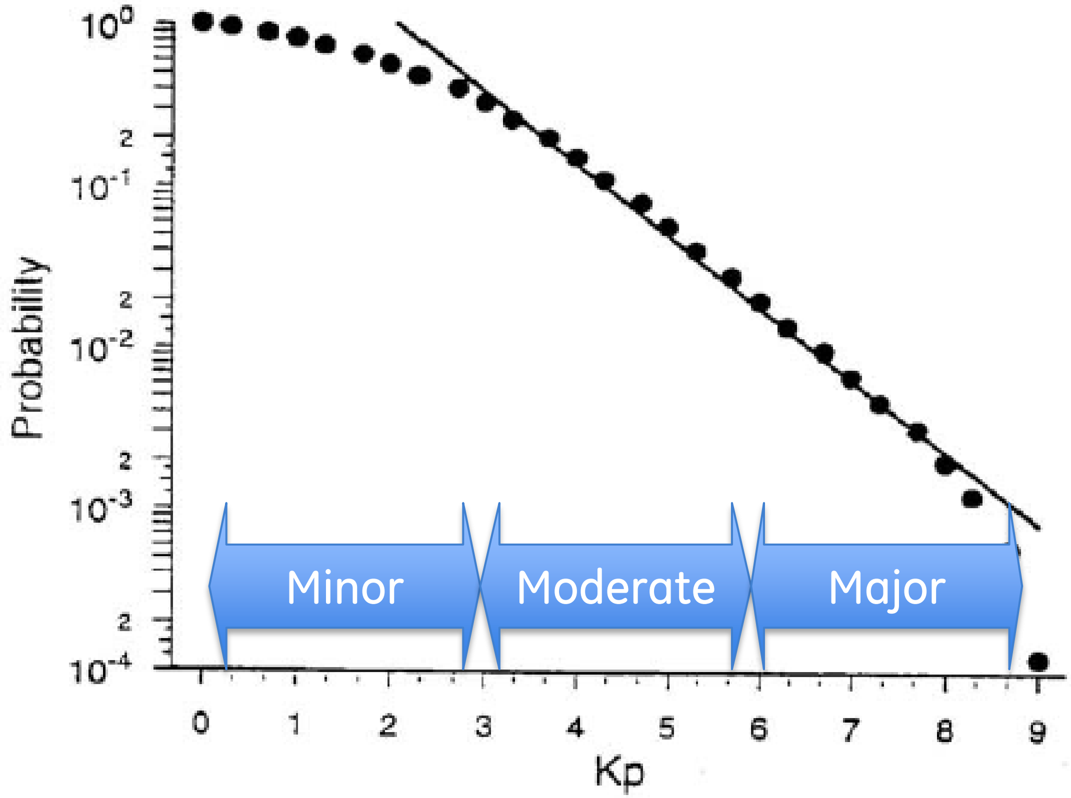
A number of satellites are used to provide space weather information, including the Solar Terrestrial Relations Observatory (STEREO) and the Advanced Composition Explorer (ACE) satellite.

Storm levels and indices

Solar Activity	A index Level	K Index Level
Quiet	A < 7	$1 < K \leq 2$
Unsettled	7 < A < 15	$2 < K \leq 3$
Active	15 < A < 30	$3 < K \leq 4$
Minor Geomagnetic Storm	30 < A < 50	$4 < K \leq 5$
Major Geomagnetic Storm	50 < A < 100	$5 < K \leq 6$
Severe Geomagnetic Storm	A > 100	$K \geq 7$

Kp Index	NOAA Space Weather Scale Geomagnetic Storm Levels
Kp = 5	G1 (minor)
Kp = 6	G2 (moderate)
Kp = 7	G3 (strong)
Kp = 8	G4 (severe)
Kp = 9	G5 (extreme)

Storm Intensity Distribution (data measured from 1932-1991)



NOAA Space Weather Notification Process

Identification

CME on the sun

Magnetic deviation detected by ACE

Notification

NOAA and STDN Issue warnings

East – MISO

West – WECC

Balancing authorities notified

NERC and TOP Functions Notified

Mitigation

Real time System Operations Actions Taken

Geomagnetic Induced Current (GIC) in Bulk Power System

Tools for GMD study

- Given the low frequency of GICs, most of its effects on the bulk power system can be studied primarily with power flow tools
- Transient stability tools can be used to simulate the faster variations of a GMD disturbance
- Ideally, a long term quasi steady state tool would be ideal to simulate long, slow varying GMD disturbances
- Quasi steady state tools are not readily available commercially so a simplified time series power flow can be used instead (under certain assumptions)

Known GMD effects on power system equipment

- Transformer thermal damage
- Harmonic-induced equipment trip (SVCs, capacitors, etc.)
- Increased Var consumption due to transformer saturation
- Low voltages
- Generator heating (negative sequence currents)
- Protection misoperation due to CT saturation, others

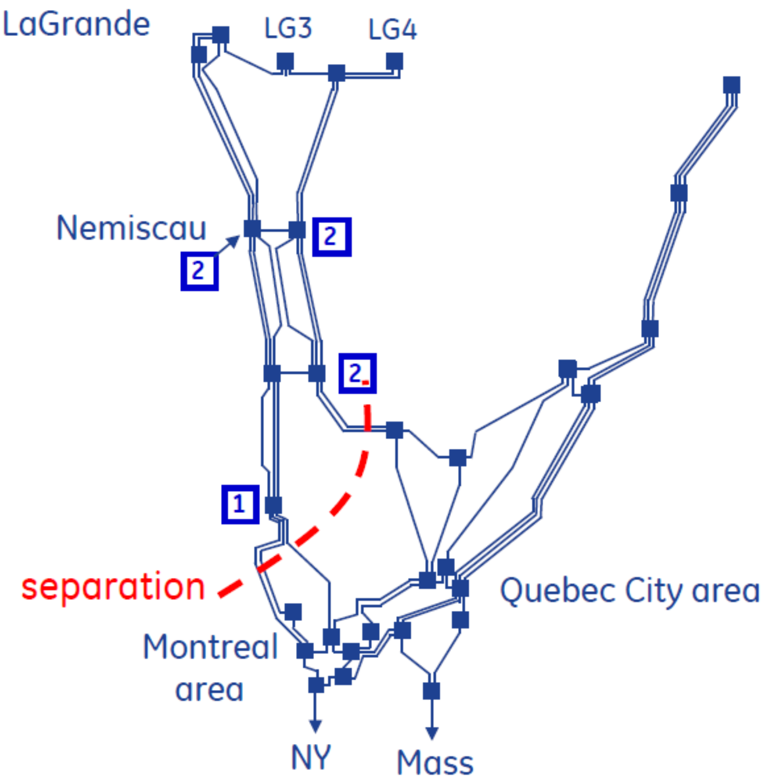
Transformer at the Salem Nuclear Plant, damaged by March 1989 solar storm

Reported transformer effects to the 1989 storm

1. **Salem Nuclear Plant (GSU #1)**
   i. Increased MVAr consumption (14% of nameplate rating)
   ii. Increase in combustible gases in oil (heating effect)
   iii. High noises
   iv. Degree of burning varied for different series connections
2. **Salem Nuclear Plant (GSU #2)**
   i. Caused minor damage to one phase of transformer
3. **Allegheny Power Systems (APS) – (3-phase, 7-leg core shell form autotransformer rated 210/280/350 MVA)**
   i. Significant increase in dissolved combustible gases
   ii. Discolored tank paint in four locations
   iii. 14% increase in MVAr demand
   iv. Increase in noise (10-15 dB)
   v. Increase in harmonic current (THDi = 9.2%)
4. **Other GMD related transformer reports in ESKROM (South Africa), National Grid (UK) and Transpower (New Zealand)**

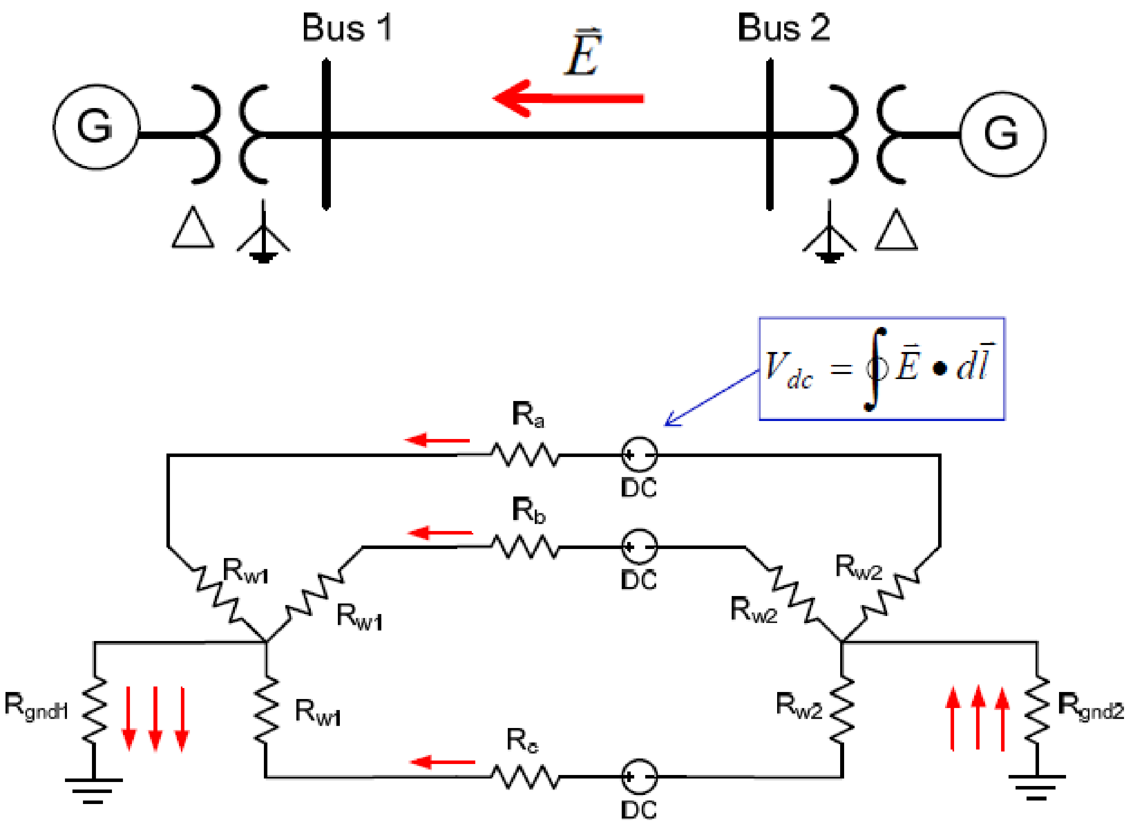
Hydro-Quebec Blackout

- HQ system was designed to operate reliability and heavily depended on 7 SVCs and shunt reactors for voltage control
- Harmonic currents injected by GIC saturated transformers cause SVC protection to trip (sensitivity to harmonics)
- Trip of SVC lead to system instability and blackout of 83% of the load in Quebec
- It took nearly a 100s before the system was disrupted - HQ system restored in 9h ~150MW load loss in NY/~1400MW NE



GIC calculation

Induced DC voltages drive GIC flow



*Picture from NERC report "Effects of Geomagnetic Disturbances on the Bulk Power Systems", February 2012.

Data required

- E-Field data
- Substation data
- Transmission line data
- Transformer data
- Shunt data (reactors)

Table A8-2: Transmission line information

Line	From Bus	To Bus	Length (km)	Resistance (Ohms/phase)
1	2	3	121.03	3.525
2	4	5	160.18	4.665

Table A8-1: Substation location and ground grid resistance

Name	Latitude	Longitude	Grounding Resistance (Ohms)
Sub 1	33.613499	-87.373673	0.2
Sub 2	34.310437	-86.365765	0.2
Sub 3	33.955058	-84.679354	0.2

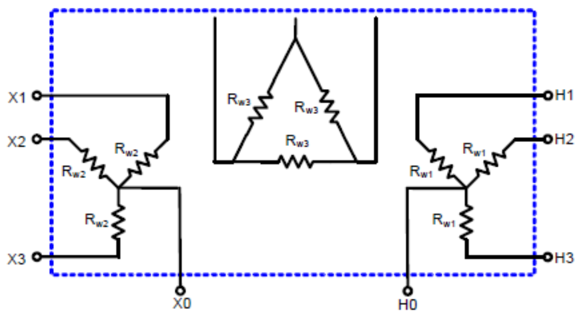
Table A8-3: Transformer and autotransformer winding resistance values

Name	Resistance W1 (ohm/phase)	Resistance W2 (ohm/phase)
T1	0.5	N/A
T2	0.2 (series)	0.2 (common)
T3	0.5	N/A

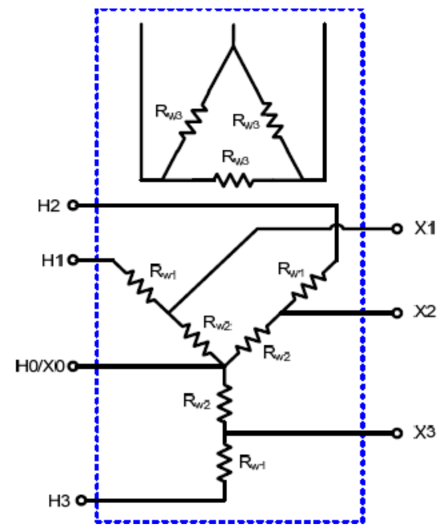
Table A8-4: Eastward and northward distance calculation results

Line	From Bus	To Bus	Northward Distance (km)	Eastward Distance (km)
1	2	3	-77.499	-92.96
2	4	5	39.518	-155.22

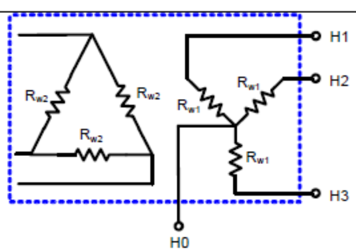
Transformer Winding Connections



Three-Winding Transformer Gy-Gy-Delta

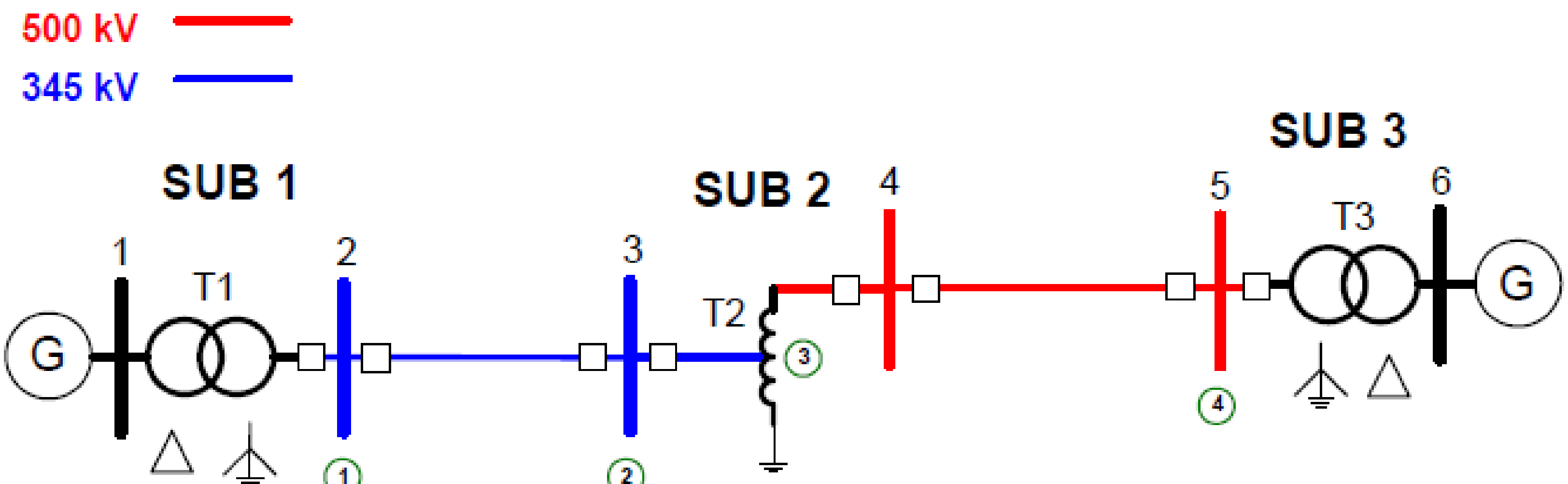


Autotransformer Gy-Gy-Delta

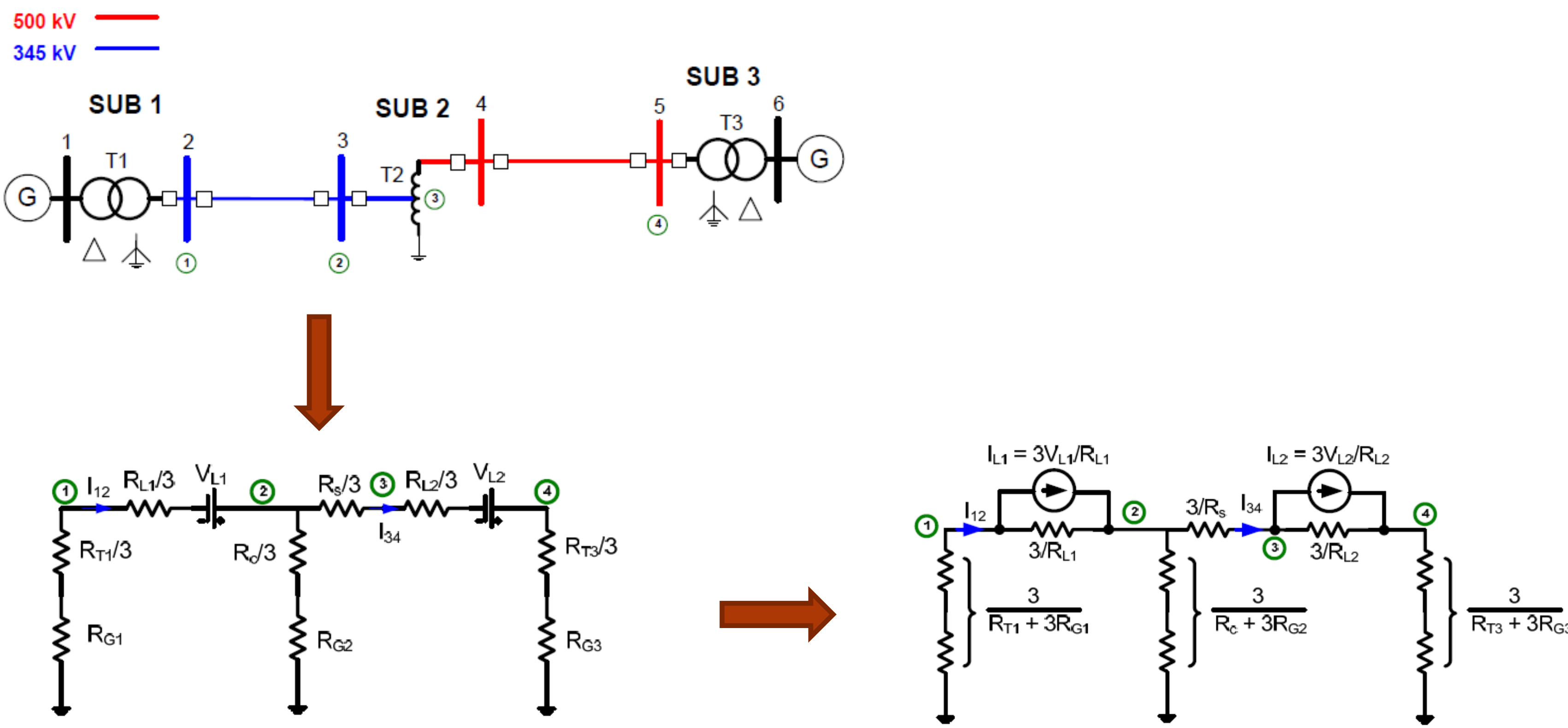


GSU Gy-Delta

NERC 6 Bus Example

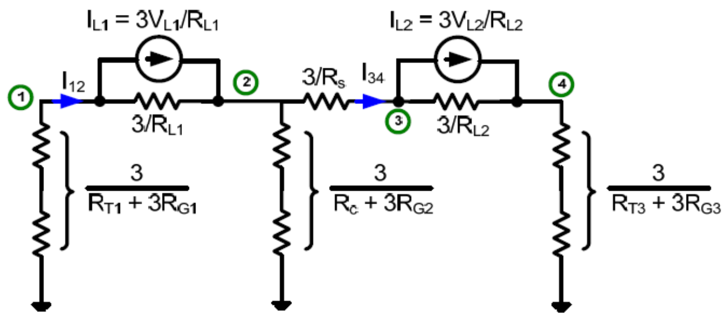


Equivalent DC network



***Example taken from NERC report “Effects of Geomagnetic Disturbances on the Bulk Power Systems”, February 2012.

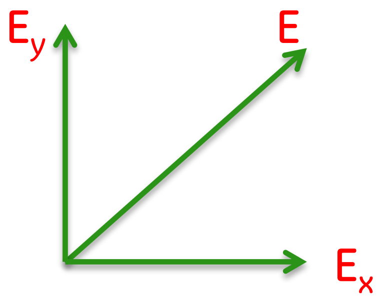
Nodal DC Voltage Calculation

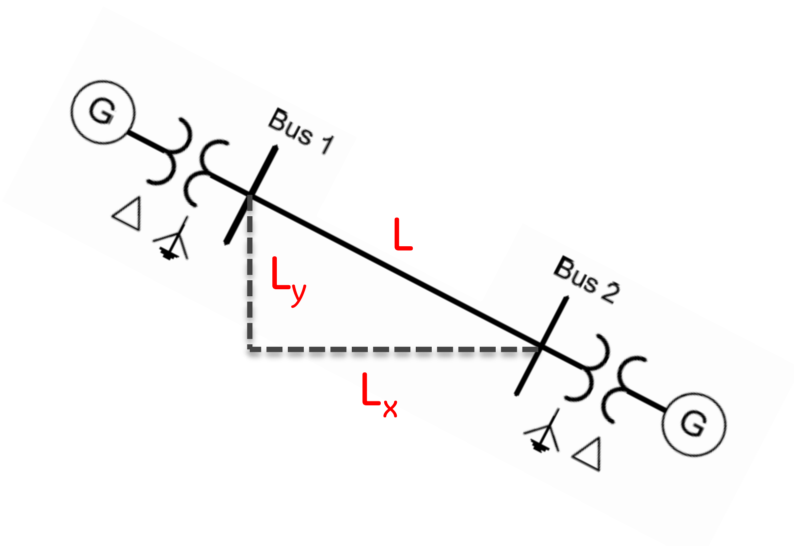


$$Y = \begin{bmatrix} \frac{3}{R_{T1}+3R_{G1}} + \frac{3}{R_{L1}} & -\frac{3}{R_{L1}} & 0 & 0 \\ -\frac{3}{R_{L1}} & \frac{3}{R_S} + \frac{3}{R_{L1}} + \frac{3}{R_C+3R_{G2}} & -\frac{3}{R_S} & 0 \\ 0 & -\frac{3}{R_S} & \frac{3}{R_S} + \frac{3}{R_{L2}} & -\frac{3}{R_{L2}} \\ 0 & 0 & -\frac{3}{R_{L2}} & \frac{3}{R_{L2}} + \frac{3}{R_{T3}+3R_{G3}} \end{bmatrix} \quad I = \begin{bmatrix} -I_{L1} \\ I_{L1} \\ -I_{L2} \\ I_{L2} \end{bmatrix}$$

$$I = YV_{DC}$$

Calculation of Induced DC Voltage

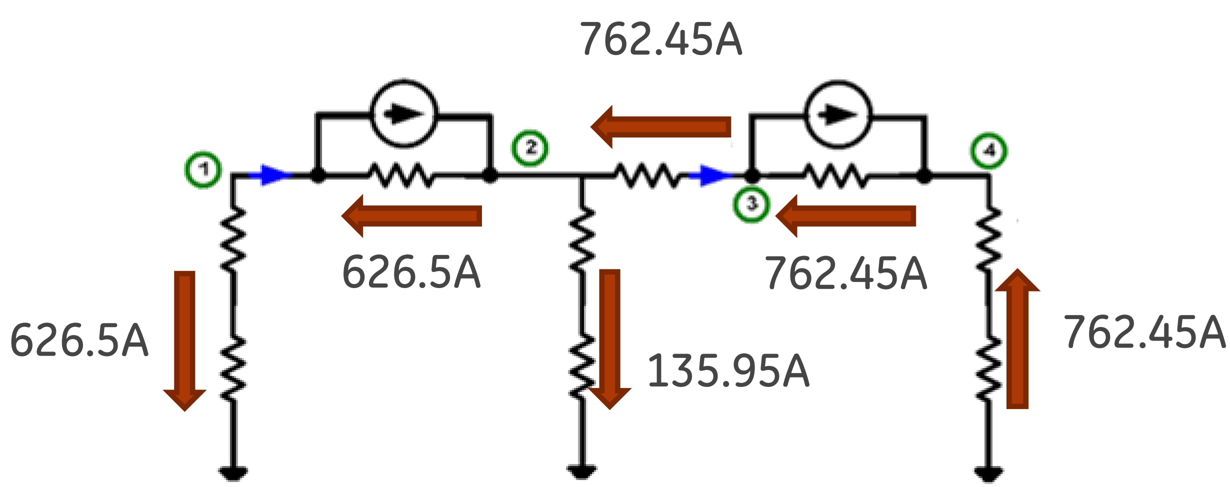




$$V_{DC} = \int \vec{E} \cdot d\vec{l} = ExL_x + EyL_y$$

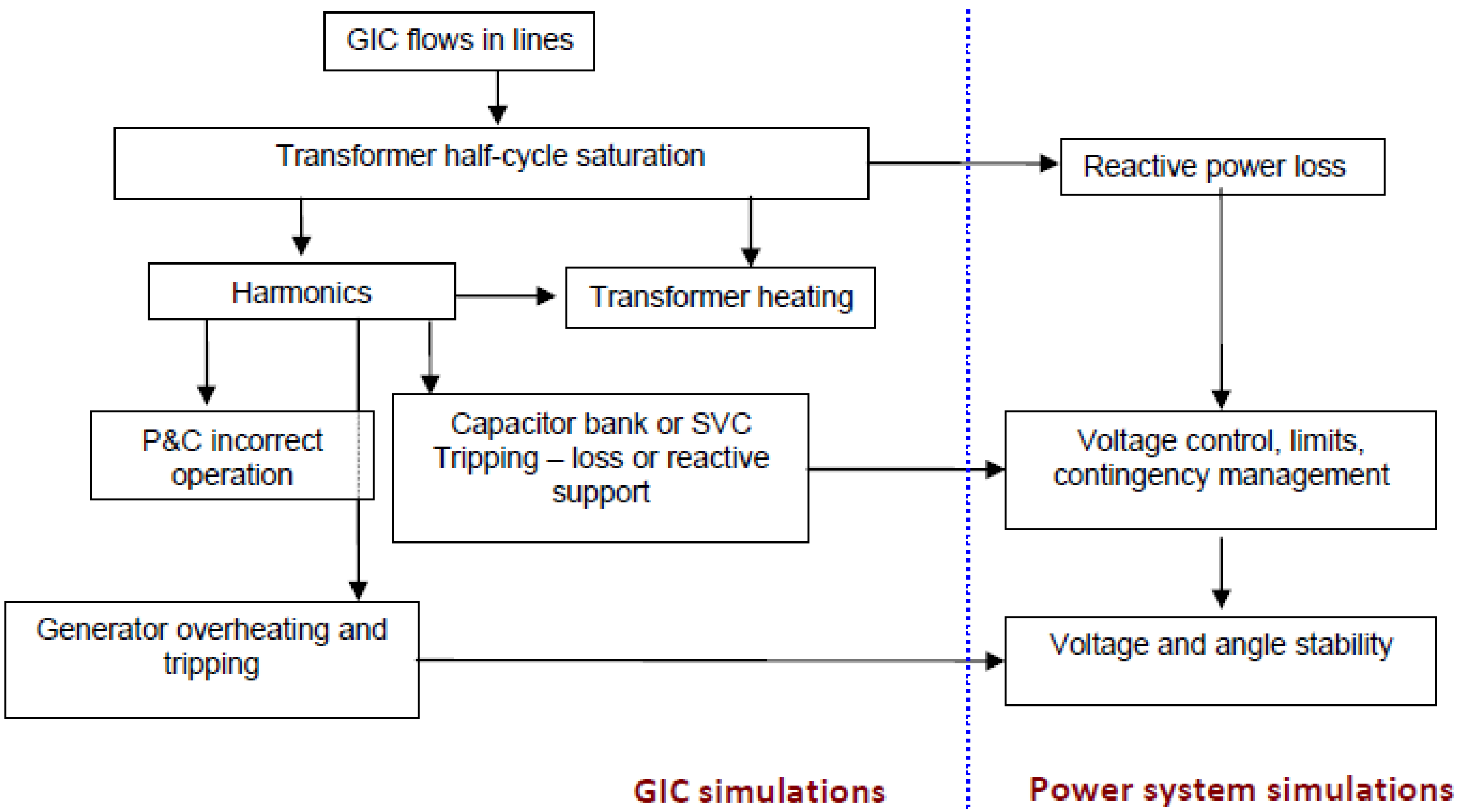
GIC Calculation

- After the DC voltages in the entire network are known, it is trivial to calculate GICs in all equipment



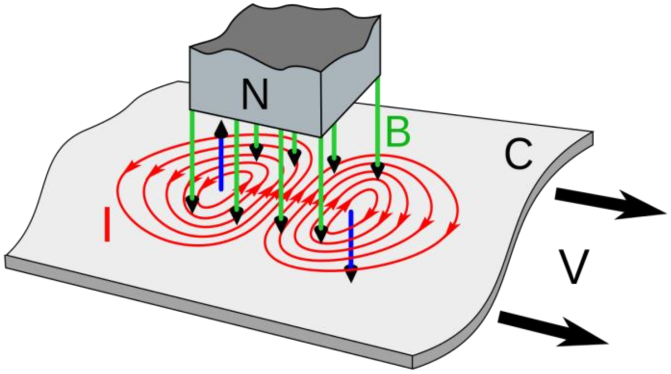
GIC Effects on Power System Equipment

Overall Power System GIC impact



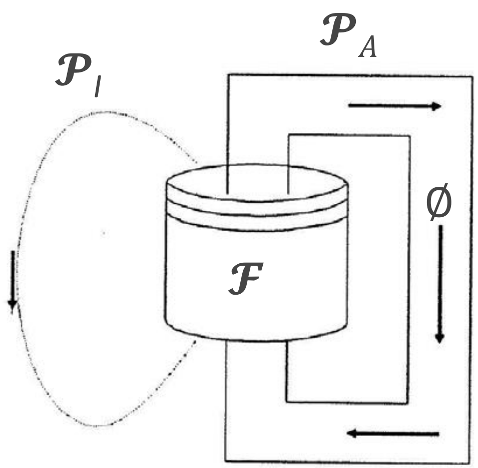
Transformer Impacts

- Increased amount of stray flux and consequently stray losses (thermal losses in structural parts)
- Core saturation places flux outside transformer core causing heating through eddy loss
- Localized heating in windings, tank walls and structural components



***"Eddy currents due to magnet" by Chetvorno - Own work. Licensed under Creative Commons Zero, Public Domain Dedication via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Eddy_currents_due_to_magnet.svg#mediaviewer/File:Eddy_currents_due_to_magnet.svg

Basics of Transformer Magnetics



$\mathcal{F}$ − *Magneto Motive Force (mmf)*
$\emptyset$ − *Magnetic Flux*
$\mathcal{R}$ − *Reluctance*
$\mathcal{P}$ − *Permeance*
N − *# of Turns*

$$\mathcal{F} = \emptyset \cdot \mathcal{R} = NI$$

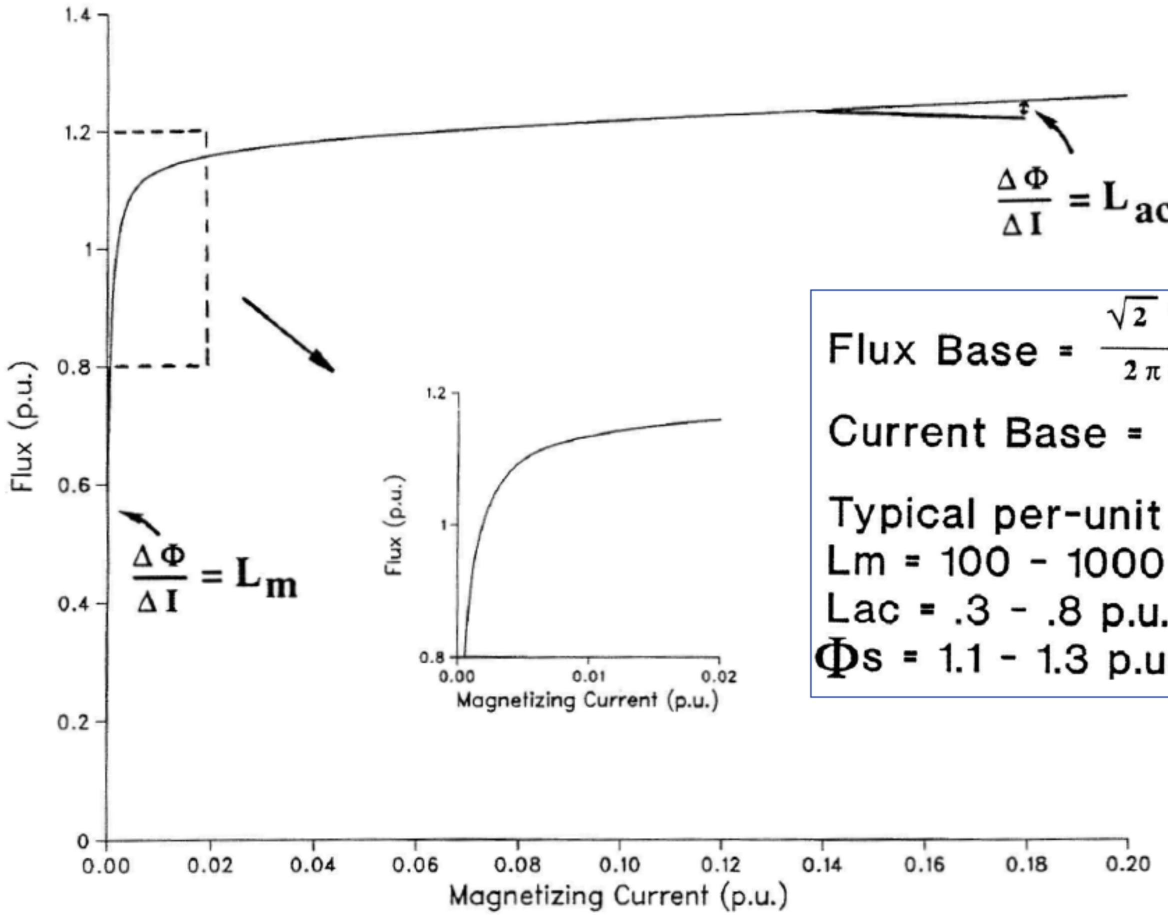
$$I = \frac{\emptyset}{N(\mathcal{P}_A + \mathcal{P}_I)}$$

$$V = -N\frac{\partial\emptyset}{\partial t}$$

$$\emptyset = \frac{-1}{N}\int V\,dt$$

$$I = -\frac{\int V\,dt}{N^2(\mathcal{P}_A + \mathcal{P}_I)}$$

Typical Saturation Curve



Flux Base = $\frac{\sqrt{2}\ V_{ln}}{2\pi\ 60}$

Current Base = $\frac{\sqrt{2}\ MVA_{1\phi}}{V_{ln}}$

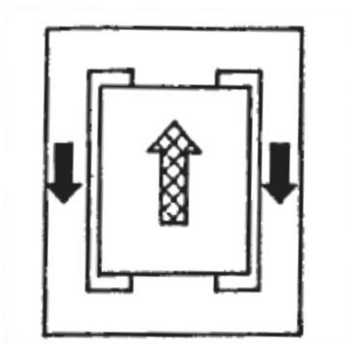
Typical per-unit values:

Lm = 100 - 1000 p.u. (= Xm = 1/Im)

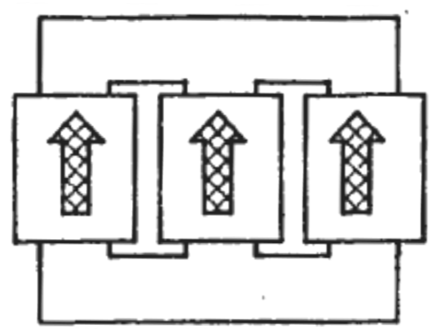
Lac = .3 - .8 p.u. (= Xac)

Φs = 1.1 - 1.3 p.u.

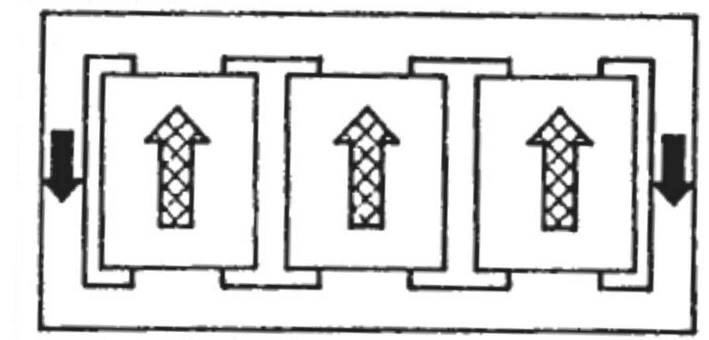
Transformer types



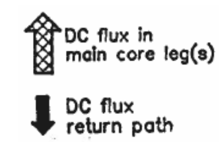
Core/shell form, 1ϕ

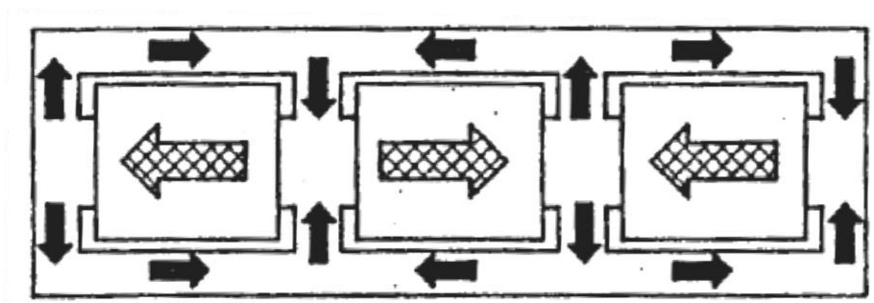


Core form, 3ϕ – 3 leg

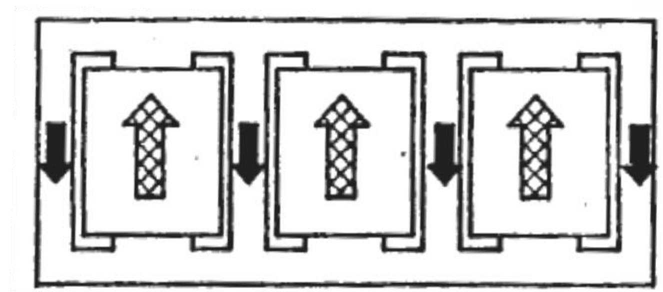


Core form, 3ϕ – 5 leg



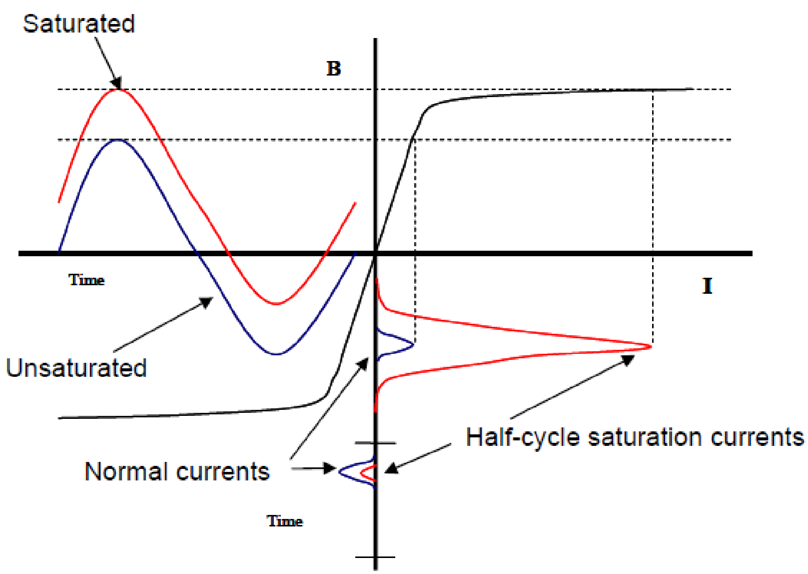


Shell form, 3ϕ



Core form, 3ϕ – 7 leg

Transformer Half-Cycle Saturation

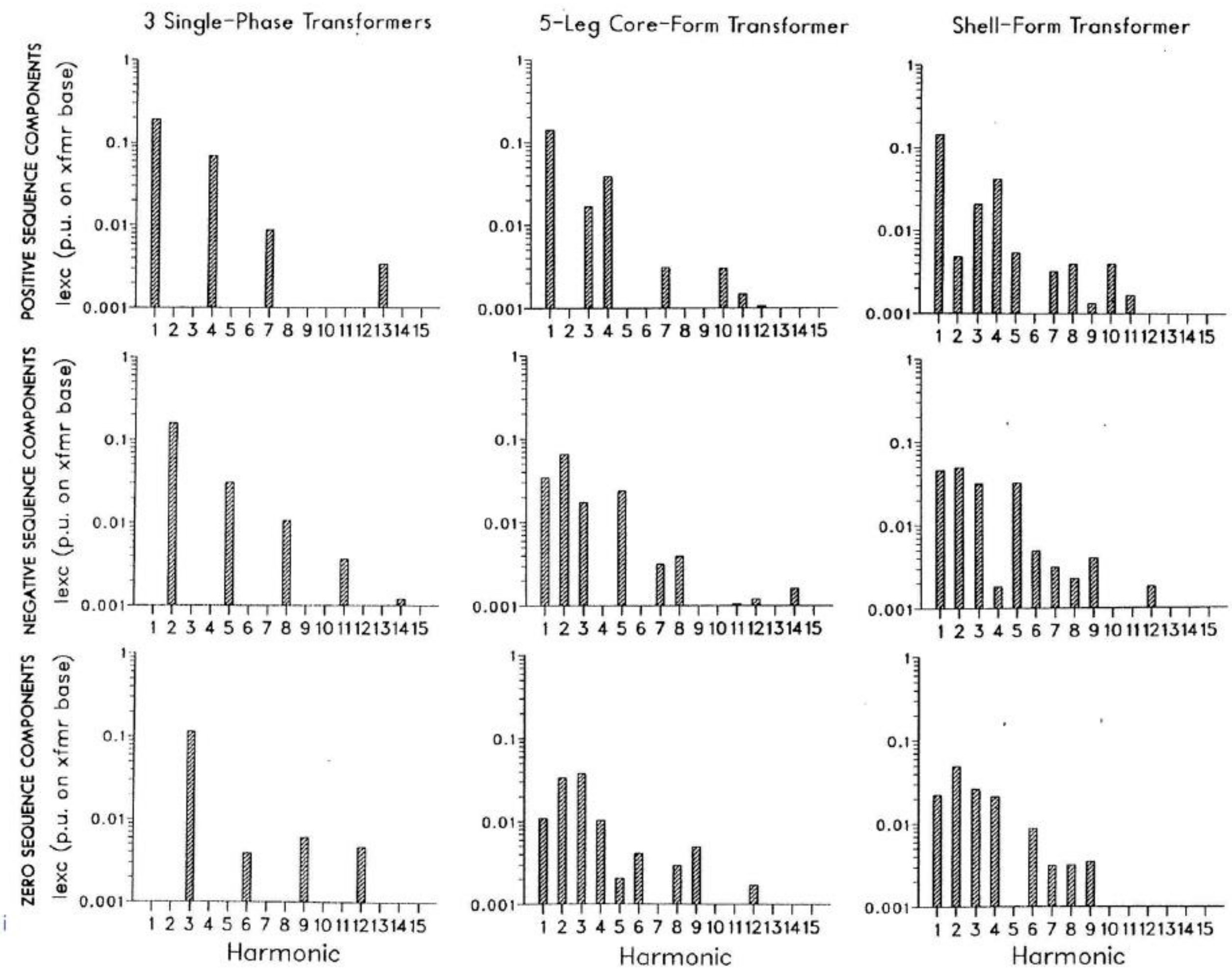


- DC current creates an offset in the magnetizing current
- Only half cycle of magnetizing current enters saturated region
- Harmonic currents have both even and odd components and decay with harmonic order

Harmonics Impacts

- Saturation distorts wave form and introduces harmonics into the system
- Causes equipment overheating due to Eddy losses
- Capacitor & SVC overload (remember, shunt capacitors are seen as low impedance paths for high frequency components)
- Control and protection misoperation mostly due to CT saturation (modern relays do not rely on CTs)
- Generator thermal stress due to negative sequence currents can cause generator heating and tripping

Symmetrical Components at 0.1 p.u GIC



Potential events during a GMD event

Reduced stability margin

- Depressed voltages
- Reduced reactive reserves
- Transformer out of service
- Increased power transfers

Increased potential for abrupt disturbances

- Protective tripping of transformers, capacitors, SVCs

Protection system less reliable

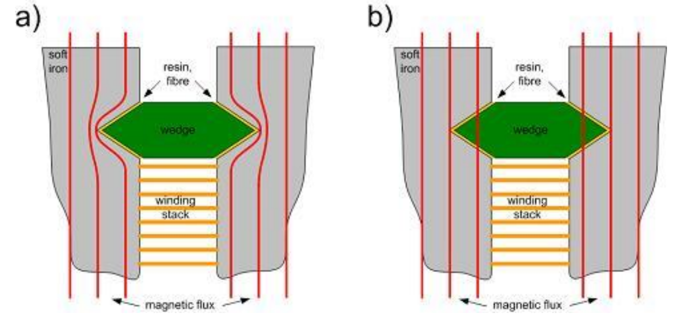
- False trips
- Delayed tripping, failure to trip for actual faults

Increased risk of operator error

- Unusual symptoms
- Unfamiliar operating regime

Generator Impacts

- Increased negative sequence harmonic currents resulting in increased generator heating
- Potential damage to rotor body/wedges due to heating can create a fatigue crack initiation site
- Increased mechanical vibration
- Potential to resonance near 6th harmonic (electrical and mechanical)
- Negative sequence relay operation or erratic behavior due to harmonics



Capacitor Bank Impacts

- Increased bank loading and RMS current due to harmonic components
- Ungrounded bank will see less RMS current because it blocks zero sequence component
- Potential resonance between cap bank and transformer air core reactance
- Failure of small portions of the bank (capacitor cans) and bank tripping due to unbalanced relay operation

NERC GMD Standards

Two Standards Were Developed

- FERC Order directs NERC to file standards that address GMDs.
- Standards are to be implemented in two stages
  - EOP-010-1 — Geomagnetic Disturbance Operations – Effective Mid 2014
  - TPL-007-1 - Transmission System Planned Performance for Geomagnetic Disturbance Events – Effective Mid 2015

EOP-010-1 Requirements

Each Reliability Coordinator shall develop, maintain, and implement a GMD Operating Plan

Each RC shall disseminate forecasted weather information to functional entities identified as recipients in the Reliability Coordinator's GMD Operating Plan

- Activities designed to mitigate the effects of GMD events
- Steps or tasks to receive space weather information.
- System Operator actions to be initiated based on predetermined conditions.
- Conditions for terminating the Operating Procedure

TPL-007-1 Requirements

Planning Coordinators and TPs must maintain models and perform studies needed to complete GMD Vulnerability

Shall develop a criteria for acceptable system steady state voltage performance for its System during the benchmark GMD event

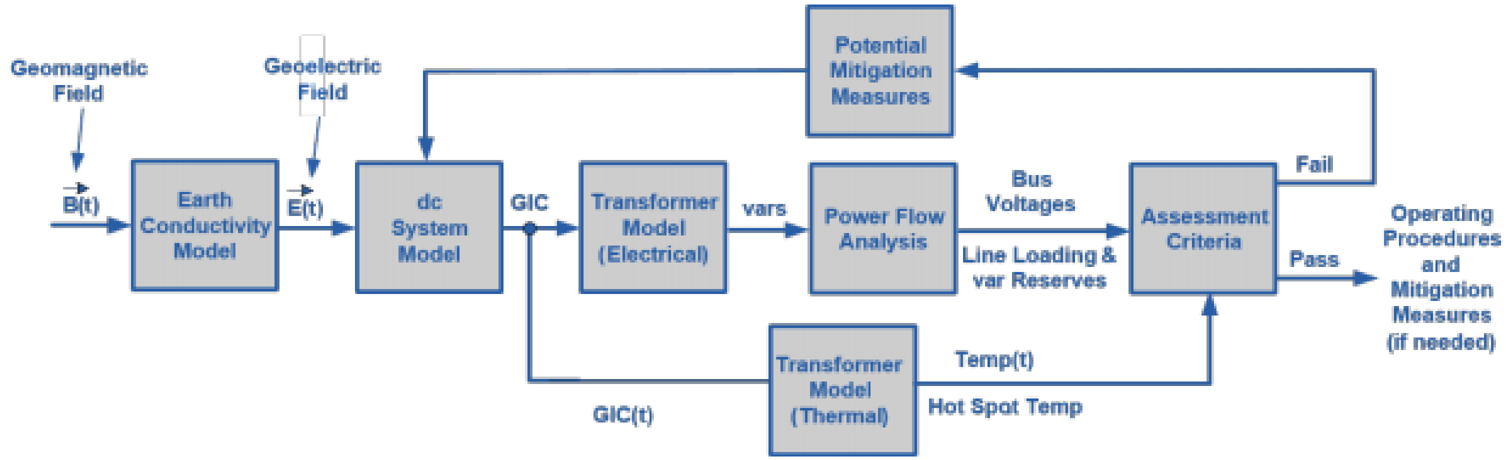
PCs and TPs shall complete a GMD Vulnerability Assessment of the Near-Term Transmission Planning Horizon once every 60 calendar months

PCs and TPs shall provide GIC flow information to be used for the transformer thermal impact assessment to each Transmission Owner and Generator Owner

TPL-007-1 Requirements (continued)

Transmission Owner and Generator Owner shall conduct a thermal impact assessment for each transformer where the maximum effective GIC value is >= 15 A/per phase

System does not meet the performance requirements of specified in the standard, a Corrective Action Plan shall be developed for adequacy



System Performance Requirements According to TPL-007-1

Table 1 –Steady State Planning Events				
Steady State: a. Voltage collapse, Cascading and uncontrolled islanding shall not occur. b. Generation loss is acceptable as a consequence of the planning event. c. Planned System adjustments such as Transmission configuration changes and re-dispatch of generation are allowed if such adjustments are executable within the time duration applicable to the Facility Ratings.				
Category	**Initial Condition**	**Event**	**Interruption of Firm Transmission Service Allowed**	**Load Loss Allowed**
GMD GMD Event with Outages	1. System as may be postured in response to space weather information[1], and then 2. GMD event[2]	Reactive Power compensation devices and other Transmission Facilities removed as a result of Protection System operation or Misoperation due to harmonics during the GMD event	Yes[3]	Yes[3]

Table 1 – Steady State Performance Footnotes

1. The System condition for GMD planning may include adjustments to posture the System that are executable in response to space weather information.
2. The GMD conditions for the planning event are described in Attachment 1 (Benchmark GMD Event).
3. Load loss as a result of manual or automatic Load shedding (e.g. UVLS) and/or curtailment of Firm Transmission Service may be used to meet BES performance requirements during studied GMD conditions. The likelihood and magnitude of Load loss or curtailment of Firm Transmission Service should be minimized.

All Requirements are Based on the Benchmark Storm

$$E = 8 \cdot \alpha \cdot \beta \text{ (V/km)}$$

E = Electric Field
α = Geomagnetic scaling factor
β = Soil conductivity scaling factor

Table 2: Geomagnetic Field Scaling Factors	
Geomagnetic Latitude (Degrees)	Scaling Factor1 (α)
≤ 40	0.10
45	0.2
50	0.3
54	0.5
56	0.6
57	0.7
58	0.8
59	0.9
≥ 60	1.0

Table 3 Geoelectric Field Scaling Factors	
USGS Earth model	Scaling Factor (β)
AK1A	0.56
AK1B	0.56
AP1	0.33
AP2	0.82
BR1	0.22
CL1	0.76
CO1	0.27
CP1	0.81
CP2	0.95
CP3	0.94
CS1	0.41
IP1	0.94
IP2	0.28
IP3	0.93
IP4	0.41
NE1	0.81
PB1	0.62
PB2	0.46
PT1	1.17
SL1	0.53
SU1	0.93
BOU	0.28
FBK	0.56
PRU	0.21
BC	0.67
PRAIRIES	0.96
SHIELD	1.0
ATLANTIC	0.79

PSLF GMD Capabilities

PSLF Capabilities

- Major studies required by TPL-007-1
  - GIC calculation (PSLF)
  - Steady state analysis (PSLF)
  - Time series analysis (PSLF)
  - Transformer thermal impact analysis (GE Energy Consulting) – NERC has a guide for transformer thermal impact analysis

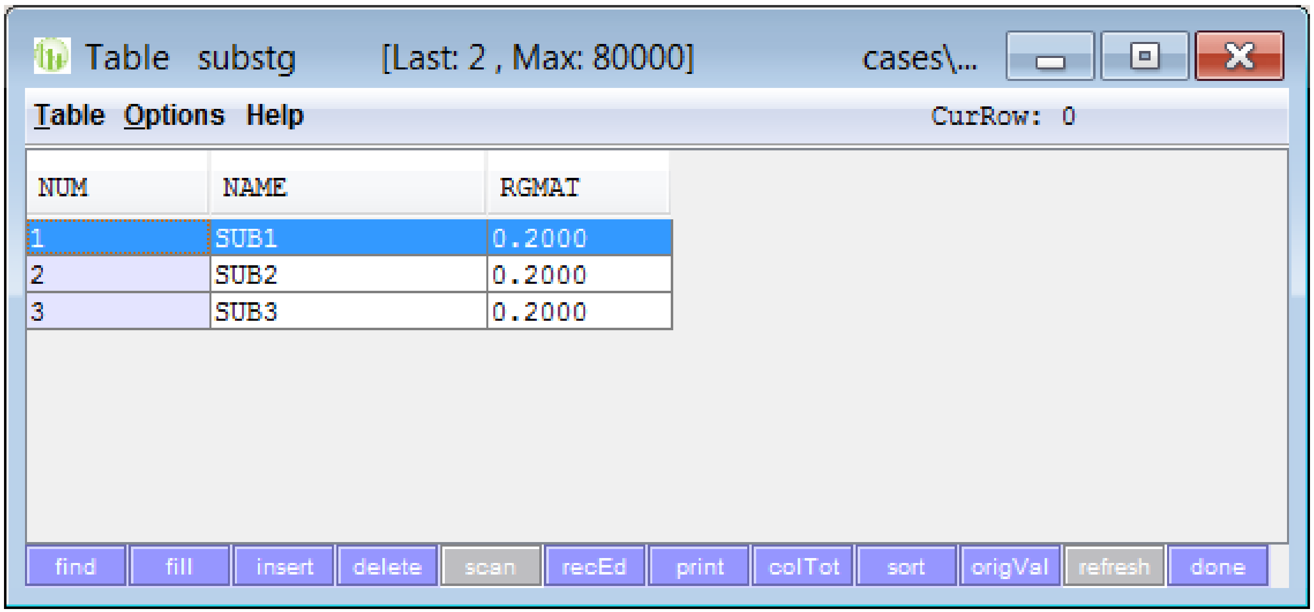
Data Required

Additional data			
GMD DISTURBANCE	**SUBSTATION**	**TRANSMISSION LINES**	**TRANSFORMERS**
GMD induced Electric Field	Ground mat resistance	Line DC resistance*	Transformer winding DC resistance*
	Bus/Substation Latitude/Longitude		Transformer winding connection*
			K factor (saturation)
			Blocking device/ground
			Transformer type (auto, 3-leg core, shell, etc)

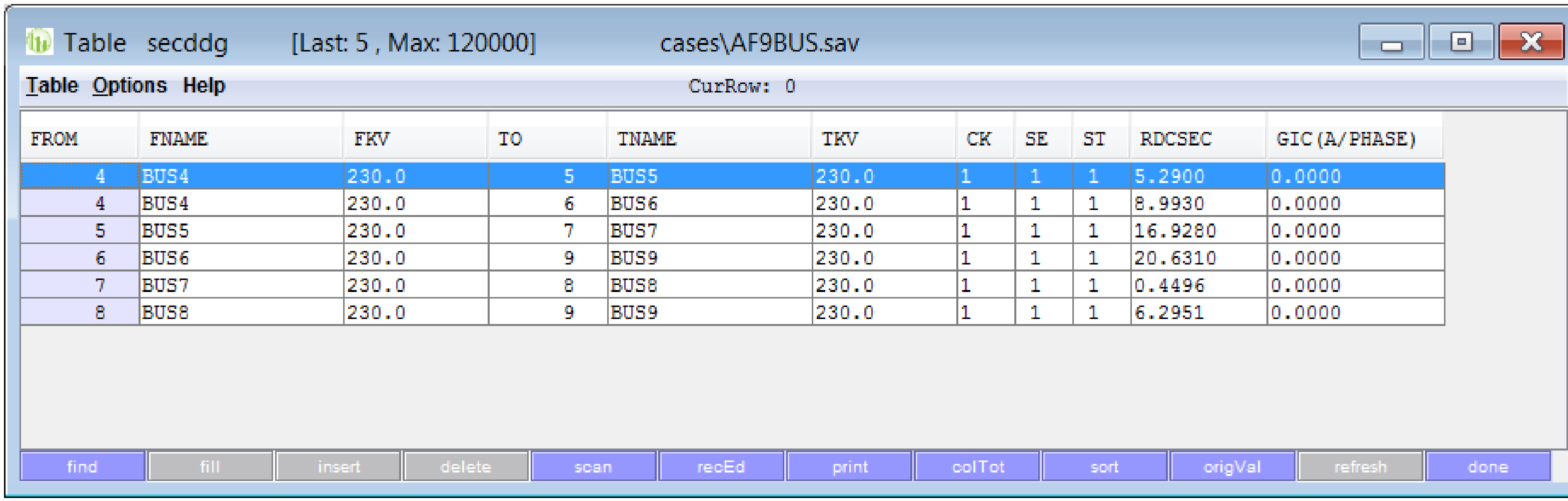
Four new tables have been created to store GMD data

- substation table
- secddg table
- trang table
- e-field table (for non-uniform e-field)

Substg table



Secddg table



FROM	FNAME	FKV	TO	TNAME	TKV	CK	SE	ST	RDCSEC	GIC(A/PHASE)
4	BUS4	230.0	5	BUS5	230.0	1	1	1	5.2900	0.0000
4	BUS4	230.0	6	BUS6	230.0	1	1	1	8.9930	0.0000
5	BUS5	230.0	7	BUS7	230.0	1	1	1	16.9280	0.0000
6	BUS6	230.0	9	BUS9	230.0	1	1	1	20.6310	0.0000
7	BUS7	230.0	8	BUS8	230.0	1	1	1	0.4496	0.0000
8	BUS8	230.0	9	BUS9	230.0	1	1	1	6.2951	0.0000

Trang table

Table trang [Last: 2 , Max: 40000] cases\AF9BUS.sav

Table Options Help CurRow: 0

FROM	FNAME	FKV	TO	TNAME	TKV	CK	S	TYPE	PWT	SWT	TWT	SUBN	AUTO	KFACT	RDCPW	RDCSW	RDCTW
1	BUS1	17	4	BUS4	230	1	1	core	d	gy	--	1	0	1.2000	0.0000	0.1000	0.0000
2	BUS2	18	7	BUS7	230	1	1	core	d	gy	--	2	0	1.2000	0.0000	0.1000	0.0000
3	BUS3	14	9	BUS9	230	1	1	core	d	gy	--	3	0	1.2000	0.0000	0.1000	0.0000

find fill insert delete scan recEd print colTot sort origVal refresh done

Table trang [Last: 2 , Max: 40000] cases\AF9BUS.sav

Table Options Help CurRow: 0

RDCTW	BDPWS	BDPT	BDPWR	BDSWS	BDST	BDSWR	BDTWS	BDTT	BDTWR	GIC-P	GIC-S	GIC-T	GIC-PN	GIC-SN	GIC-TN
0.0000	0	0	0.0000	0	0	0.0000	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0	0	0.0000	0	0	0.0000	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0	0	0.0000	0	0	0.0000	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

find fill insert delete scan recEd print colTot sort origVal refresh done

Efield Table

Table efield [Last: 20 , Max: 5000] cases\AF...

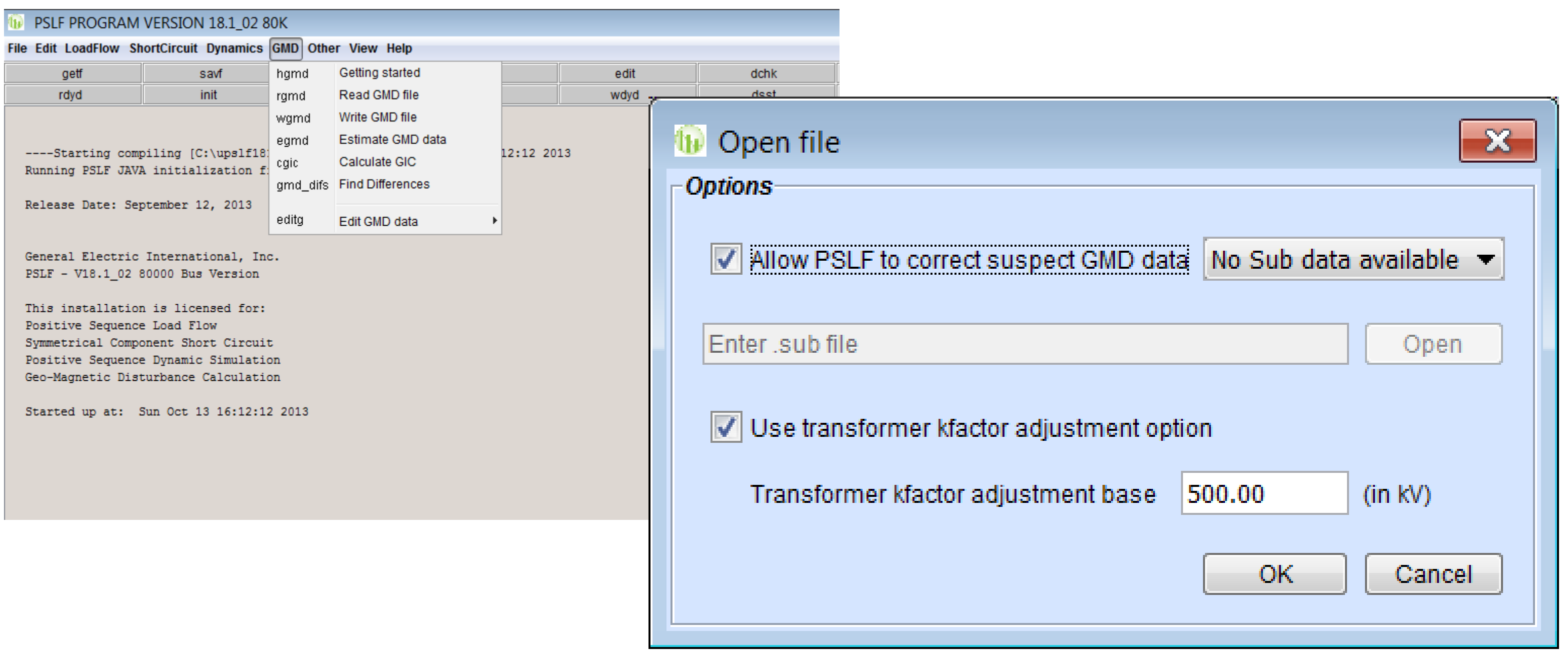
Table Options Help CurRow: 0

NUM	X-COMP	Y-COMP	LAT.	LONG.
1	1.0000	0.0000	43.1054	-75.8786
2	1.0000	0.0000	42.7408	-73.0337
3	1.0000	0.0000	42.2476	-74.6834
4	1.0000	0.0000	40.5742	-73.6592
5	1.0000	0.0000	41.6074	-75.7256
6	1.0000	0.0000	42.7161	-72.5768
7	1.0000	0.0000	41.7136	-71.5407
8	1.0000	0.0000	39.4888	-74.6359
9	1.0000	0.0000	39.4900	-74.1086
10	1.0000	0.0000	41.0913	-73.8443
11	1.0000	0.0000	42.6477	-74.6928
12	1.0000	0.0000	43.7780	-75.7065
13	1.0000	0.0000	42.2254	-73.4415
14	1.0000	0.0000	40.9284	-75.4669
15	1.0000	0.0000	40.5779	-72.6251
16	1.0000	0.0000	41.5779	-75.6251
17	1.0000	0.0000	39.4848	-73.3771
18	1.0000	0.0000	42.0447	-75.7406
19	1.0000	0.0000	41.3184	-74.2514
20	1.0000	0.0000	40.1296	-73.2073
21	1.0000	0.0000	43.5374	-72.7169

find fill insert delete scan recEd print colTot sort origVal refresh done

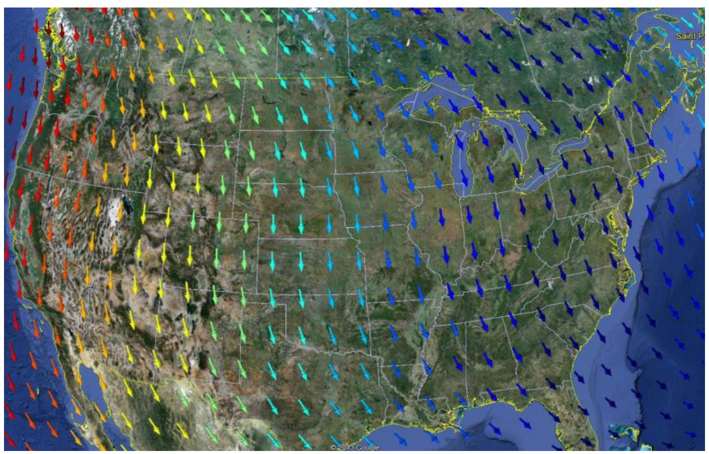
Estimate GMD data with egmd tool

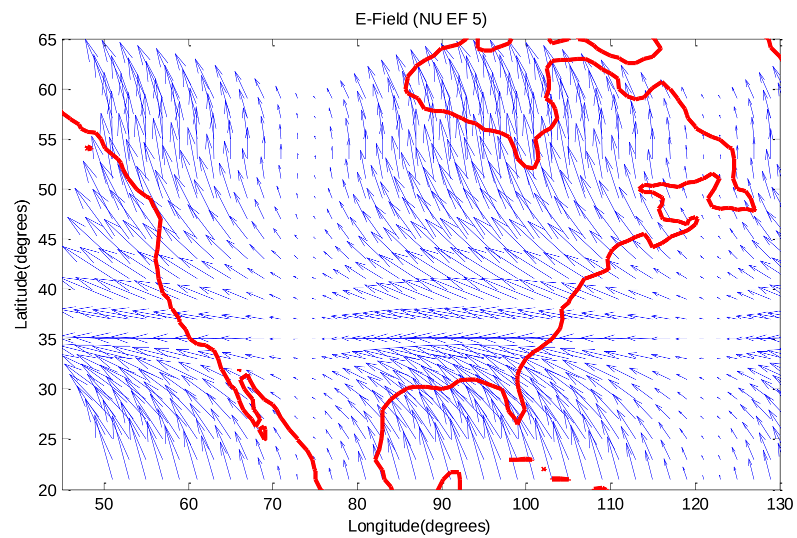
Starts from a power flow case and estimates the remaining GMD data



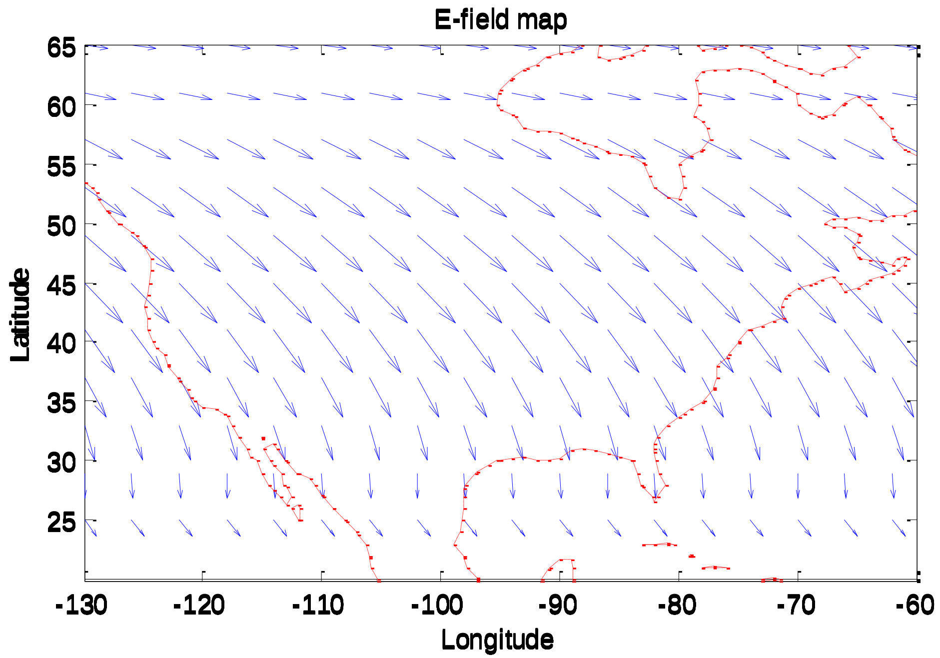
Simulates Uniform and Non-Uniform Electric Fields

Enables users to model very complex E-field scenarios spanning over various latitudes and soil conductivity profiles

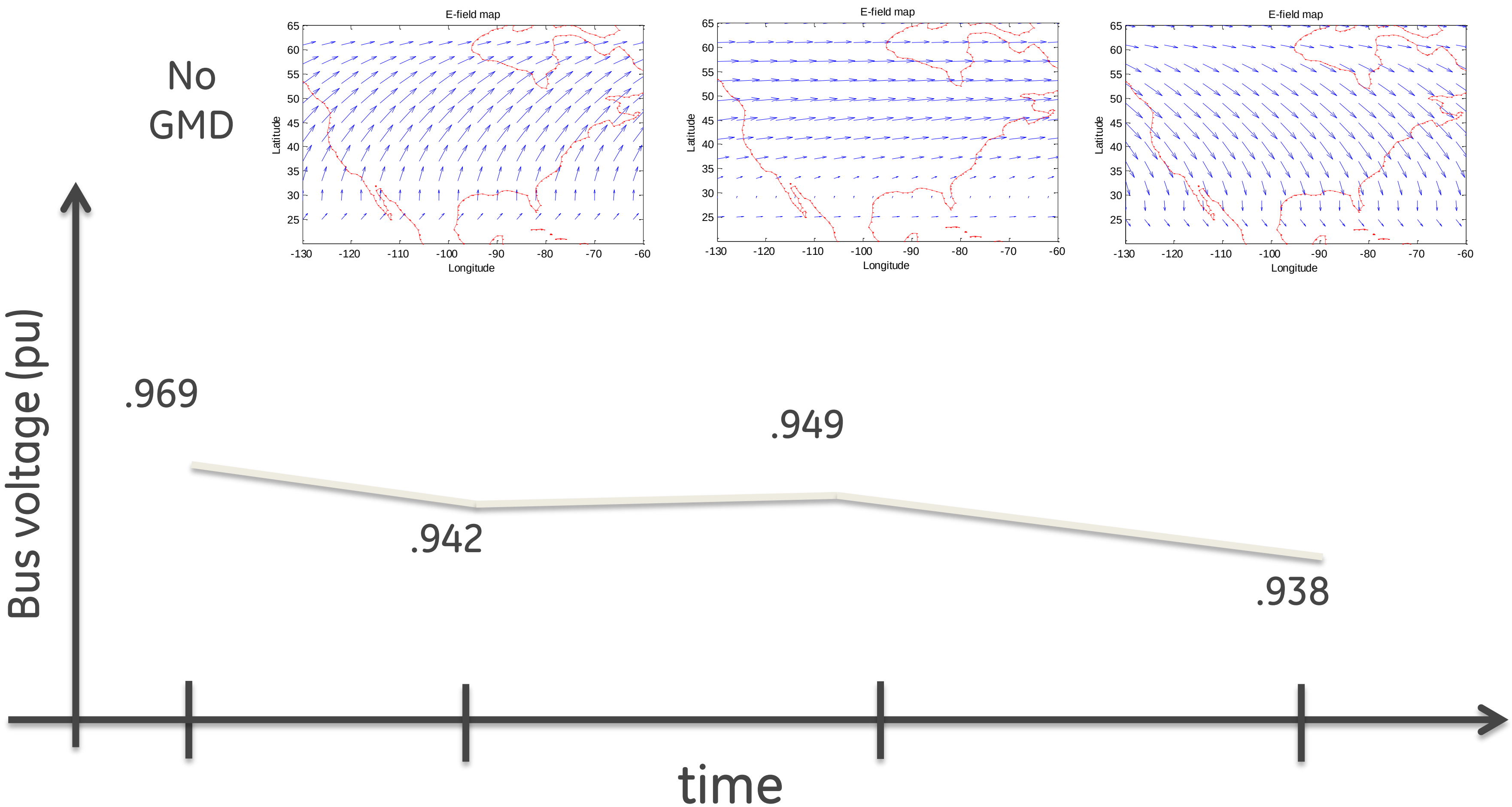




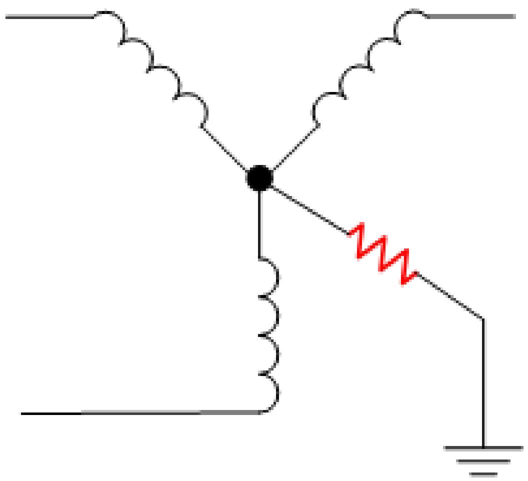
Non-uniform time varying E-field maps

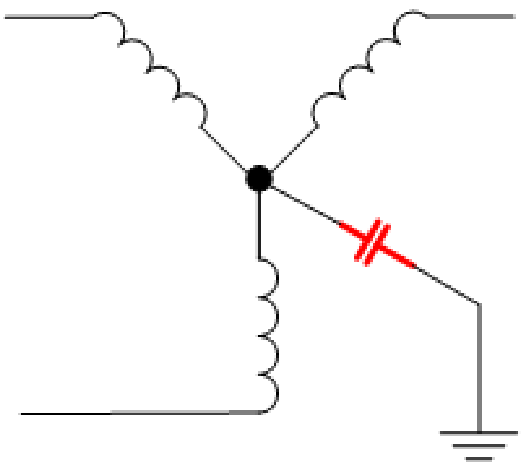


Time-series power flow analysis



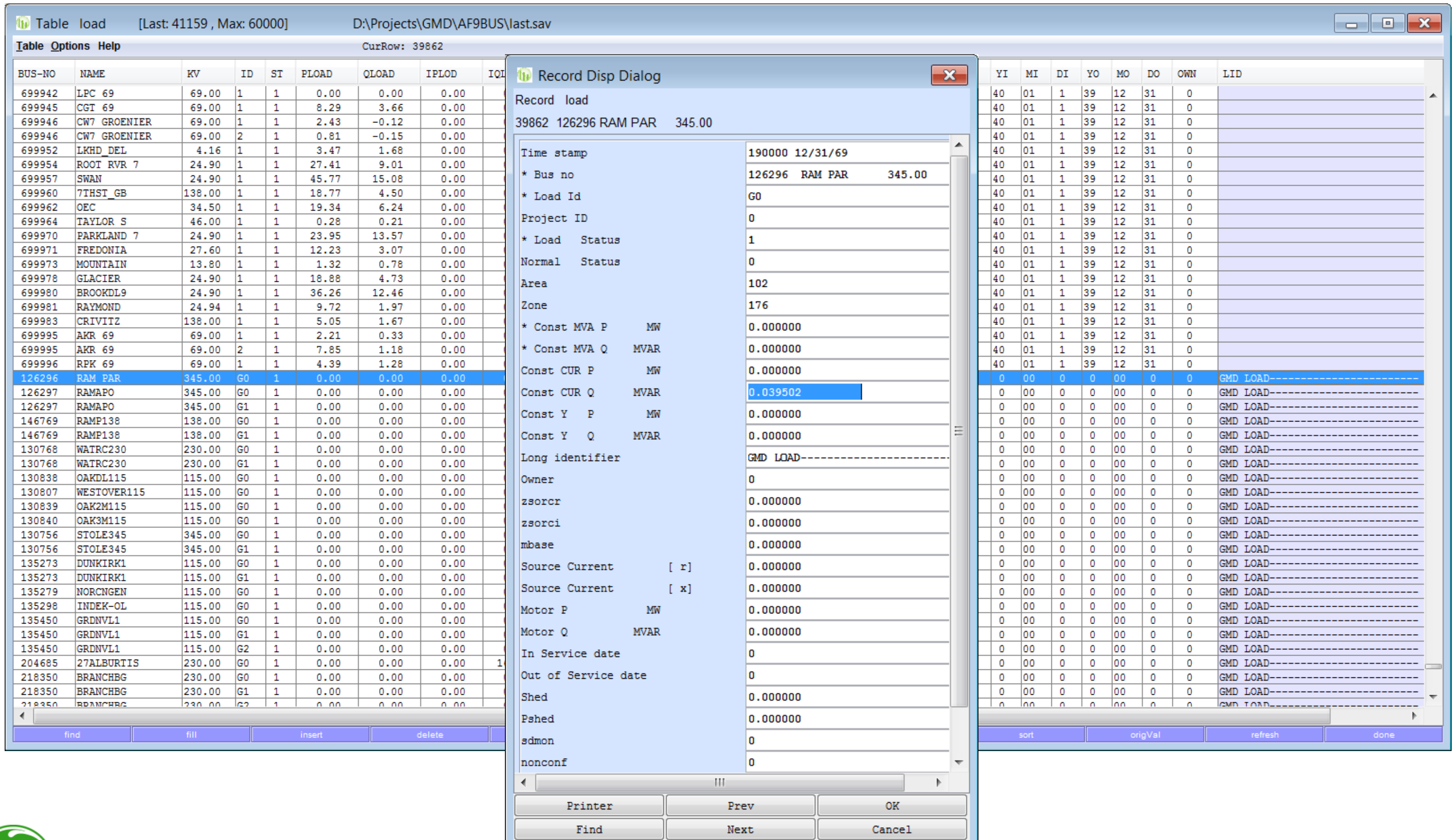
Transformer Neutral Blocking Devices





Allows modeling of resistive or capacitive blocking devices in transformer neutrals

GMD loads directly added to power flow case



Fully EPCL compatible

- GMD structures are exposed similarly to other PSLF data structures
- User is provided with default EPCLs for detailed analysis
- User's guide has easy copy and paste samples of EPCL code for GMD analysis

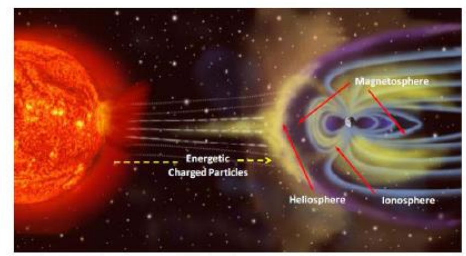
Allows the same automation flexibility already available in other PSLF tools

GMD manual

- Describes how to set up a GMD case
- Description of GMD data structures
- EPCL code samples

Geomagnetic Disturbance Analysis in GE PSLF - User's Manual

September 2013



imagination at work

PSLF Demo

From: Don Howell
To: Randy Lobb; Rick Sterling; Terri Carlock; Matt Elam
Subject: FW: FERC Technical Conference - GMD
Date: Wednesday, December 23, 2015 1:21:14 PM
Attachments: image001.png

FYI   don

From: FERC - State Relations [mailto:FERCStateRelations@ferc.gov]
Sent: Wednesday, December 23, 2015 7:52 AM
To: Cameron Schilling <Cameron.Schilling@ferc.gov>
Subject: FERC Technical Conference - GMD

See below for more details on an upcoming technical conference regarding geomagnetic disturbance events.

December 23, 2015 - FERC To Convene a Technical Conference on Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events on March 1, 2016 Notice | Errata Notice | Event Details

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