Utility Perspective GIC Mitigation

March 27 2015

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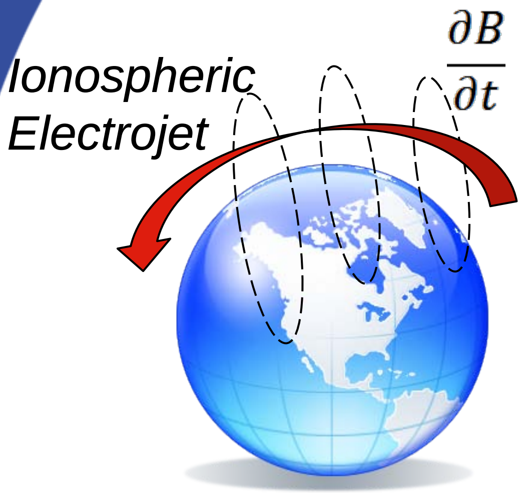
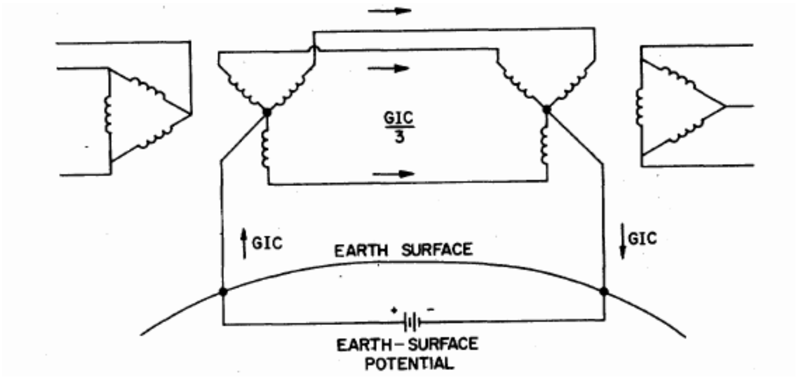
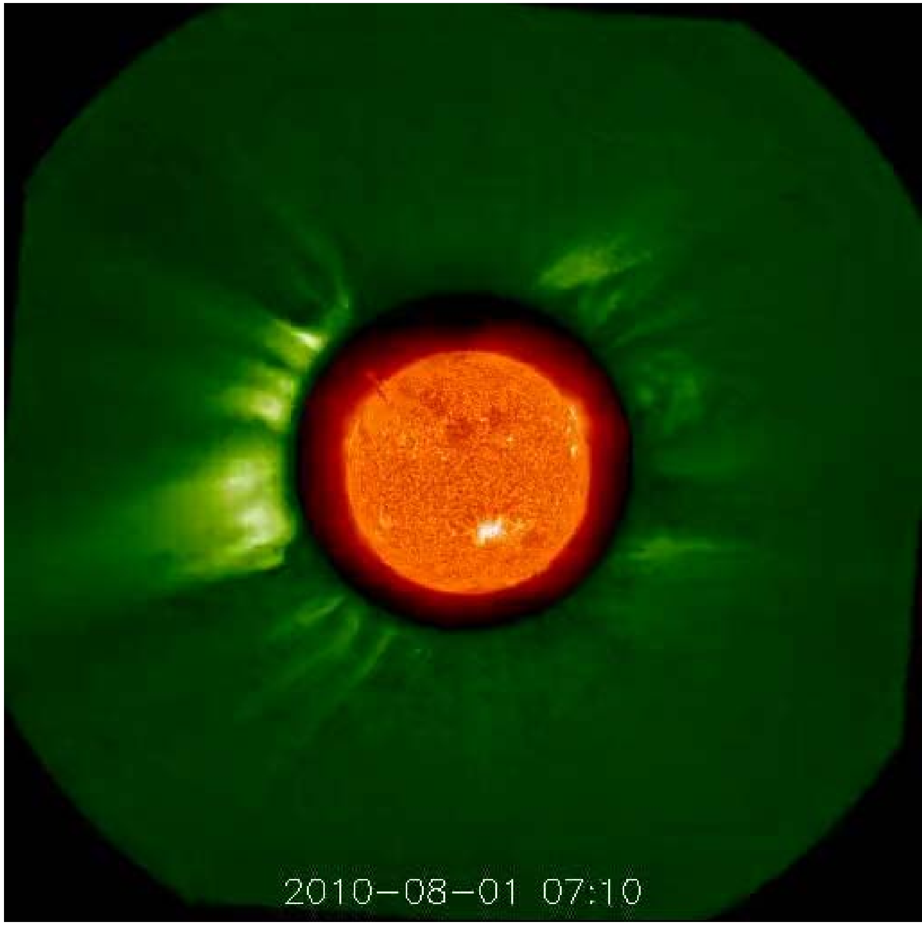
2015 Dominion

GMD Induced Currents







Effects on Power System Equipment

Saturation of transformers cause harmonics

Capacitor reliability, false trips and failures

Filter Banks reliability, false trips and failures

SVC's reliability, false trips and failures (Filter Banks)

March 1989 Dominion Tripped 13 115 KV Capacitor Banks

GIC Storm March 13 1989

Reactive Power Consumed by transformers

Initiating Event tripping of 7 SVC’s

Filter banks failed and SVC Controls ? Off ?

Hydro Quebec System Separation

Voltage Anomalies

Lines Tripped and System Collapse

GIC Storm March 13 1989

Hydro Quebec Effects

N-7 Contingencies in 52 sec

Total Collapse in 92 sec

21,500 MW lost generation

Restoration Time 82% 9 hours

Looking Forward What To Do ?

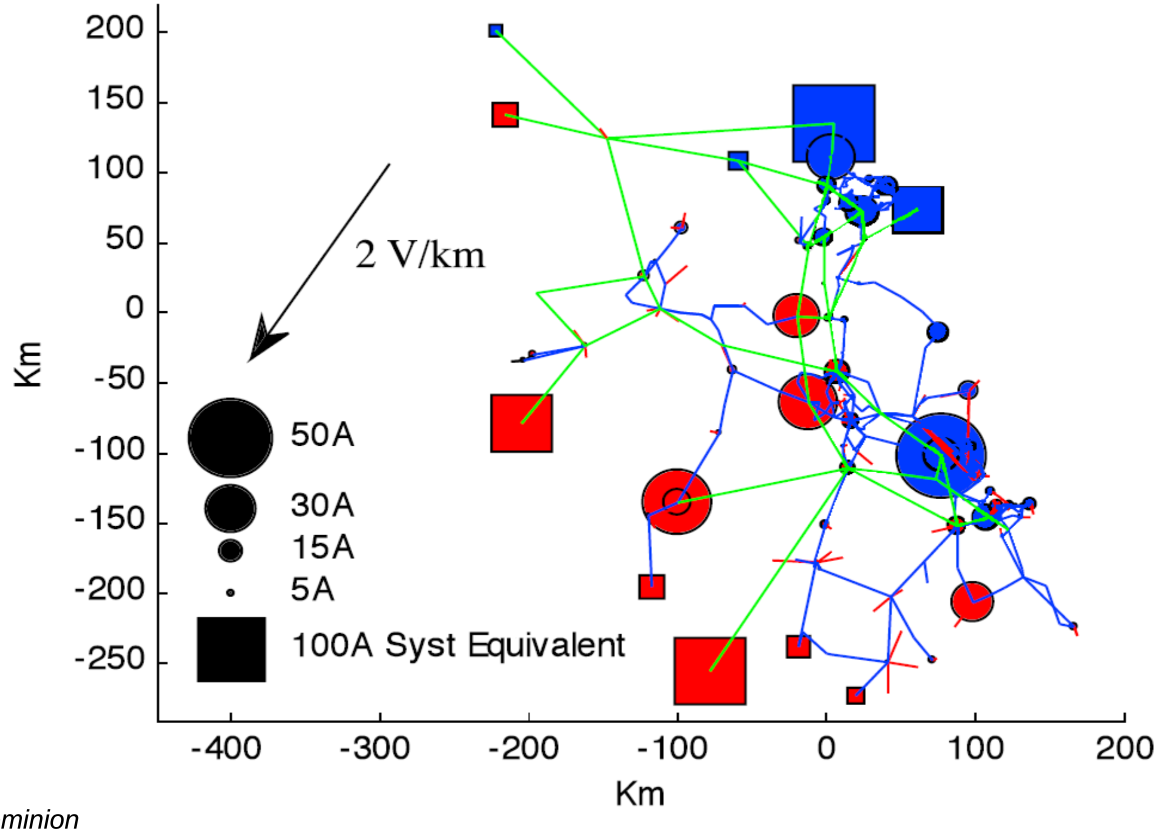
Harden The Power System

Treat GIC AS A Service Condition

What Is The Vulnerability ???

Model Your System

100 Year Model Scenario

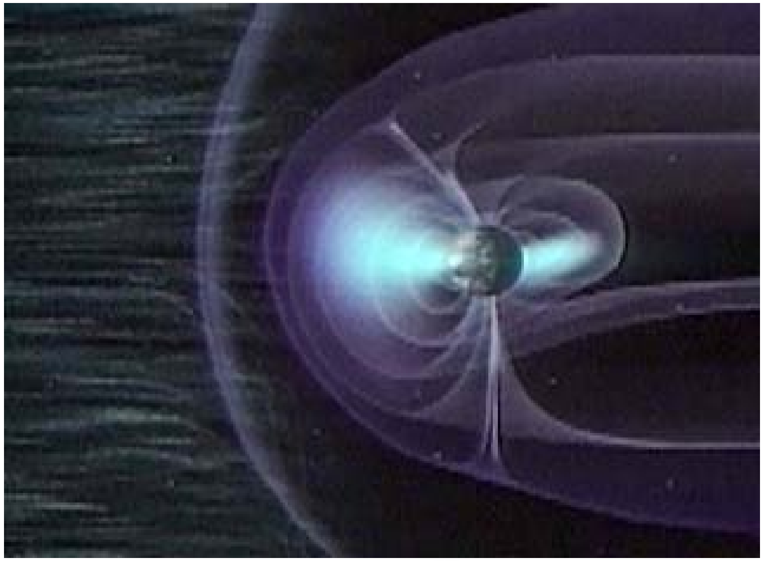


Effects on Power System Equipment

- ***GMD flowing in transformers causes saturation effects***
  - ***Saturation effects power transformers produce harmonics***
  - ***Saturation effects in power transformers consume system VAR's***
  - ***Current Transformers (CT's) , Not Split Core or Fiber Optic***
  - ***Saturation effects power transformers heating***

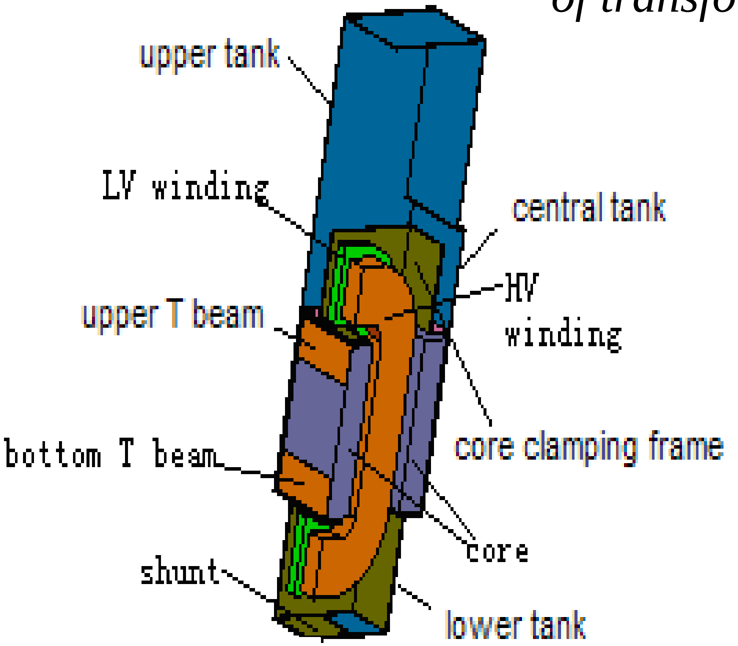
Transformer Heating

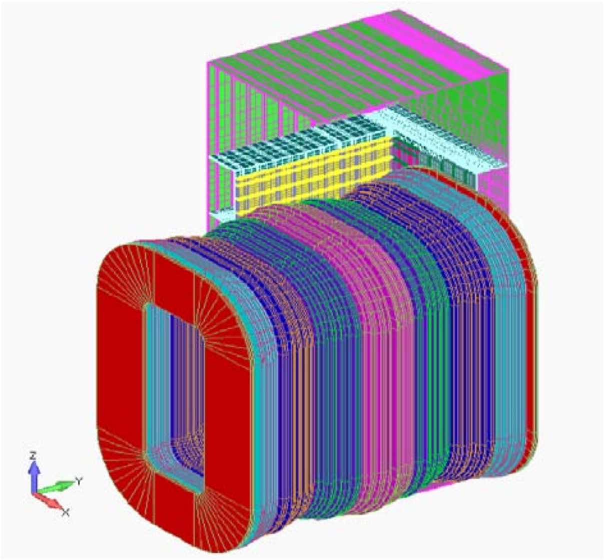
One of the most important effects of Quasi DC current on power system is that it can overheat the transformer and at the worst situation, it can damage the transformer. The effect of DC current on a shell-form autotransformer that is used on Virginia's 500kV power system was researched . A 3D finite element transformer model was established. The transformer loss with different DC currents is studied. Based on the losses of transformer tank, T beam and core clamping frame, their temperature rises are researched. The temperature rises of LV winding and HV winding also be calculated based on the winding current.



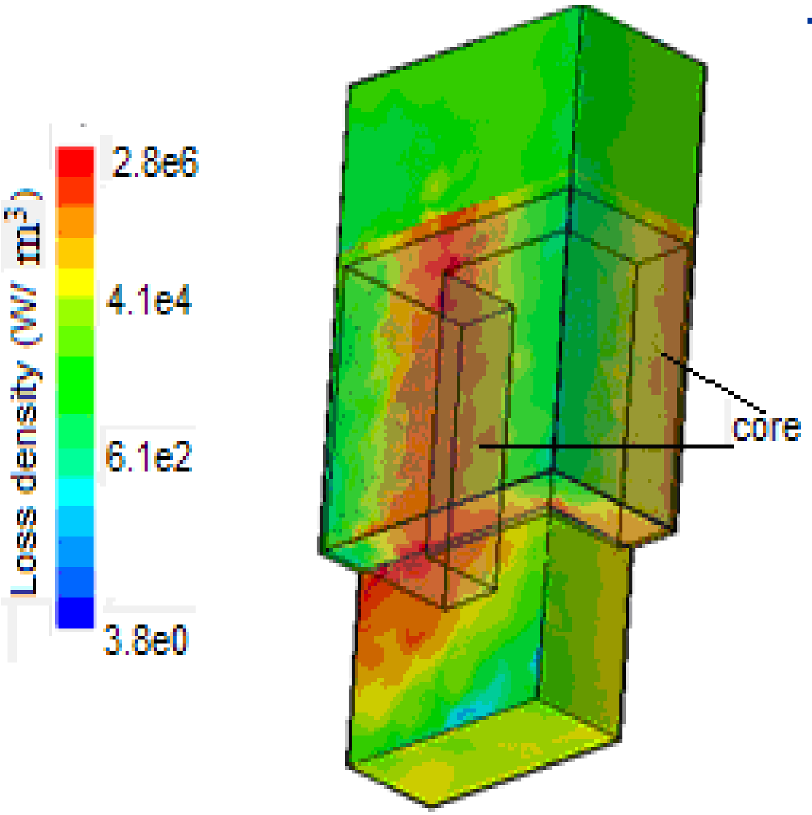
3D FE Shell Form Autotransformer Model

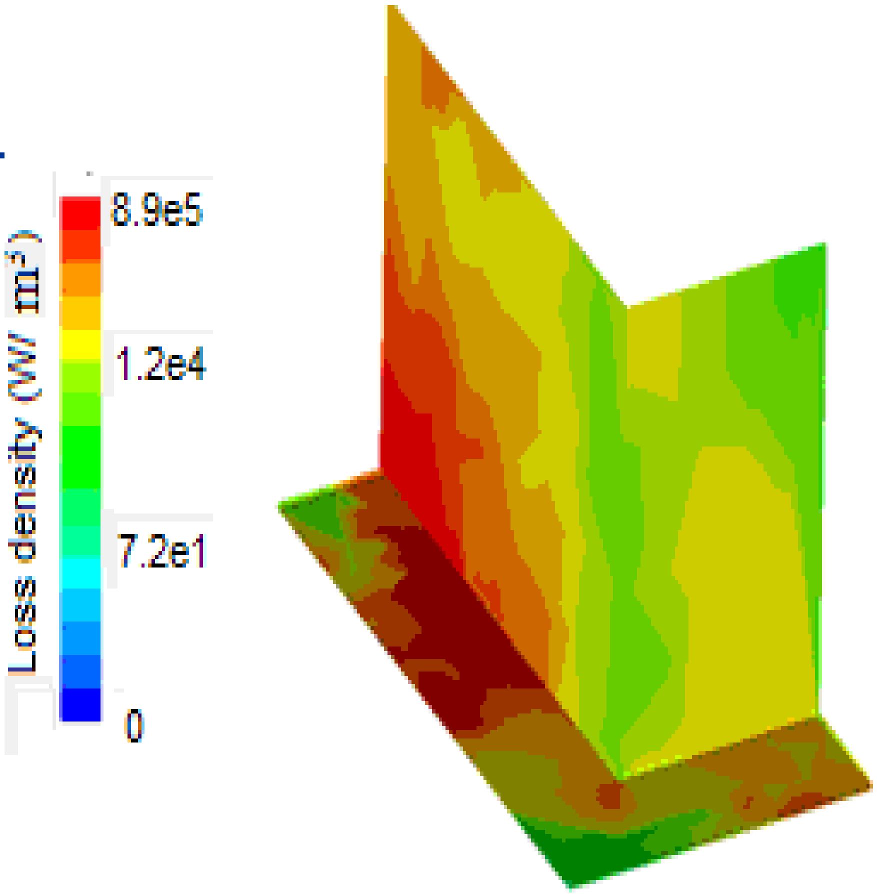
A 224MVA 500kV/230kV single phase shell-form autotransformer on Virginia's power system has been researched. In order to save the simulation time, 3D FE model of a quarter transformer was established based on the symmetrical structure of transformer, as shown below





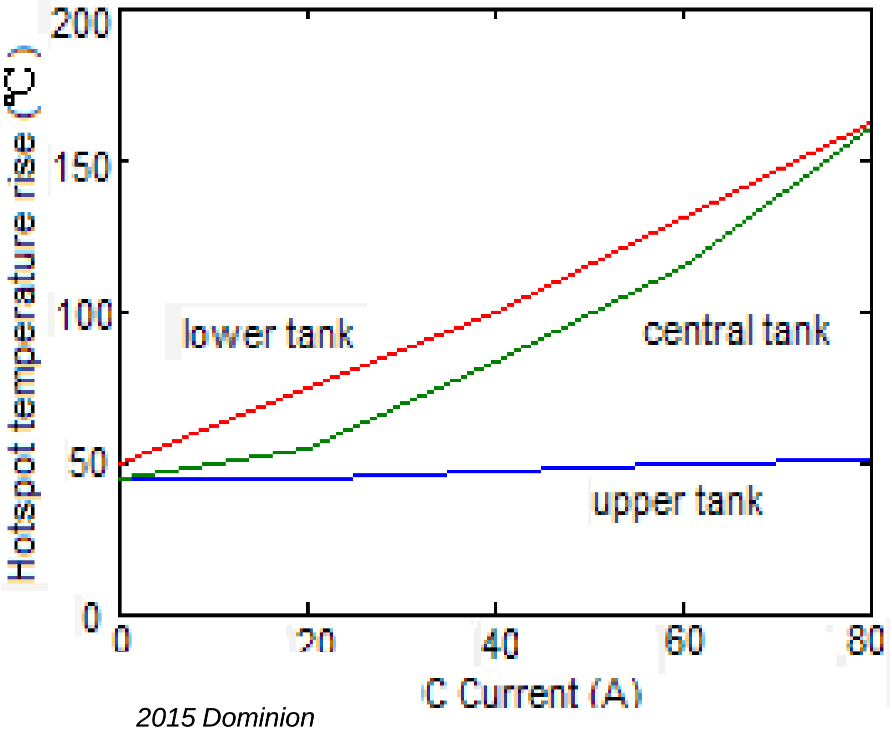
Core and Tank Wall Heating

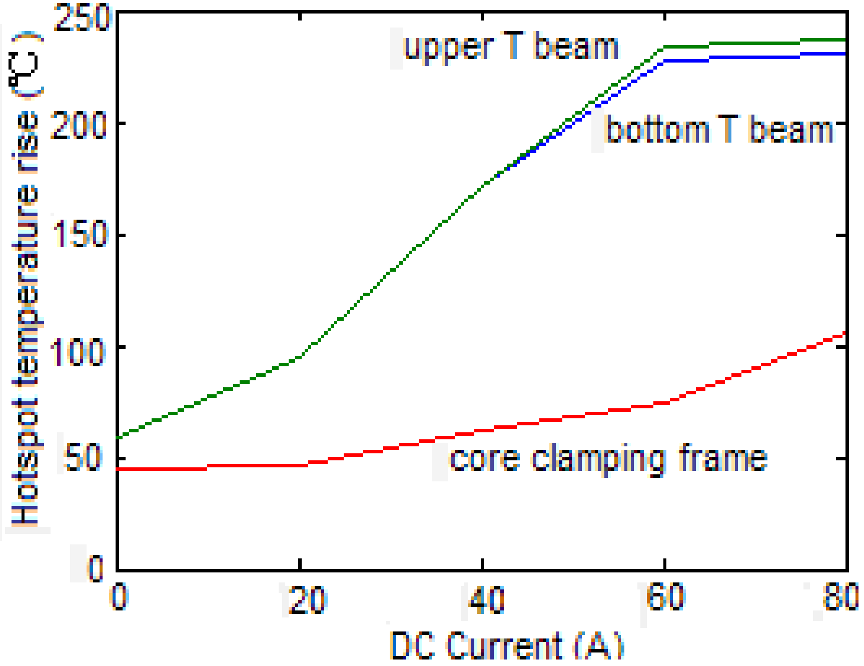




Transformer Temperature Rise

The increase of transformer loss will cause the increase of transformer temperature. This transformer cooling type is ONAF cooling .The heat transfer coefficient of surface of the transformer components that touched with the oil is assumed to be 100W/m2·℃ [10]. Fig. 9 shows the relation between the hotspot temperature rise of transformer over environment temperature and DC current.

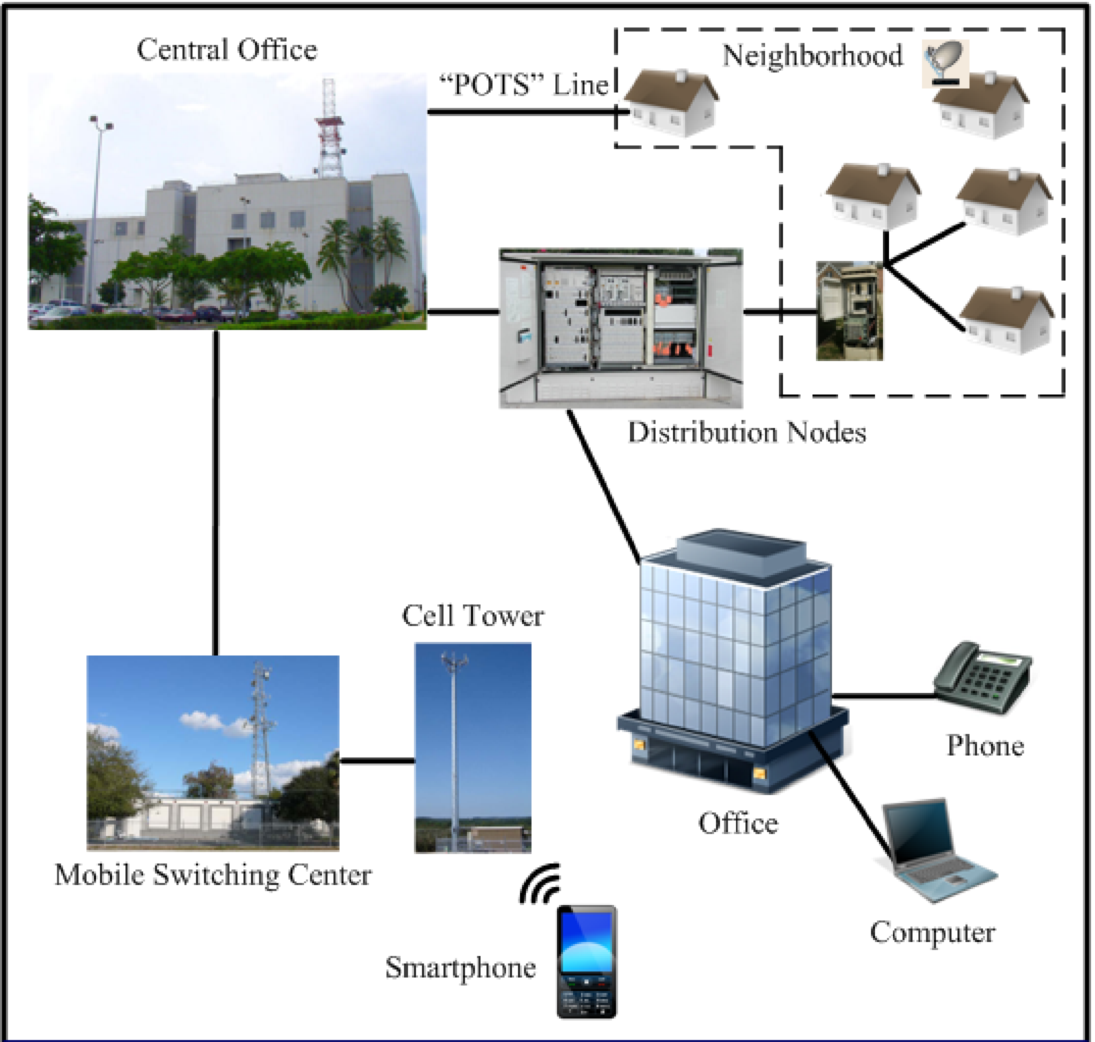




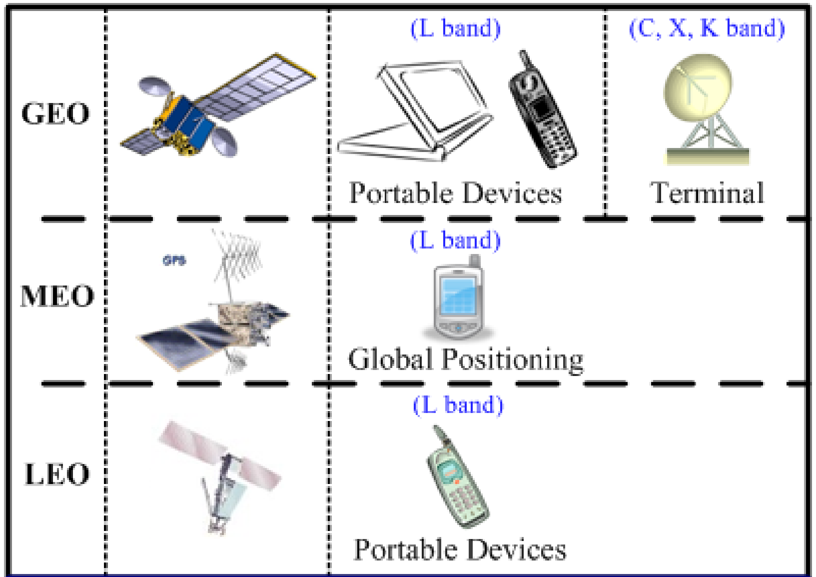
Effects on Communication and Impacts on Relay Protection

- Loss or Interference with Microwave Communications
  - Rural Utilities use Microwave Communications for line protection
  - Use of microwave communications for alarms and SCADA interrupted
- Loss of Global positioning Systems (GPS)
- Most Utilities use GPS for sync of relay and syncrophasers
- Most Utility Companies Use GPS for navigation
- Loss of L-band Satellite Phones
- Many public safety organizations use L-Band Sat Phone
- Many Utilities use L-Band Sat phones

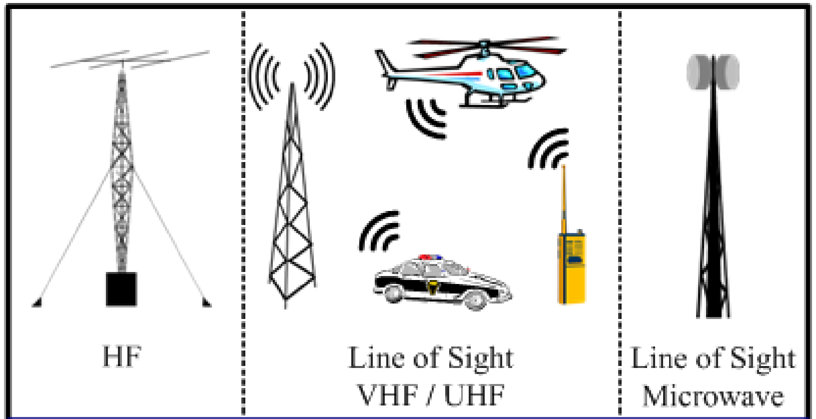
Terrestrial radio and satellite communications focus on systems used in emergency and contingency communications.



"Last Mile" Communications



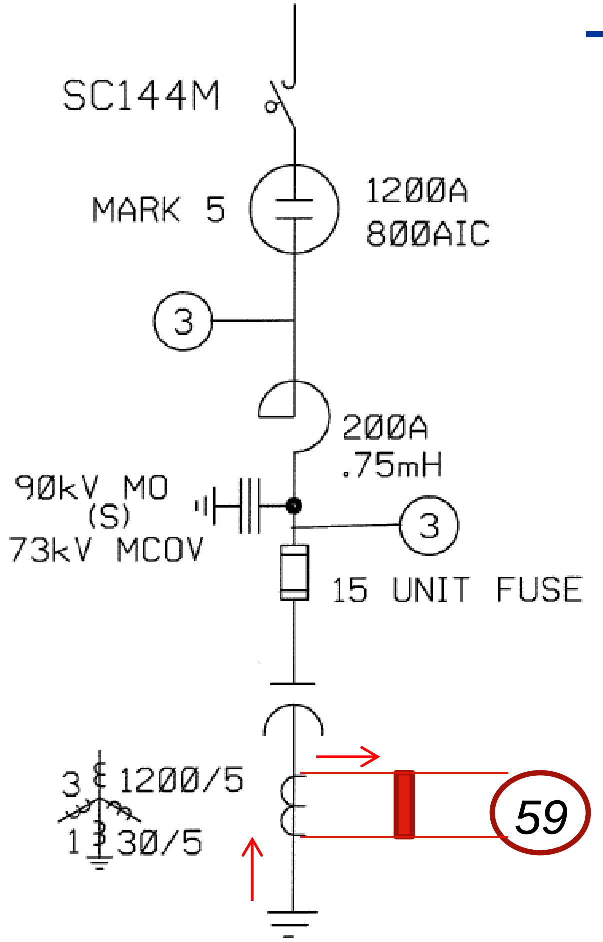
Satellite Communications



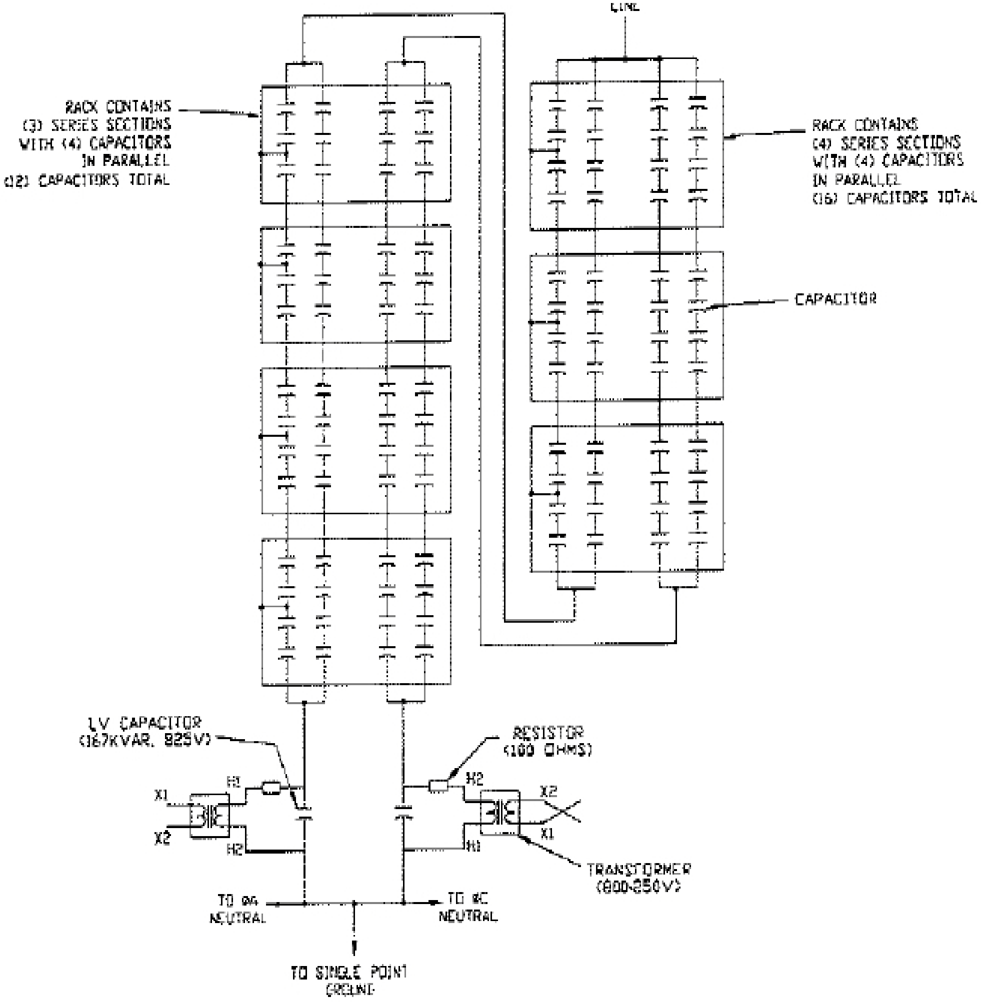
Terrestrial Radio

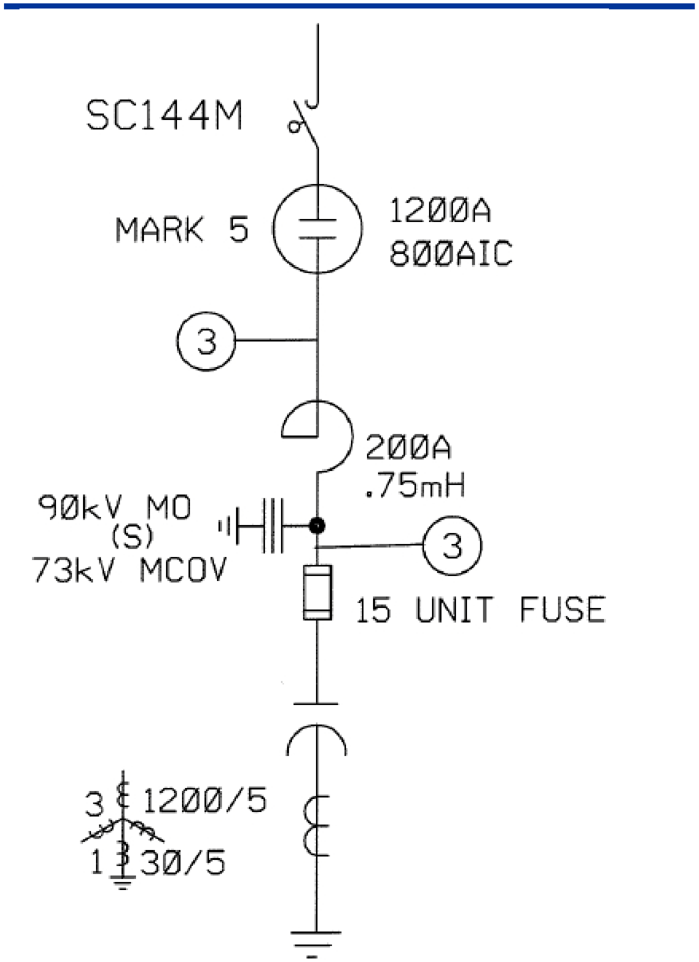
"Last Mile" photos courtesy of AT&T and FEMA"

Effects on Capacitor Protection



Effects on Capacitor Protection





Effects on Capacitor Ratings

- **IEEE 18 & IEEE 1036 Nominal Ratings**
  - **110% of rated rms voltage**
  - **120% of rated peak voltage, i.e. crest voltage not exceeding 1.2 × × rated rms voltage, including harmonics but excluding transients**
  - **135% of nominal rms current based on rated kvar and rated voltage**
  - **135% of rated kvar**

- **IEEE 1531 IEEE Guide for Specification and Application of Harmonic filters provides ratings guidance**

  - **Shunt Capacitor (Bank Ratings)**
  - **Harmonic Filter (Transmission) (Bank Ratings)**
  - **SVC Harmonic Filters (Bank Ratings)**

Effects on Capacitor Ratings

- Capacitors are low impedance path for generated *h*armonics and will *s*ource them

$$I_{rms} = \sqrt{(I_1)^2 + (I_2)^2 + (I_3)^2 + \cdots + (I_n)^2}$$

where n = harmonic number

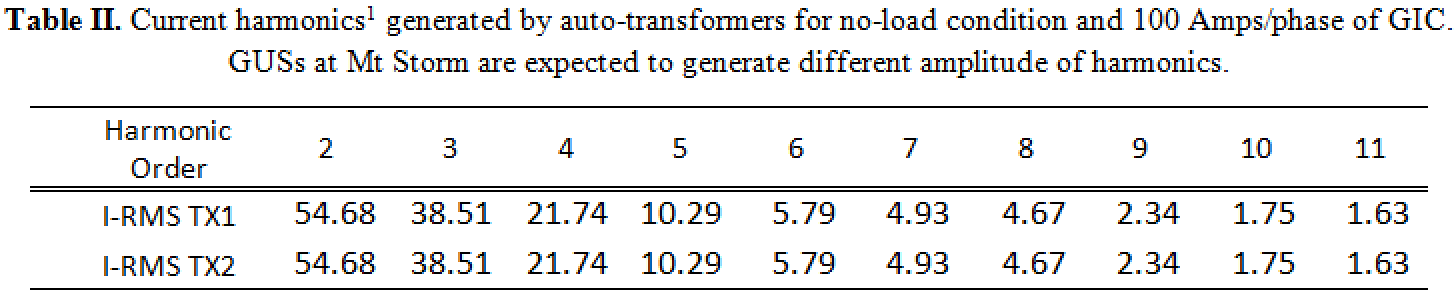


Table II. Current harmonics[1] generated by auto-transformers for no-load condition and 100 Amps/phase of GIC. GUSs at Mt Storm are expected to generate different amplitude of harmonics.

Harmonic Order	2	3	4	5	6	7	8	9	10	11
I-RMS TX1	54.68	38.51	21.74	10.29	5.79	4.93	4.67	2.34	1.75	1.63
I-RMS TX2	54.68	38.51	21.74	10.29	5.79	4.93	4.67	2.34	1.75	1.63

$$I_{rms} = \sqrt{(150)^2 + (54.68)^2 + (38.51)^2 + (21.74)^2 + (10.29)^2 + (5.79)^2}$$

*% overload =(166.08/ 150) *100 =111 %*

Effects on Capacitor Ratings

IEEE C37.99 section 11.2 “Capacitors Rated For Higher Voltages May Be Used”

$$KVAR_{E_2} = kvar_{E_1} \frac{(E_{Vapplied})^2}{(E_{Vrated})^2}$$

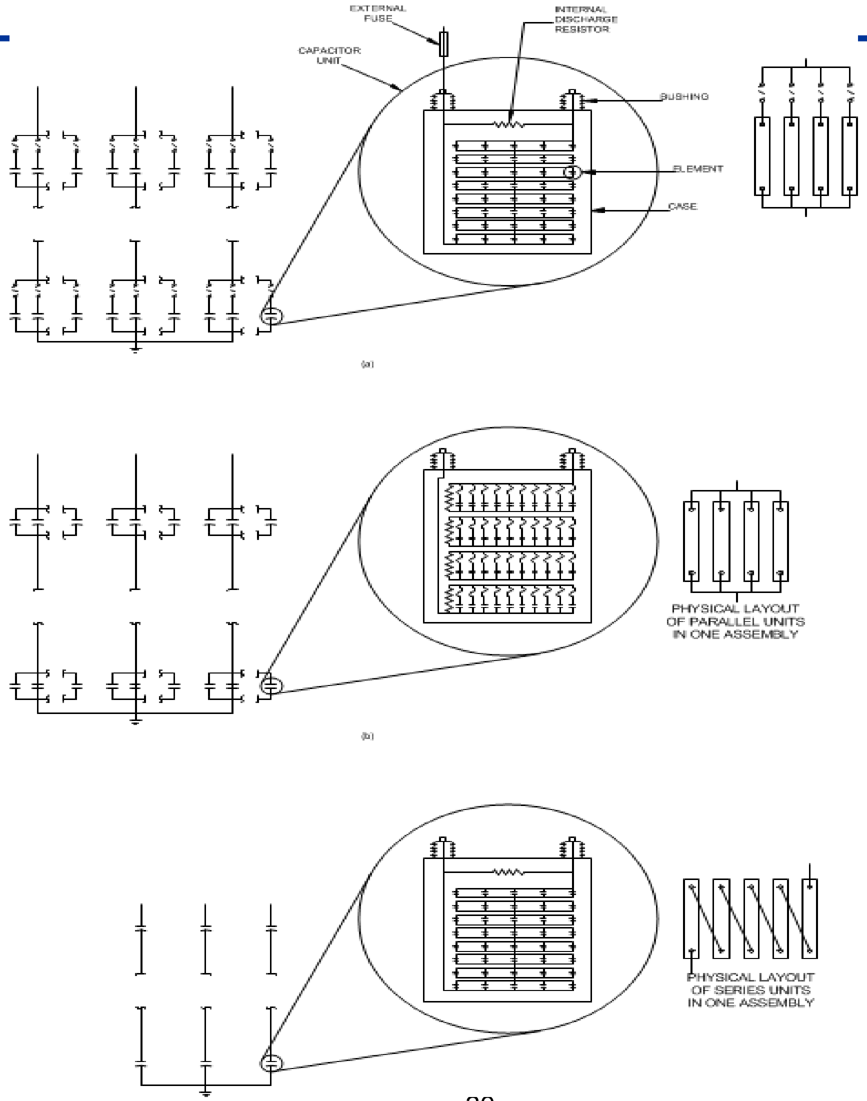
$$KVAR_{E_2} = 92.3 \frac{(500)^2}{(554.7)^2}$$ = 75 MVAR

Icap=KVAR / Vrated

Icap= 166.3 amps at 60 HZ

*% overload =(152.67/ 166.3) *100 =91.8 %*

Effects on Capacitor Ratings



GIC Mitigation

- *First Rule of Mitigation is Do No Harm*
- *You should not be worse off with mitigation than you were before solution is applied*
- *Law of unintended consequences. You change one component to solve a problem and you create another problem*

Thank You

Dominion
It all starts here.

Resources On GIC

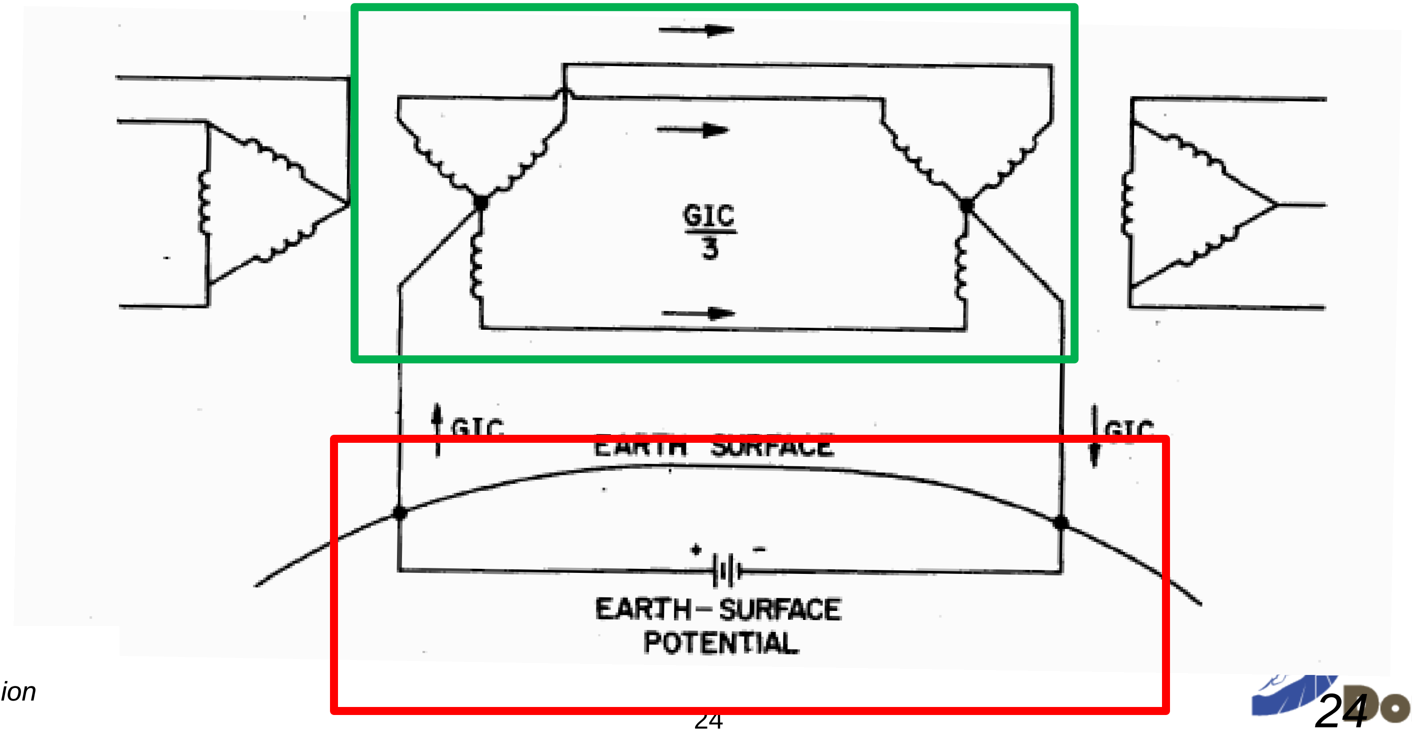
[1] P. R. Barnes; D. T. Rizy; B. W. McConnell, “Electric Utility Industry Experience with Geomagnetic Disturbances”, Oak Ridge National Laboratory & F. M. Tesche, 1991

[2] Pulkkinen A. A. Pulkkinen , E. Bernabeu , J. Eichner , C. Beggan and A. W. P. Thompson "Generation of 100-year geomagnetically induced current scenarios", Space Weather, vol. 10, pp.S04003 2012

[3] E. Bernabeu, Modeling Geomagnetically Induced Currents in Dominion Virginia Power Using Extreme 100-Year Geoelectric Field Scenarios—Part 1, Power Delivery, *IEEE Transactions on, Volume: 28, Issue: 1,* pp.516 – 523, 2013

GIC Modeling & Assumptions

1. Calculation of Geoelectric Field (Induced Voltage), assumed 1 V/km.
2. Network Model (DC)

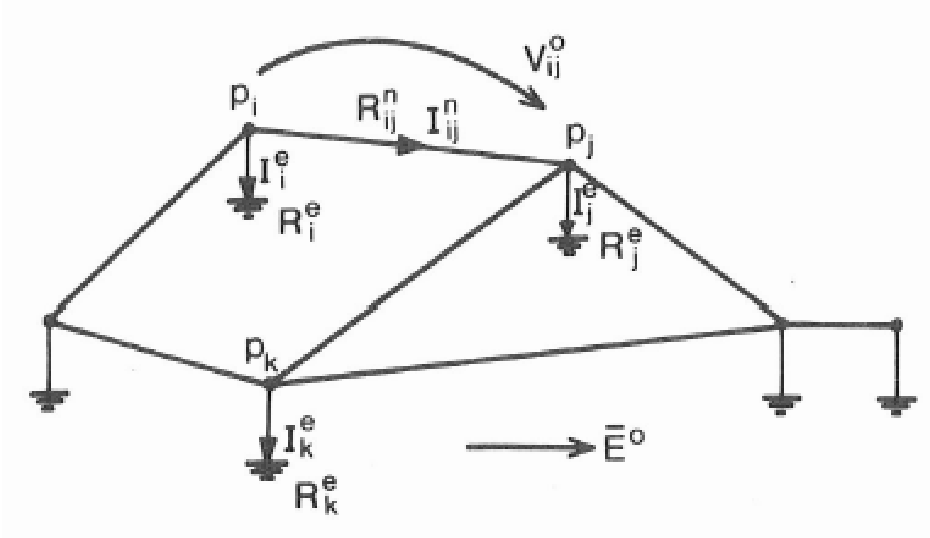


Pirjola & Lehtinen ‘85

$$\boxed{\mathbf{I}^e = (\mathbf{1} + \mathbf{Y}^n \mathbf{Z}^e)^{-1} \mathbf{J}^e}$$

$$J_i^e = \sum_{j \neq i} J_{ji}^n$$

$$J_{ij}^n = V_{ij}^0 / R_{ij}^n$$



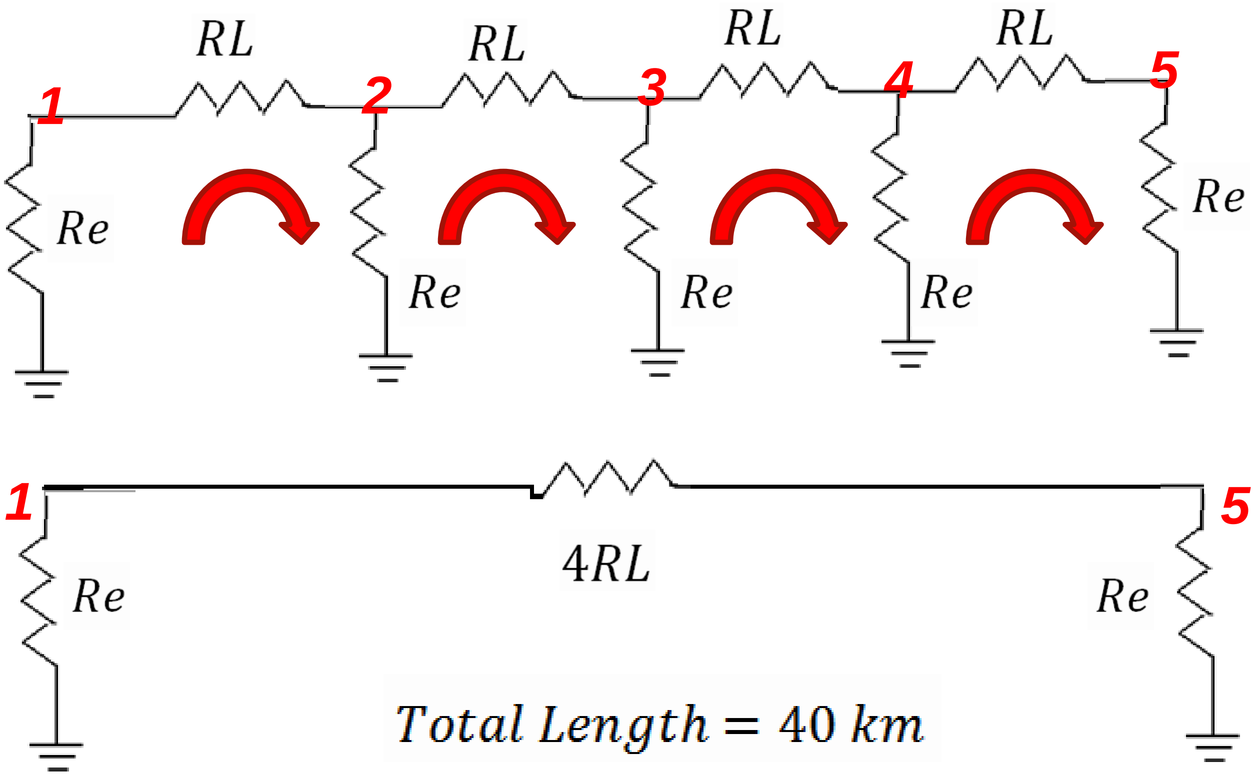
$$Y_{ij}^n = \begin{cases} -\,1/R_{ij}^n\,, & i \neq j \\ \sum_{k \neq i} 1/R_{ik}^n\,, & i = j\,. \end{cases}$$

$$Z^e = Diagonal(R^e)$$

Long Lines & Extreme Points

$Re = 0.2\Omega$ $RL = 0.6\Omega$ $1\ Volt/km$

	GIC 1	GIC 2
1	-13.1	-14.2
2	-2.6	-
3	0	-
4	2.6	-
5	13.1	14.2



$Total\ Length = 40\ km$