GMD Effects on Shunt Capacitor Banks

IEEE Power & Energy Society
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New Energy Horizons
Opportunities and Challenges

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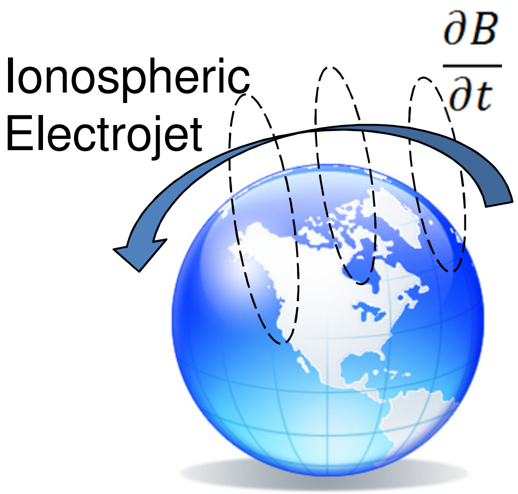
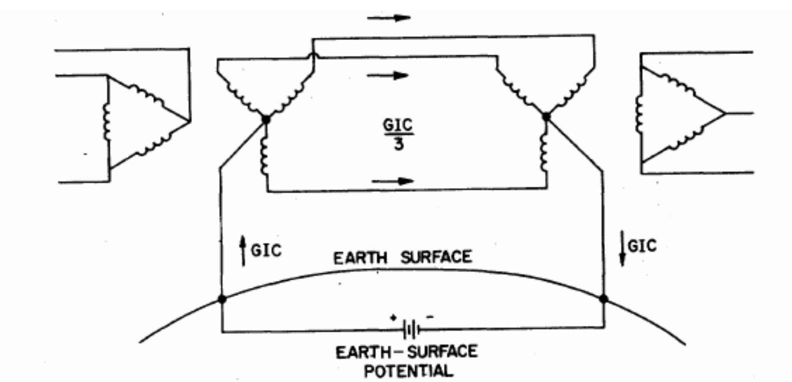
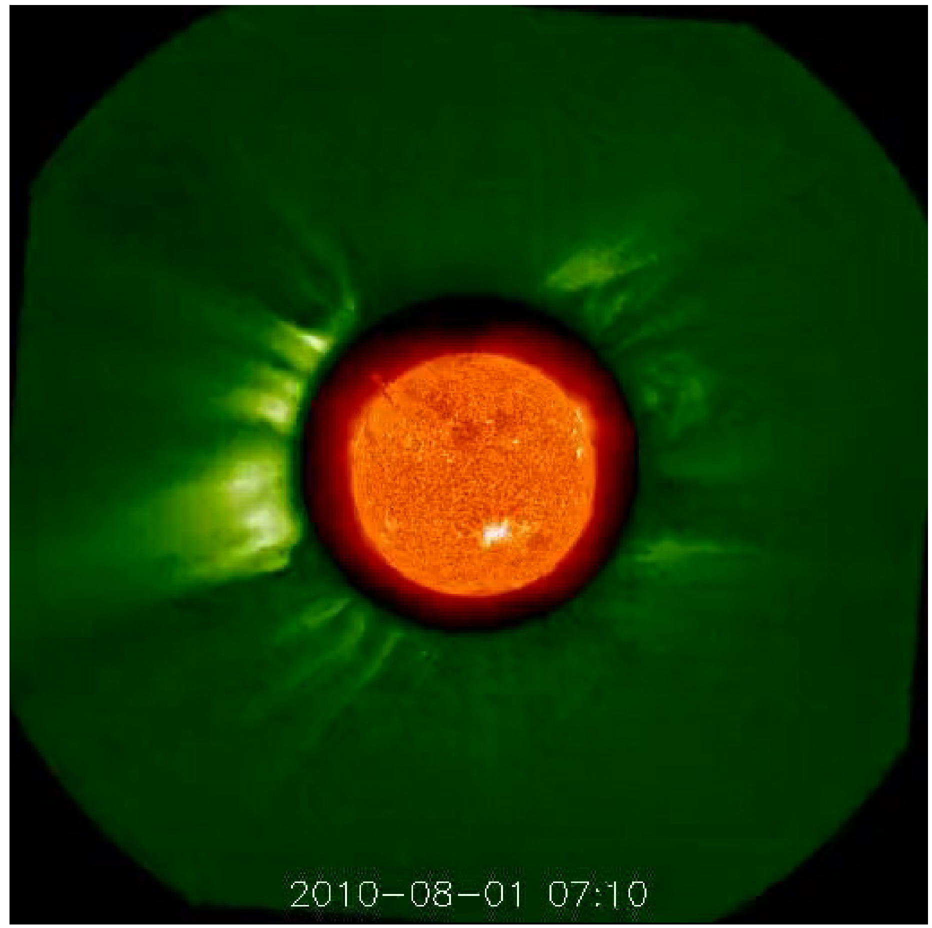
GMD Induced Currents



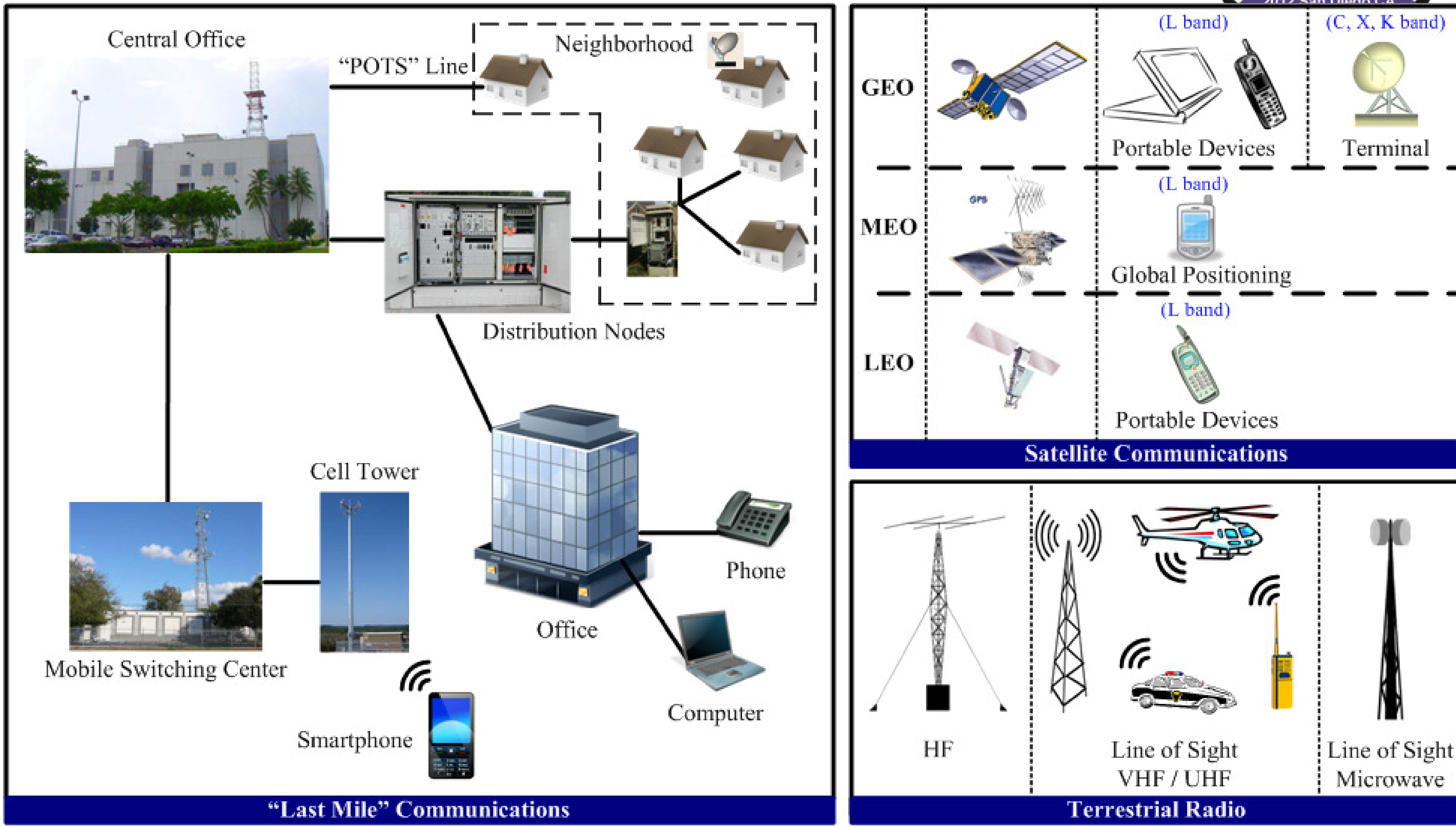




Effects on Power System Equipment

- 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

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



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

Effects on Communication and Impacts on Relay Protection

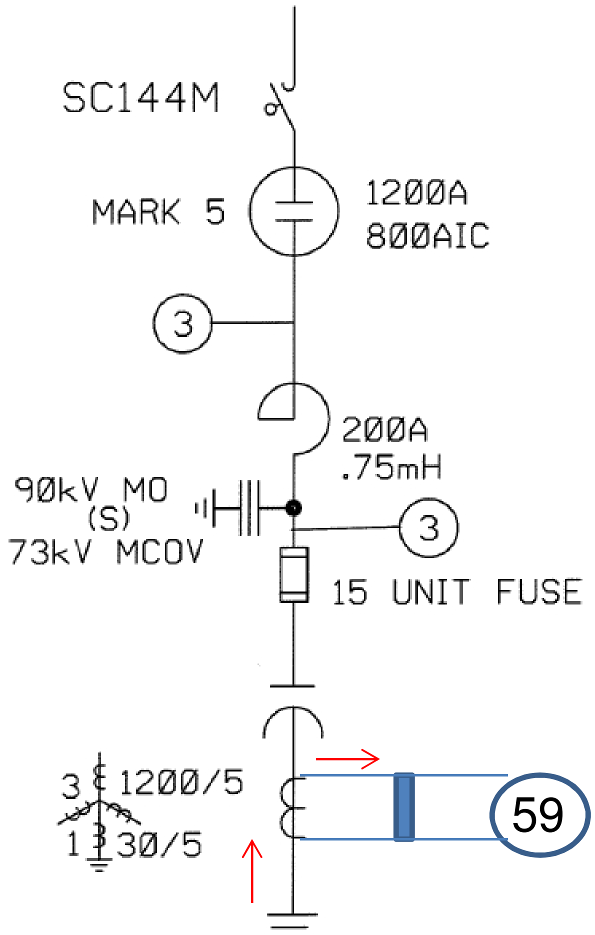
- Impact on Satellite Communication
  - Loss or Interference with Microwave Communications
    - Rural Utilities use Microwave Communications for line protection
    - Use of microwave communications for alarms and SCADA interrupted
  - Loss of Global positioning Systems (GPS)
    - Most Utilities use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

Effects on Power System Equipment

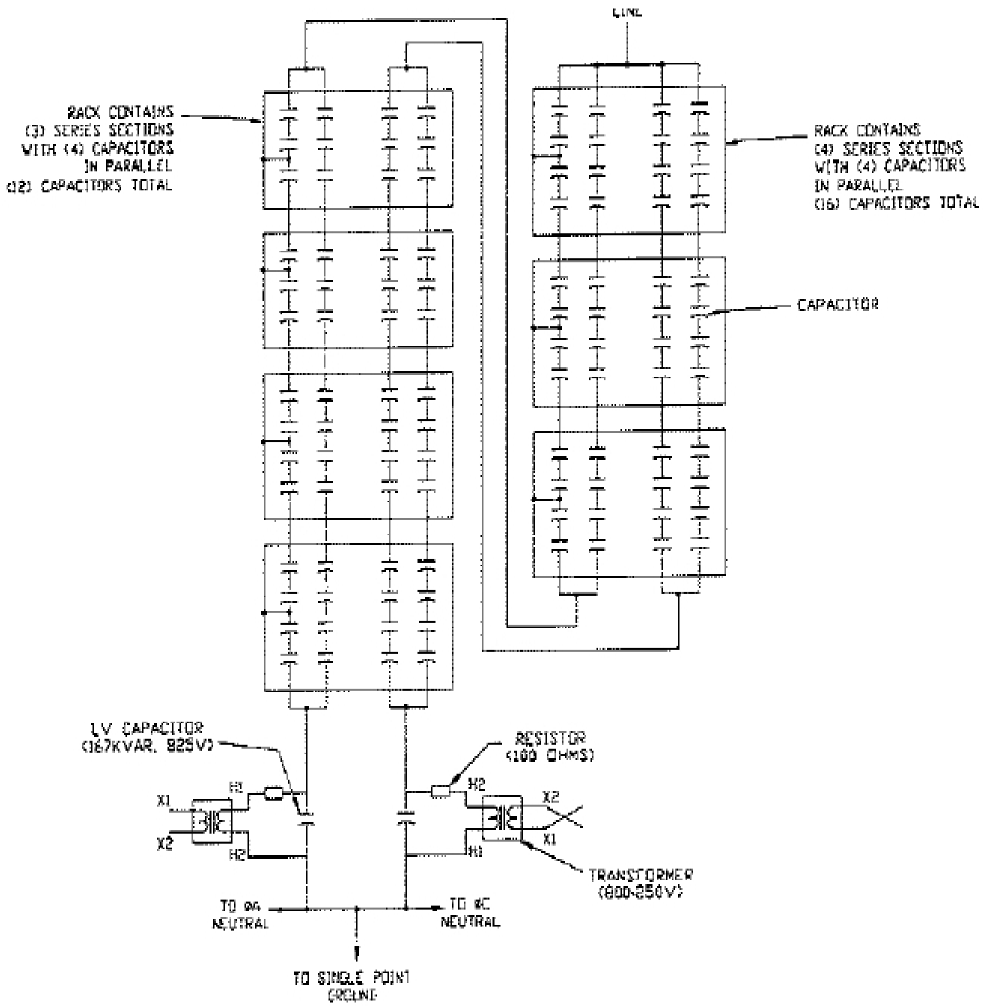
- Saturation of transformers cause harmonics
  - Capacitor reliability, false trips and failures
  - Filter Banks reliability, false trips and failures
  - SVC's reliability, false trips and failures (Filter Banks)

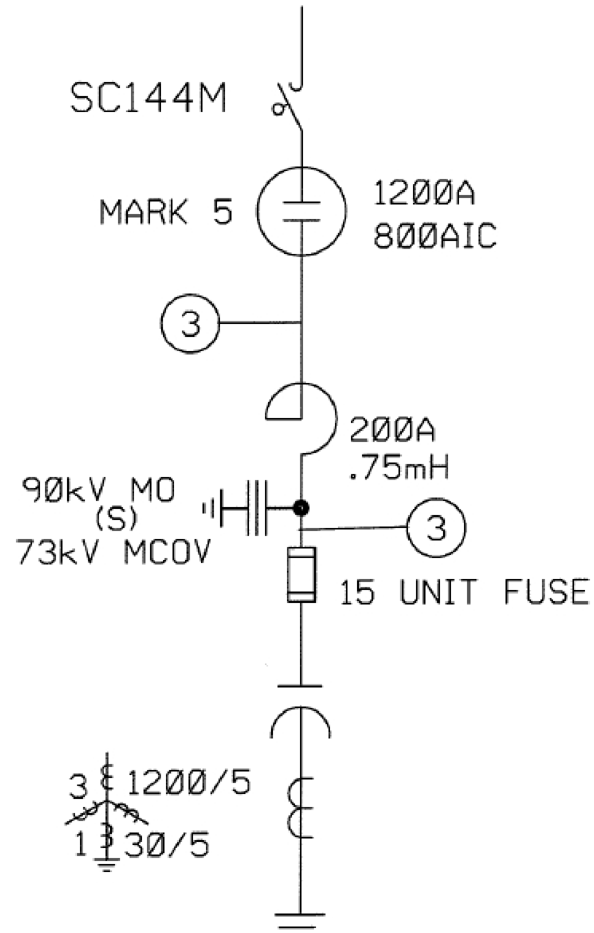
- March 1989 Dominion Tripped 13 115 KV Capacitor Banks

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 harmonics and will source 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

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

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

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

Icap=KVAR / Vrated
Icap= 166.3 amps at 60 HZ
% overload =(152.67/ 166.3) *100 =91.8 %

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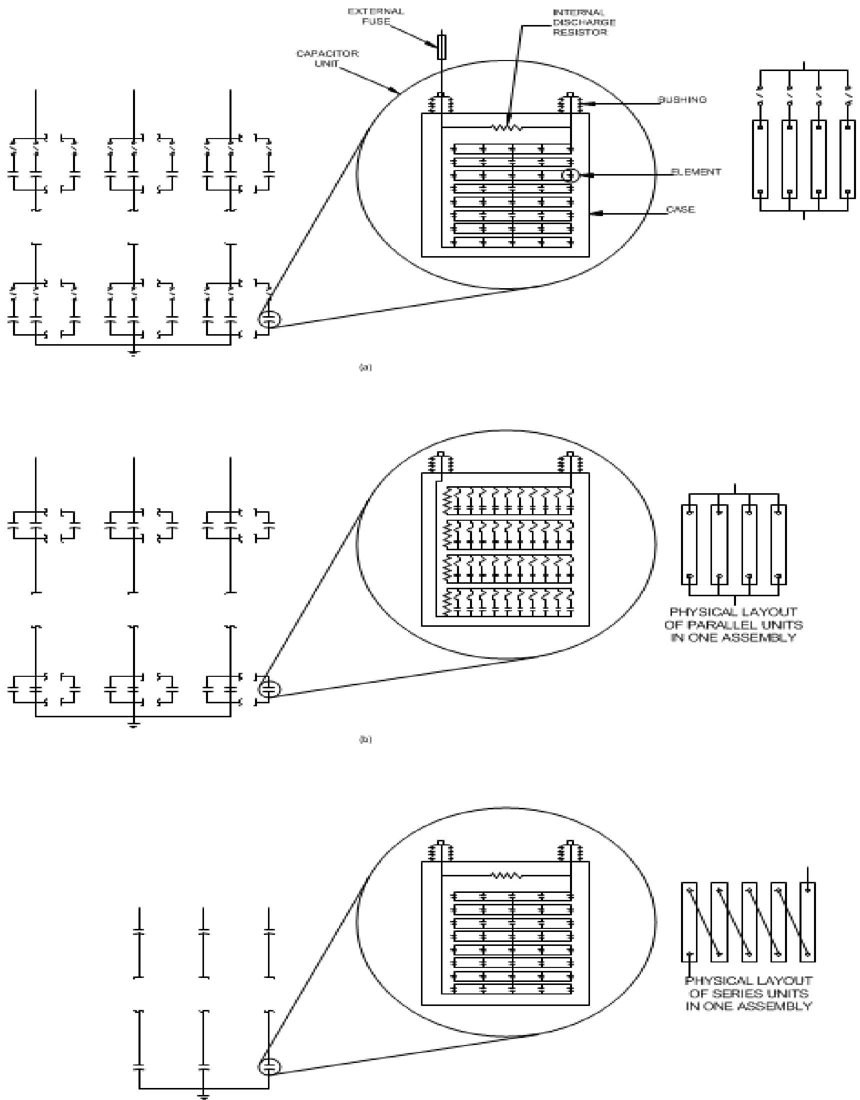
Effects on Capacitor Ratings



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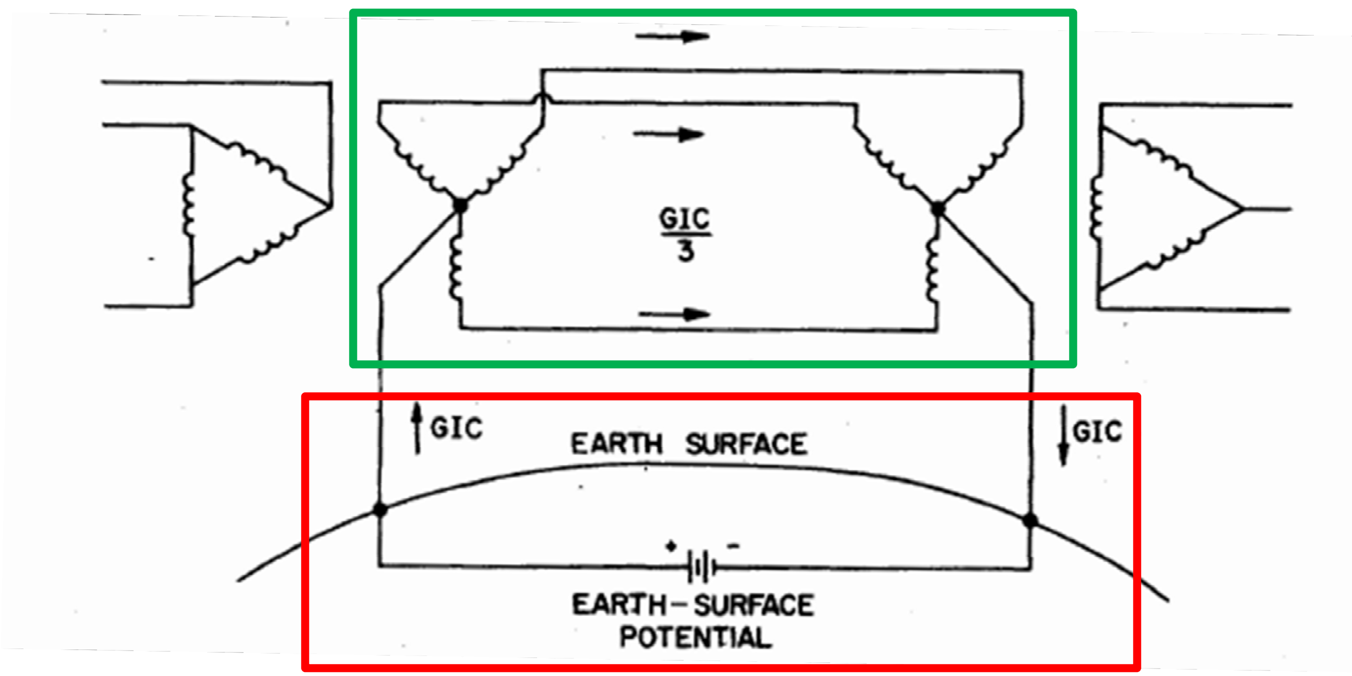
GIC Modeling & Assumptions

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

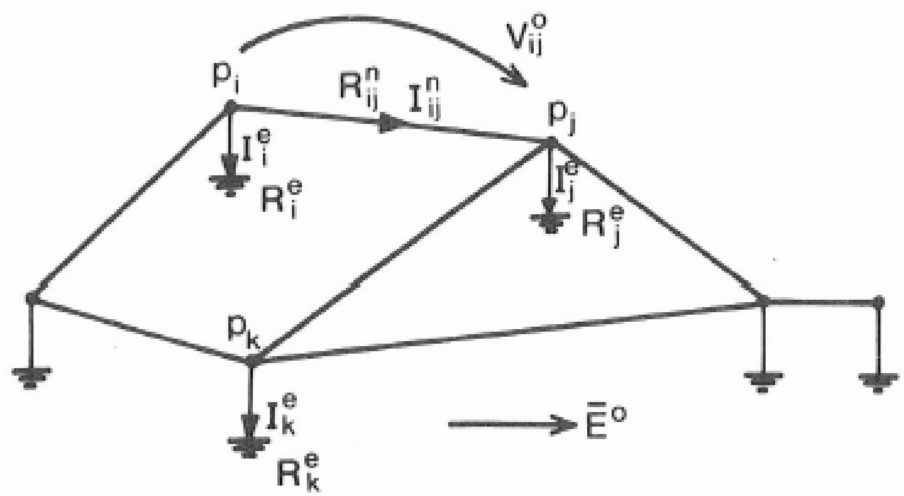


Pirjola & Lehtinen '85

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

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

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



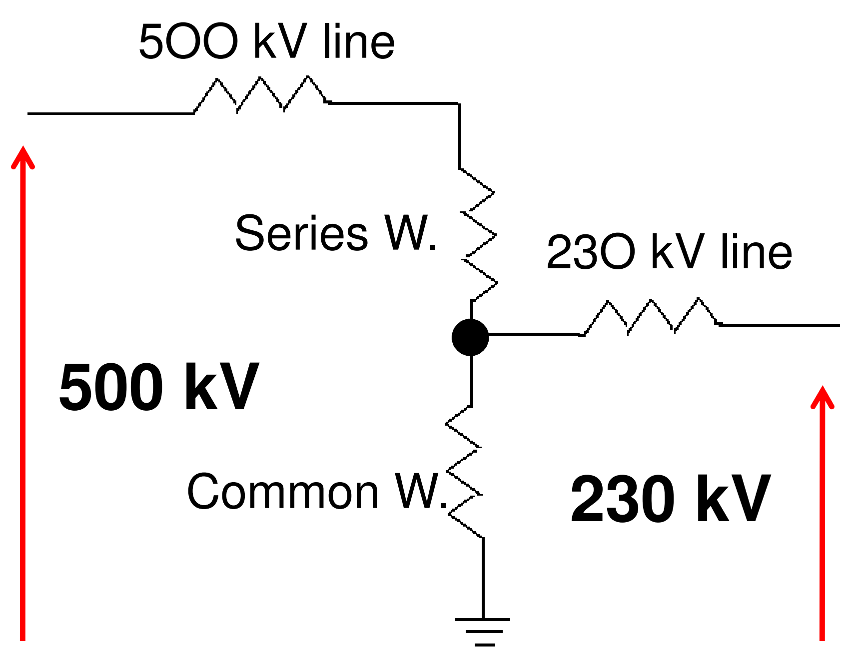
$$Y_{ij}^n = \begin{cases} -1/R_{ij}^n, & i \neq j \\ \sum_{k \neq i} 1/R_{ik}^n, & i = j. \end{cases}$$

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

Autotransformers

- Autotransformers provide a direct path between both voltage levels for GIC.
- DVP has autotransformers in most of its transmission system.

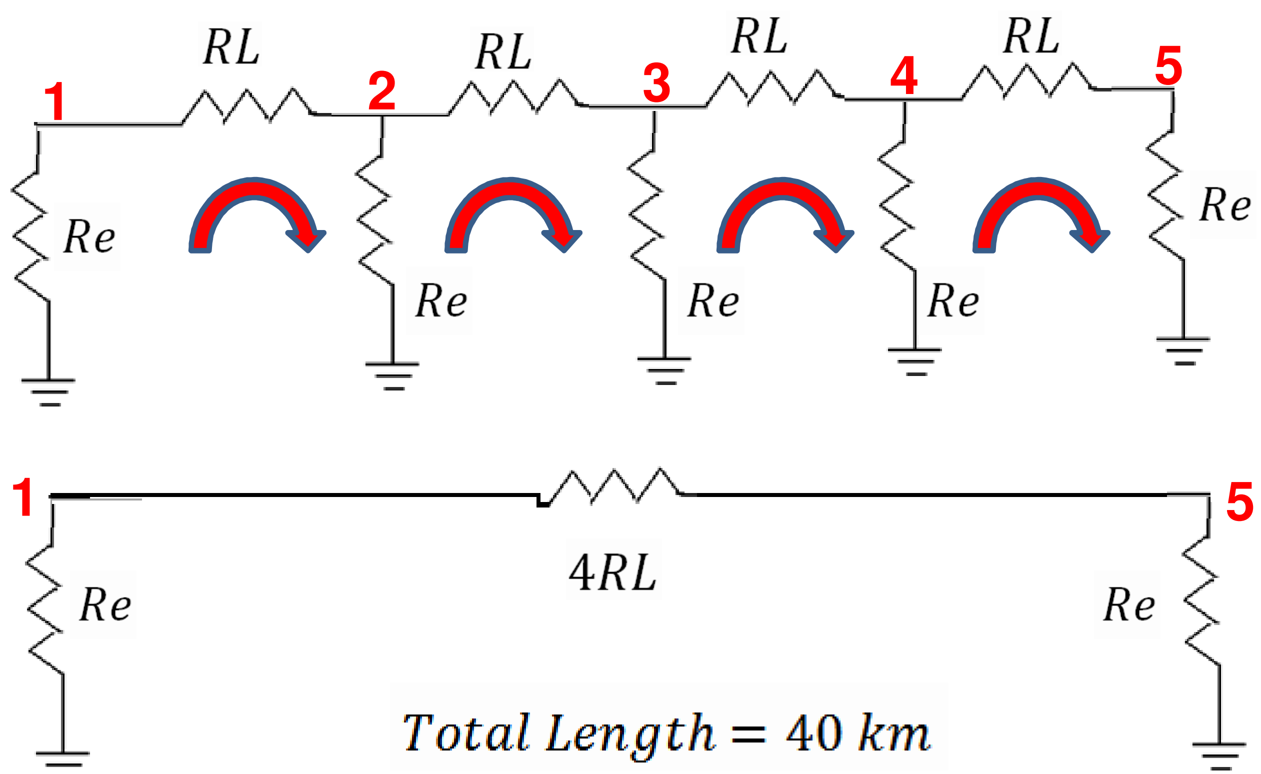
500/230/115
Possum
Elmont
Yadkin
Bristers
Loudoun
Dooms
Suffolk
Lexington



Long Lines & Extreme Points

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

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



$Total\ Length = 40\ km$

GIC Mitigation

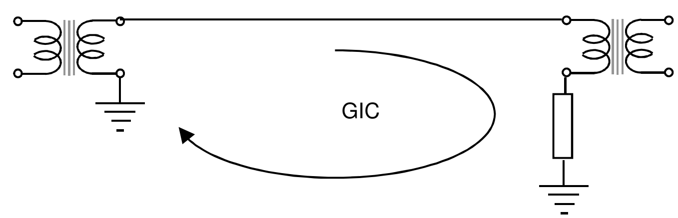
- First Rule of Mitigation is Do No Harm
  - You should not be worse off with mitigation than you were before solution is applied
    - Law of unintended consequences. You change one component or to solve a problem and you create another problem

GIC Mitigation

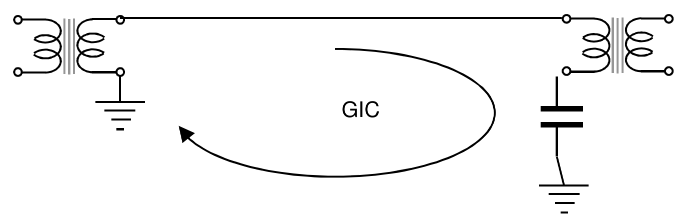
- Model and Study The Problem
  - Mitigation should not be a solution looking for a problem
    - Develop strategies that may combine operating configurations and blocking devices
    - Strategies should be coordinated with neighboring utilities since what one utility mitigation will impact another

GIC Mitigation

- GIC Reduction
  - Series Capacitors are a Mature Technology
  - Transformer Neutral Blocking device
    - Resistance or Reactance



    - Capacitive Device



GIC Mitigation

Design Issues

- Harmonic or resonance study
- Feroresonance Study
- Insulation coordination study
- Stability issue generator with small signal noise
- Must use smallest impedance to reduce neutral overvoltage
- Impact of capacitive inrush on transformer when filter bank inserted
- Impact of TRV when filter bypassing
- Impact of resonant circuit on energization of transformer transient modeling

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