University of Idaho

# ECE 525

# POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 21

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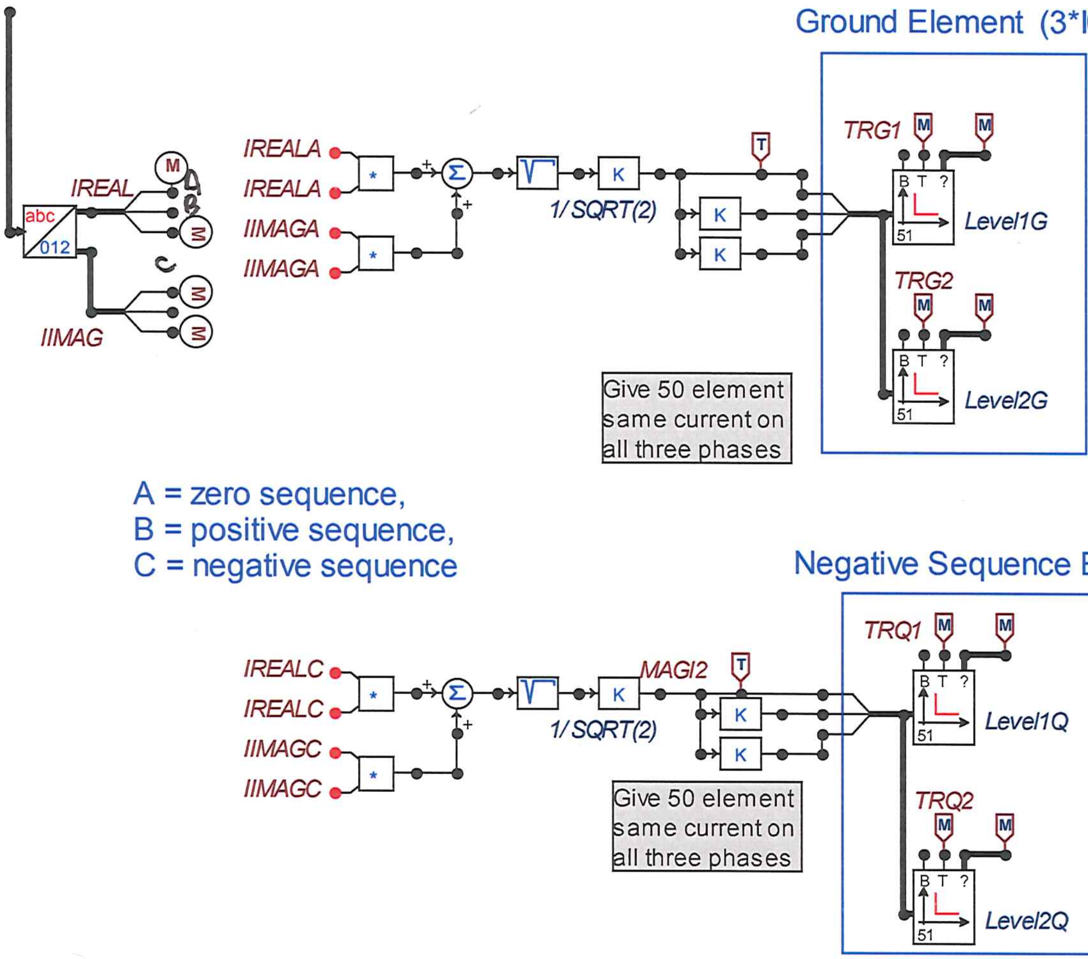
- Negative Sequence and Ground Elements

**Note, this uses sine filters so does not fully remove decaying dc offset**




Enter your trip settings as Is in the Level1G and Level2G icons

Enter your trip settings as Is in the Level1Q and Level2Q icons

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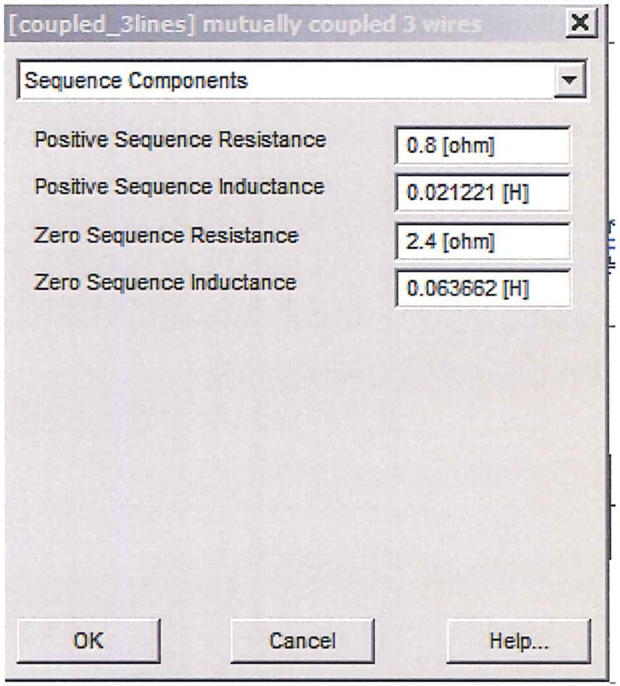
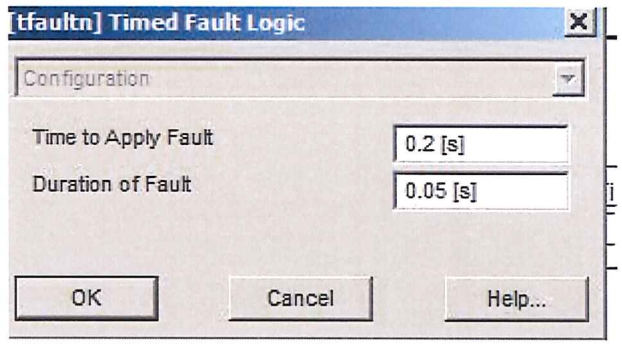
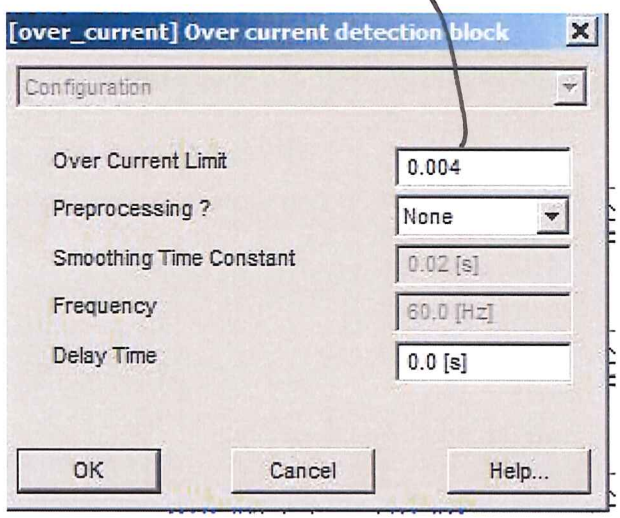
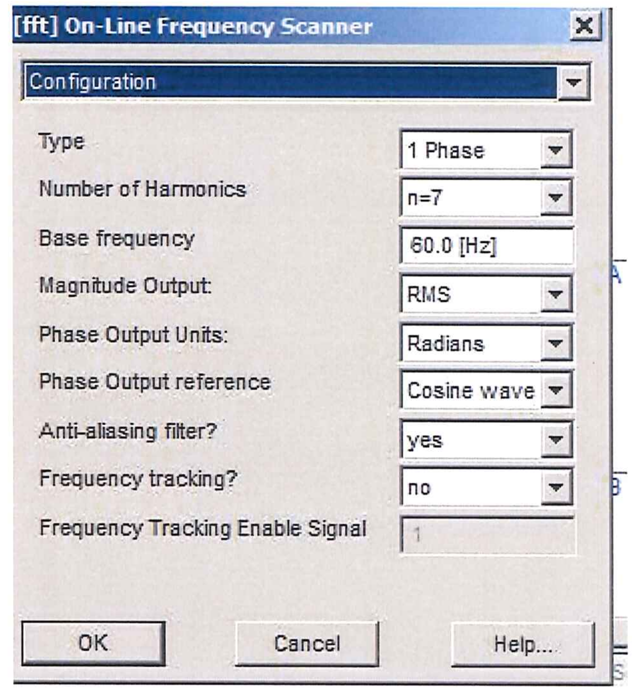
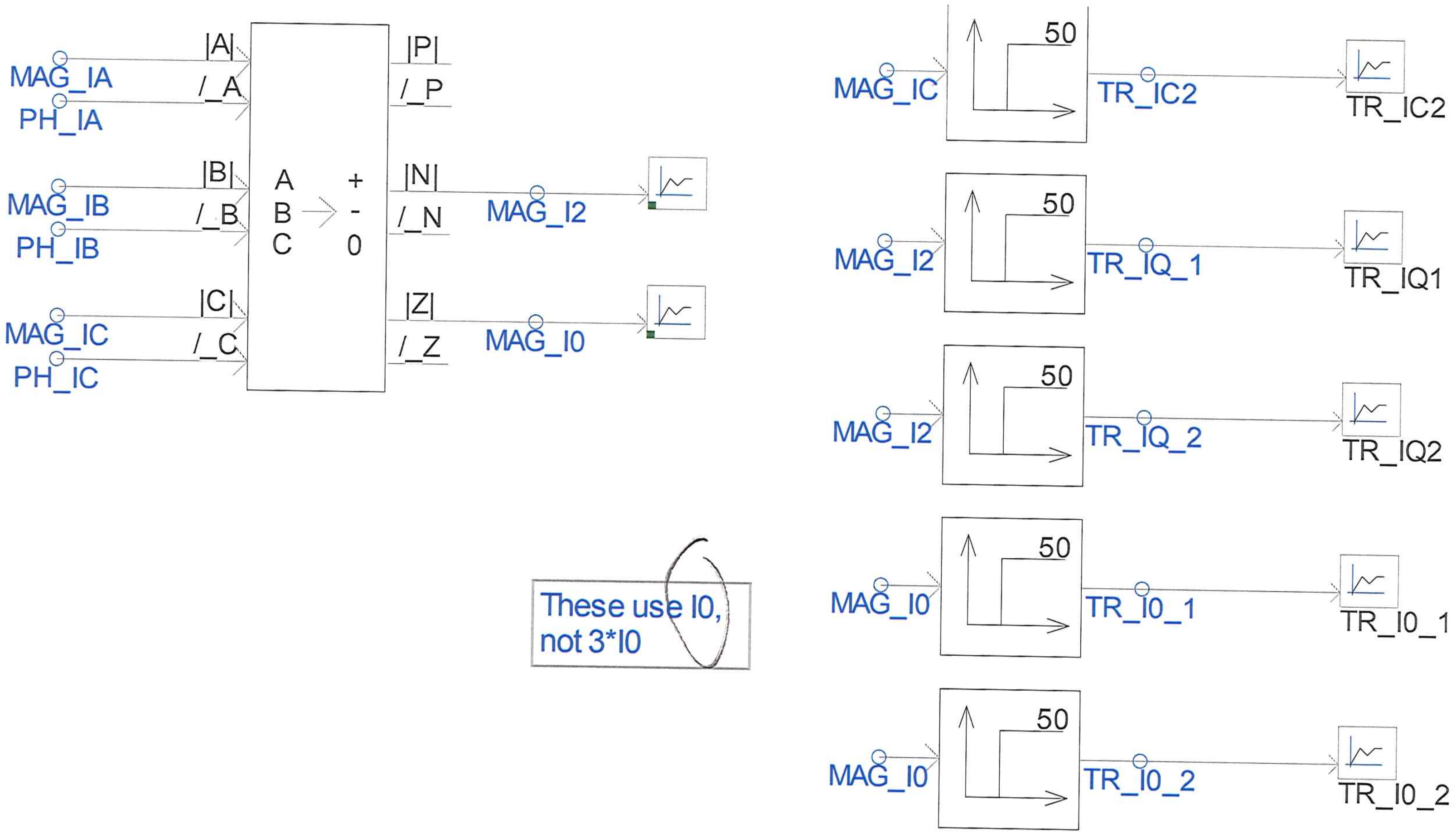


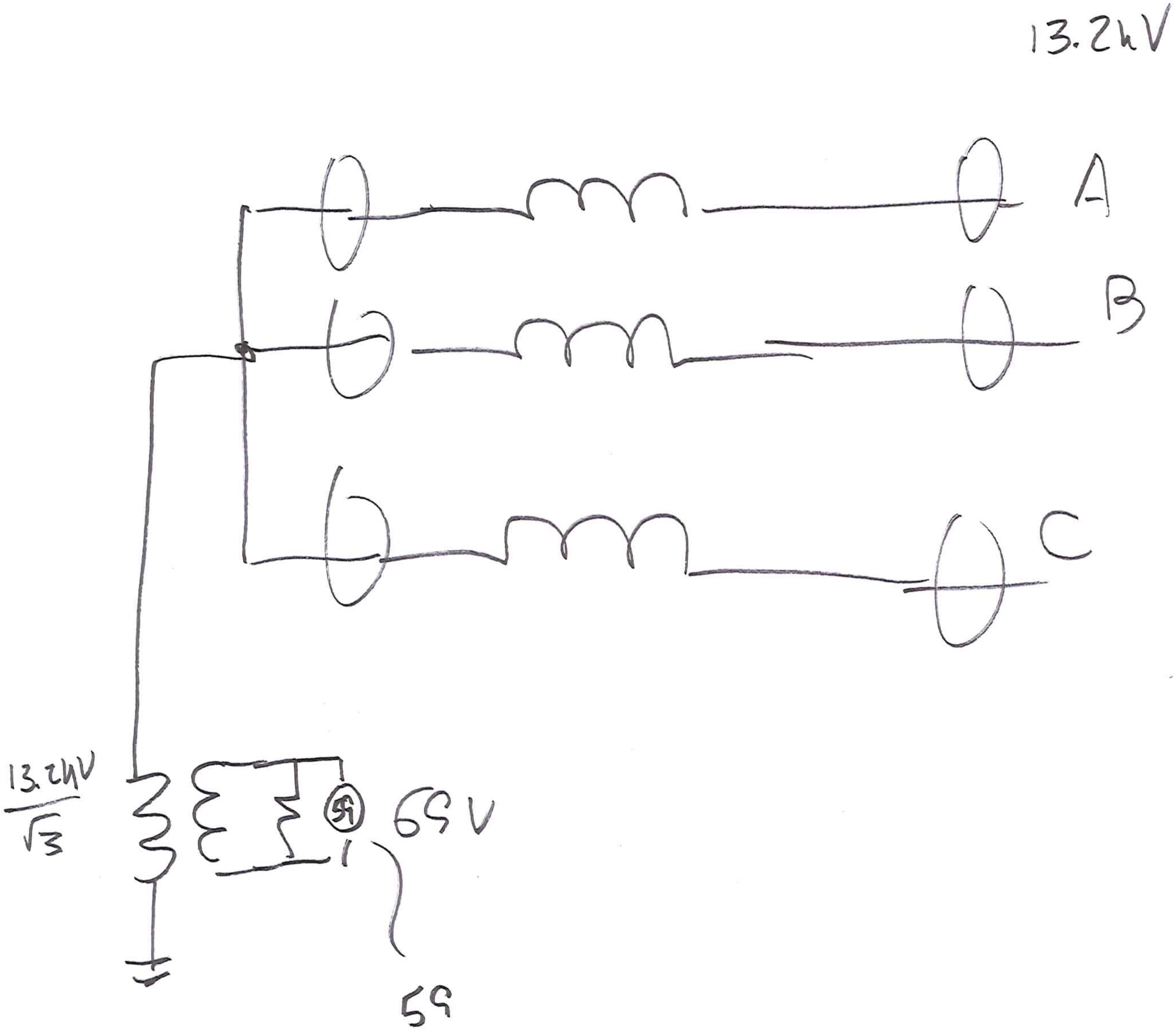



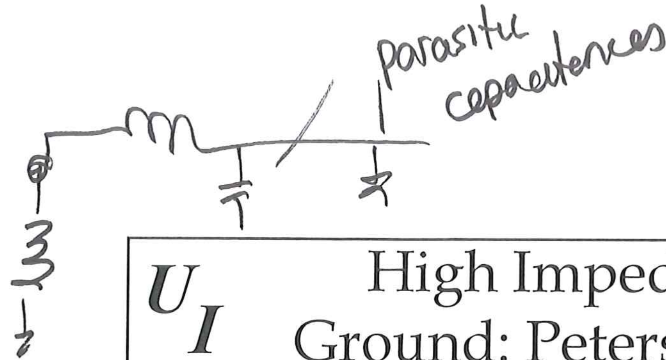

4A (on a uA scale)




MAG_IA
PH_IA
MAG_IB
PH_IB
MAG_IC
PH_IC
|A|
/_A
|B|
/_B
|C|
/_C
A
B
C
+
-
0
|P|
/_P
|N|
/_N
|Z|
/_Z
MAG_I2
MAG_I0
These use I0, not 3*I0
MAG_IC
50
TR_IC2
TR_IC2
MAG_I2
50
TR_IQ_1
TR_IQ1
MAG_I2
50
TR_IQ_2
TR_IQ2
MAG_I0
50
TR_I0_1
TR_I0_1
MAG_I0
50
TR_I0_2
TR_I0_2


13.2kV
A
B
C
13.2kV
√3
59
69V
59






## High Impedance Ground: Peterson Coil

- Normal unbalanced operation on distribution line poses problems
- Still need line to line rating on insulation
  - Ground fault neutralized
  - Resonant ground



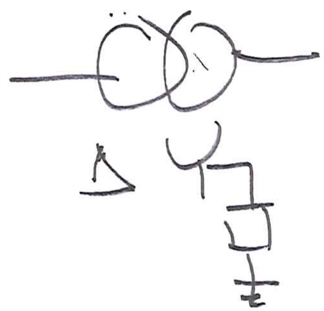


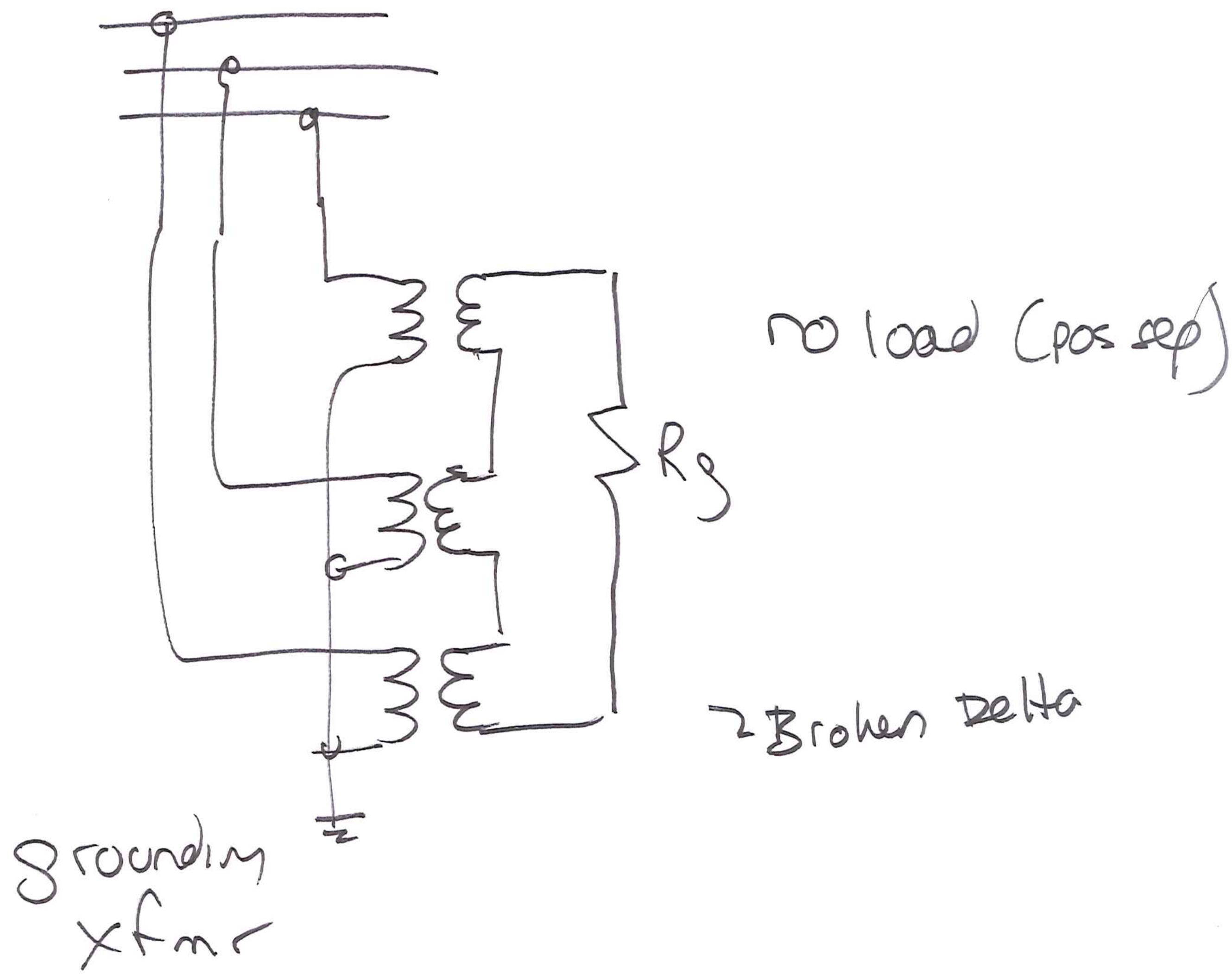
## Impedance Ground

- Resistance Ground
  - » High R: ($I_f$ < 10 A)
  - » Low R: (10A < $I_f$ < 1000A)
- Inductive Ground
  - » Zig-zag transformer
  - » Poor performance in general

  } large inductance
- Resonant Ground (ground fault neutralizer)

## Low impedance ground configs





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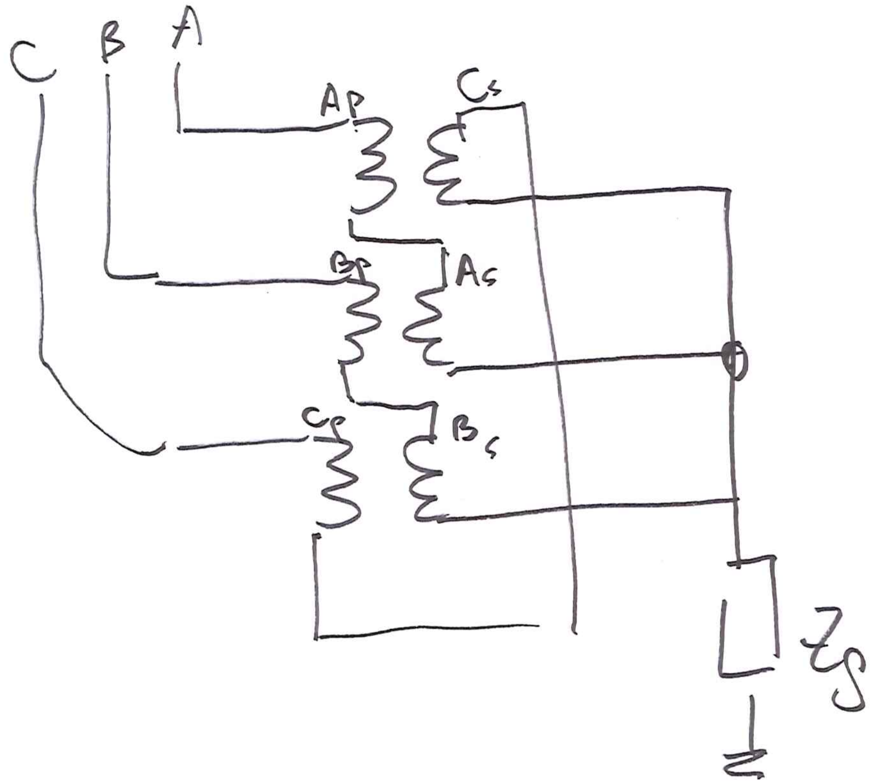
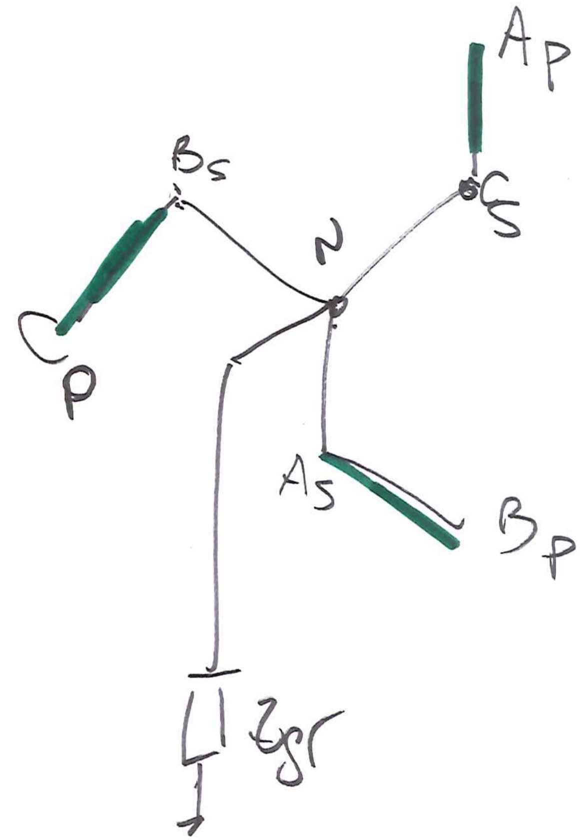
# Zig zag transformer



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## Low Impedance Ground:

ECE525

Lecture 19

- Limit fault current to 50-600 A ~ ~1000A
- Current sensing used for relaying and can do direction sensing
- Limit over voltages nearly as well as effective ground
- Sometimes use zig-zag transformer with resistor on neutral (if no R, then magnetizing branch is ground path)



## Solid Effective Grounding

ECE525

Lecture 19

- Most popular in North America
- $X_0/X_1 \leq 3$ and $R_0/X_1 \leq 1$ and are positive
- Uni-grounded (Europe) versus multi-grounded (U.S.)
- Best for detecting faults, sensing direction, and fault locating

# Grounding Examples

$a := 1 \cdot e^{j \cdot 120deg}$ $\qquad A_{012} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$ $\qquad MVA := 1000kW$ $\qquad pu := 1$

A 4160 V feeder is supplied by the WYE connected side of a 75 MVA transformer. The system $MVA_{sc}$ supplying the delta side of the transformer is 650 MVA. The transformer has a leakage reactance of 10%. A ground impedance will be connected in the neutral of 4.16kV side of the transformer to limit fault currents.

**A** Sketch the per unit diagram for the system

$MVA\_base := 100MVA$

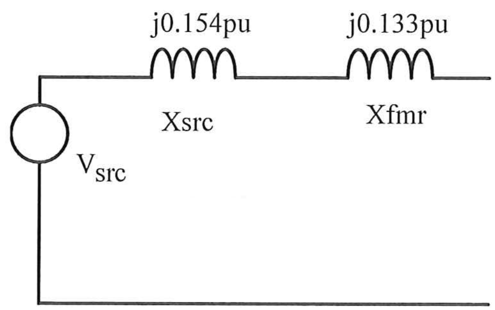
$Srated := 75MVA \qquad V\_LL := 4.16kV \qquad V\_ln := \frac{V\_LL}{\sqrt{3}} \qquad V\_ln = 2.402 \cdot kV$

$MVAsc := 650MVA$

$$Xsrc\_pu := \frac{1.0^2}{\left(\frac{MVAsc}{MVA\_base}\right)} \qquad Xsrc\_pu = 0.154 \cdot pu$$

$$X\_xfmr := 0.1 \cdot \left(\frac{4160V}{4160V}\right)^2 \left(\frac{MVA\_base}{Srated}\right)$$

$X\_xfmr = 0.133 \cdot pu$




$Xgndpu := Im(Zgnd)$ $\qquad$ $Xgndpu = 2.077$ per unit

$Xgnd := Xgndpu \cdot Zbase$ $\qquad$ $Xgnd = 0.359\,\Omega$

$$Lgnd := \frac{Xgnd}{2 \cdot \pi \cdot 60Hz} \qquad Lgnd = 0.954 \cdot mH \text{ at 60Hz}$$

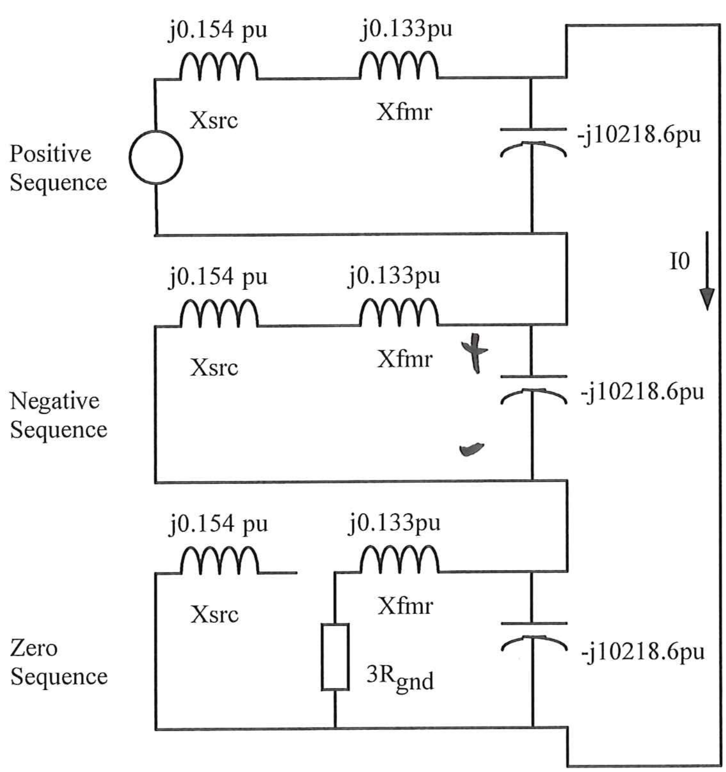
**D** If the feeder is largely underground, the capacitance cannot be neglected. If the total per phase capacitance to ground is 1.5 μF, determine the grounding resistance needed to limit the single line to ground fault current to 20 A.

$$Cparasitic := 1.5\mu F \qquad Xc := \frac{1}{2 \cdot \pi \cdot 60Hz \cdot Cparasitic} \qquad Xc = 1.768 \cdot k\Omega$$

$$Xc\_pu := \frac{Xc}{Zbase} \qquad Xc\_pu = 10218.6 \cdot pu$$

$$Islg\_max := 20A \qquad Islgpu := \frac{Islg\_max}{Ibase} \qquad Islgpu = 1.441 \times 10^{-3} \cdot pu$$

The sequence networks will now change with the addition of the capacitance as shown.



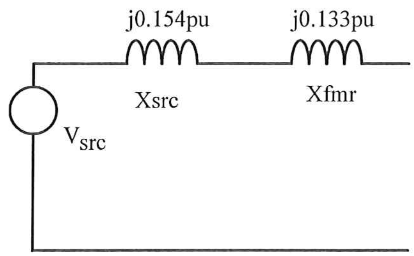

Alterate selection for Rgnd
→ If Capacitance is known

3Rgr = Xc0

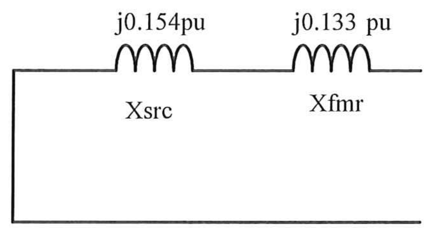
→ limits SLG current to ~ charging current

**B** Determine sequence networks for the system

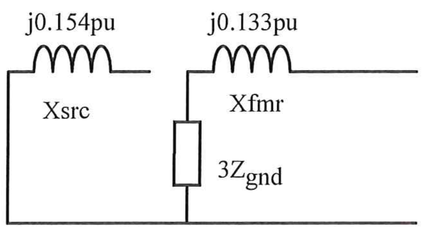
Positive Sequence:




Negative Sequence:




Zero Sequence:




Note that this is a Δ-Y grounded transformer. Also, assuming that zero sequence leakage impedance equal to positive and negative sequence values.

**C** Assume that the feeder is all overhead lines with negligable capacitance. Determine the ground *reactance* needed to limit the single line to ground fault current to 6000A.

$If\_slgmax := 6000A$

$Ibase := \frac{MVA\_base}{\sqrt{3} \cdot V\_LL}$ $\quad Ibase = 13.88 \cdot kA$ $\quad Zbase := \frac{V\_LL^2}{MVA\_base}$

$Ifpu := \frac{If\_slgmax}{Ibase}$ $\quad Ifpu = 0.432 \cdot pu$

For a SLG fault we have (connect positive, negative and zero sequence circuits in series):

$I_0 = \frac{Vfault}{Z1 + Z2 + Z0 + 3 \cdot jXgnd}$ where $Vfault := 1.0 \cdot e^{j \cdot 90deg}$

$Z1 := jXsrc\_pu + jX\_xfmr$ $\quad Z2 := Z1$

$Z0 := jX\_xfmr$

and we know for a SLG fault: $I_0 := \frac{Ifpu}{3}$

Solve for Zgnd

$Zgnd := \frac{1}{3}\left[\frac{Vfault}{I_0} - (Z1 + Z2 + Z0)\right]$ $\quad Zgnd = 2.0772i$ per unit

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**E** Calculate the line to ground voltages on the unfaulted phases in parts **C** and **D** and calculate the zero sequence voltages and currents.

**Part C:**

$$I0\_partC := \frac{Vfault}{Z0 + 3\cdot jXgndpu + Z1 + Z2}$$ $I0\_partC = 0.144$

$I1\_partC := I0\_partC$

$I2\_partC := I0\_partC$

as a check: $Ia\_partC := 3\cdot I0\_partC$ $\quad |Ia\_partC| = 0.432$ pu $\quad |Ia\_partC|\cdot Ibase = 6\cdot kA$

$V1\_partC := Vfault - I1\_partC\cdot Z1$ $\quad V1\_partC = 0.959i$

$V2\_partC := -I2\_partC\cdot Z2$ $\quad V2\_partC = -0.041i$

$V0\_partC := -I0\_partC\cdot(Z0 + 3\cdot j\cdot Xgndpu)$ $\quad V0\_partC = -0.917i$

$$Vabc\_partC := A_{012}\cdot\begin{pmatrix} V0\_partC \\ V1\_partC \\ V2\_partC \end{pmatrix} \qquad Vabc\_partC = \begin{pmatrix} 0 \\ 0.866 - 1.376i \\ -0.866 - 1.376i \end{pmatrix}$$

at fault point

$$\overrightarrow{|Vabc\_partC|} = \begin{pmatrix} 0 \\ 1.626 \\ 1.626 \end{pmatrix} \qquad \overrightarrow{arg(Vabc\_partC)} = \begin{pmatrix} 90 \\ -57.812 \\ -122.188 \end{pmatrix}\cdot deg$$

overvoltage on unfaulted phase

$$V\_ln\cdot\overrightarrow{|Vabc\_partC|} = \begin{pmatrix} 0 \\ 3.905 \\ 3.905 \end{pmatrix}\cdot kV$$

**Part D:**

$$ZgndD := \frac{(3\cdot Rgnd\_pu + Z0)\cdot(-j\cdot Xc\_pu)}{(3\cdot Rgnd\_pu + Z0) - j\cdot Xc\_pu}$$

$$I0\_partD := \frac{Vfault}{ZgndD + Z1 + Z2}$$ $I0\_partD = -9.771\times 10^{-5} + 4.703i\times 10^{-4}$

$I1\_partD := I0\_partD$ $\quad I2\_partD := I0\_partD$ $\quad |I0\_partD| = 4.804\times 10^{-4}$

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as a check: $Ia\_partD := 3 \cdot I0\_partD$ $\quad |Ia\_partD| = 1.441 \times 10^{-3}$ pu

$|Ia\_partD| \cdot Ibase = 20.001 \cdot A$

$V1\_partD := Vfault - I1\_partD \cdot Z1$ $\quad |V1\_partD| = 1$ ✓ $V_1 = 1$ $\quad V_1 + V_2 + V_0 = 0$

$V2\_partD := -I2\_partD \cdot Z2$ $\quad |V2\_partD| = 1.38 \times 10^{-4}$

$V0\_partD := -I0\_partD \cdot (ZgndD)$ $\quad |V0\_partD| = 1$ $\quad ? V_0 = -1$

$$Vabc\_partD := A_{012} \cdot \begin{pmatrix} V0\_partD \\ V1\_partD \\ V2\_partD \end{pmatrix} \qquad Vabc\_partD = \begin{pmatrix} 0 \\ 0.866 - 1.5i \\ -0.866 - 1.5i \end{pmatrix}$$

at fault point

$$\overrightarrow{|Vabc\_partD|} = \begin{pmatrix} 0 \\ 1.732 \\ 1.732 \end{pmatrix} \qquad \overrightarrow{\arg(Vabc\_partD)} = \begin{pmatrix} 107.593 \\ -60.013 \\ -120.01 \end{pmatrix} \cdot deg$$

$$V\_ln \cdot \overrightarrow{|Vabc\_partD|} = \begin{pmatrix} 0 \\ 4.16 \\ 4.161 \end{pmatrix} \cdot kV$$

**F** Compute the single line to ground fault current and the voltage on the unfaulted phases if the transformer is solidly grounded. Calculate the zero sequence voltages and currents.

$$I0\_gnd := \frac{Vfault}{Z0 + Z1 + Z2} \qquad I0\_gnd = 1.413$$

$I1\_gnd := I0\_gnd$

$I2\_gnd := I0\_gnd$

$Ia\_gnd := 3 \cdot I0\_gnd$ $\quad Ia\_gnd = 4.239$ per unit

$Ia\_gnd \cdot Ibase = 58.833 \cdot kA$

$V1\_gnd := Vfault - I1\_gnd \cdot Z1$ $\quad V1\_gnd = 0.594i$

$V2\_gnd := -I2\_gnd \cdot Z2$ $\quad V2\_gnd = -0.406i$

$V0\_gnd := -I0\_gnd \cdot Z0$ $\quad V0\_gnd = -0.18841i$

# Fault Detection & Direction Determination as impacted by grounding

(1) solidly grounded:

Detection: overcurrent protection
- → phase elements
- → ground elements
- – negative sequence elements

⇒ $I_{fault}$ typically much larger than load current (can use phase elements)

Direction sensing:

→ voltage & current

→ Torque elements

- phase quantities
- negative sequence
- positive sequence

② Low impedance grounded

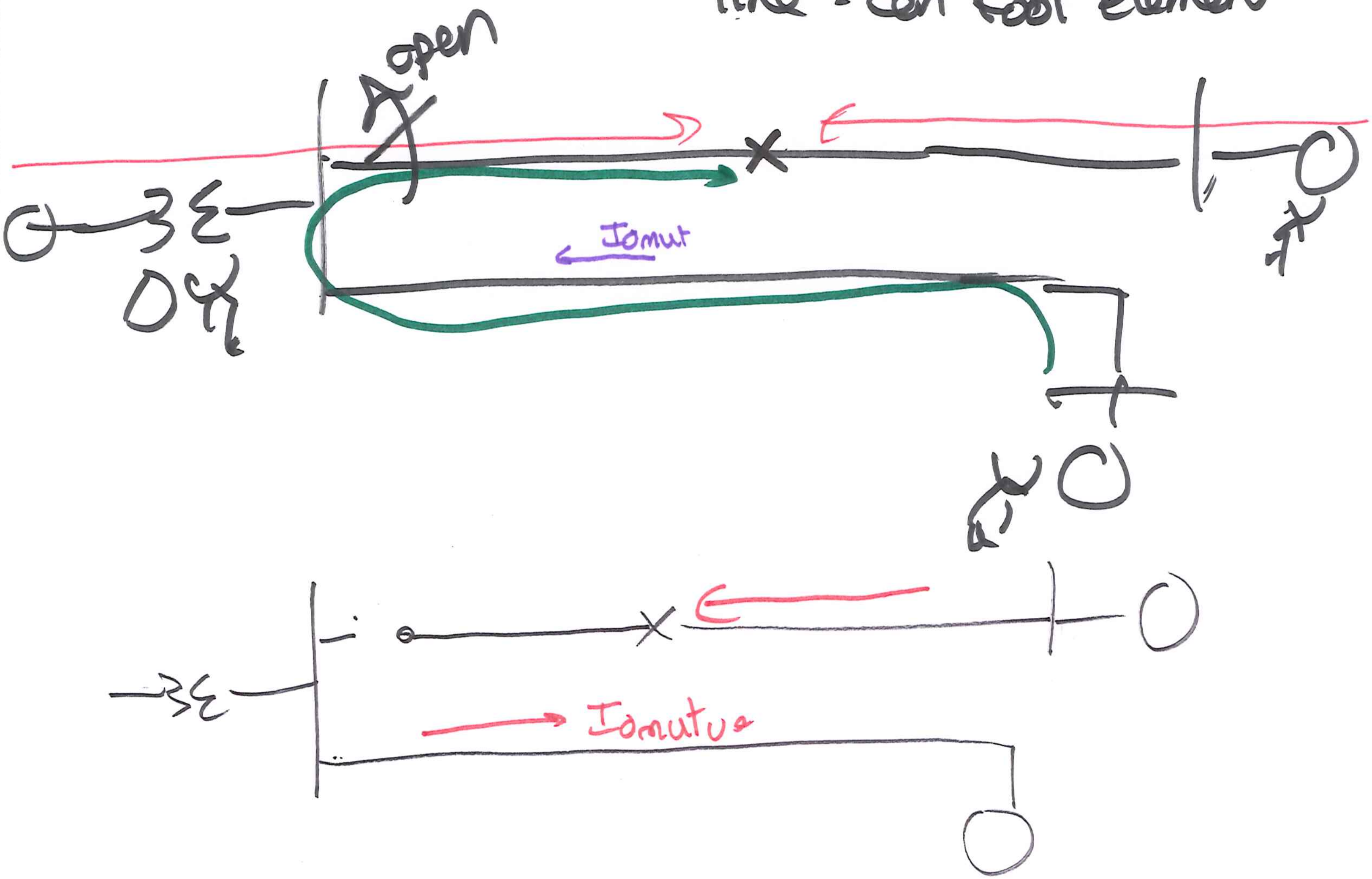
Detection:

- SLG : Limits $I_0$ - can still use overcurrent elements → ground overcurrent
- DLG, 3Ø, LL : overcurrent as above

Direction - largely same as above, zero seq directional

- caution with zero seq direction

→ mutual coupling to parallel line - can fool element



# High Resistance Grounded

Fault Detection

SLG: $V_{ng} = 3V_0$ → also for ungrounded

LL, DLG, $3\phi$ : overcurrent
- same as earlier

Direction determination - same as earlier