Grounding Examples

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

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

$MVA\_base := 100MVA$

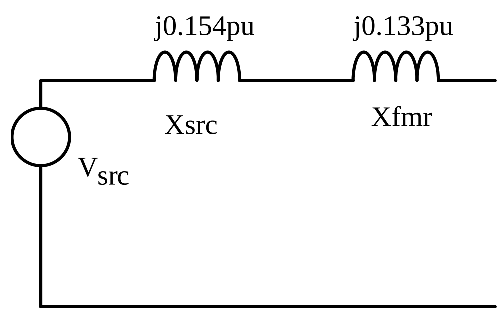
$Srated := 75MVA$ $V\_LL := 4.16kV$ $V\_ln := \frac{V\_LL}{\sqrt{3}}$ $V\_ln = 2.402 \cdot kV$

$MVAsc := 650MVA$

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

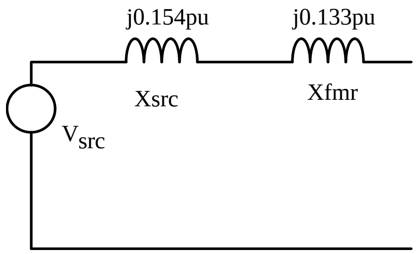
$X\_xfmr := 0.1 \cdot \left(\frac{4160V}{4160V}\right)^2 \left(\frac{MVA\_base}{Srated}\right)$

$X\_xfmr = 0.133 \cdot pu$

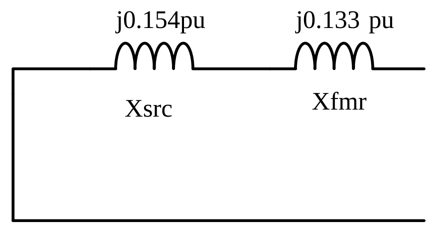


B Determine sequence networks for the system

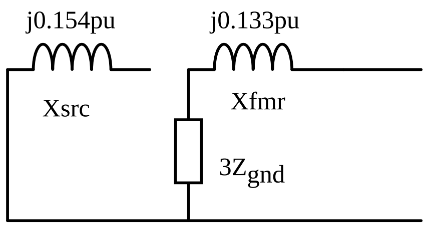
Positive Sequence:



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.

$$\text{If\_slgmax} := 6000\text{A}$$

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

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

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

$$I_0 = \frac{\text{Vfault}}{\text{Z1} + \text{Z2} + \text{Z0} + 3\cdot j\text{Xgnd}}$$

where

$$\text{Vfault} := 1.0\cdot e^{j\cdot 90\text{deg}}$$

$$\text{Z1} := j\text{Xsrc\_pu} + j\text{X\_xfmr} \qquad \text{Z2} := \text{Z1}$$

$$\text{Z0} := j\text{X\_xfmr}$$

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

Solve for Zgnd

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

per unit

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

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

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

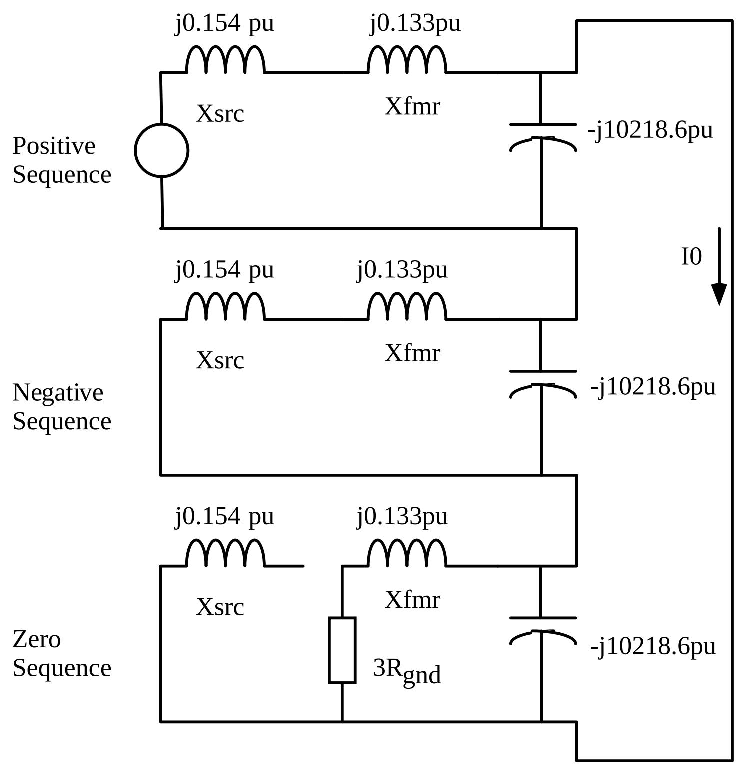
D If the feeder is largely underground, the capacitance cannot be neglected. If the total per phase capacitance to ground is 1.5 μF, determine the grounding resistance needed to limit the single line to ground fault current to 20 A.

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

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

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

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



$$I0 = \frac{Vfault}{Z1 + Z2 + \frac{[(Z0 + 3\cdot Rg)\cdot(-jXc)]}{Z0 + 3Rg - j\cdot Xc}}$$

Note that Z1+Z2 will be much much smaller than the parallel combination of 3R and -jXc, to that Z1 and Z2 can be neglected, as can Z0

We also, only care about the magnitude of the reduced current, not the angle.

So we are actually solving:

$$|I0| = \left| \frac{Vfault}{\frac{[(Z0+3\cdot Rg)\cdot(jXc)]}{Z0+3Rg-j\cdot Xc}} \right|$$

which requires an iterative solution.

$$I_0 := \frac{Islgpu}{3}$$

Initial Guess:

$$Rg := 1000$$

MathCAD solve block:

Given

$$I_0 - \left| \frac{Vfault}{\frac{(3\cdot Rg+Z0)\cdot(-j\cdot Xc\_pu)}{(3\cdot Rg+Z0)-j\cdot Xc\_pu}} \right| = 0$$

$$Rgnd\_pu := Find(Rg)$$

$$Rgnd\_pu = 708.786$$

$$Rgnd := Rgnd\_pu\cdot Zbase$$ $$Rgnd = 122.66\,\Omega$$

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:

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

$$I1\_partC := I0\_partC$$

$$I2\_partC := I0\_partC$$

as a check: $Ia\_partC := 3 \cdot I0\_partC \qquad |Ia\_partC| = 0.432 \text{ pu} \qquad |Ia\_partC| \cdot Ibase = 6 \cdot kA$

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

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

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

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

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

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

Part D:

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

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

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

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

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

$V1\_partD := Vfault - I1\_partD \cdot Z1$ $\quad |V1\_partD| = 1$

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

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

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

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

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

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.

$I0\_gnd := \dfrac{Vfault}{Z0 + Z1 + Z2}$ $\quad I0\_gnd = 1.413$ $\quad I1\_gnd := I0\_gnd$

$I2\_gnd := I0\_gnd$

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

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

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

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

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

$$Vabc := A_{012} \cdot \begin{pmatrix} V0\_gnd + 10^{-16} \\ V1\_gnd \\ V2\_gnd \end{pmatrix} \qquad Vabc = \begin{pmatrix} 0 \\ 0.866 - 0.283i \\ -0.866 - 0.283i \end{pmatrix} \qquad \overrightarrow{|Vabc|} = \begin{pmatrix} 0 \\ 0.911 \\ 0.911 \end{pmatrix}$$

$$\overrightarrow{arg(Vabc)} = \begin{pmatrix} 0 \\ -18.073 \\ -161.927 \end{pmatrix} \cdot deg$$

Note that Vb and Vc are nearly 1.0 per unit, and are slightly depressed. If Z0=Z1=Z2 then they would be 1.0 and offset from each other by 120 degrees.

$$V\_LL \cdot \overrightarrow{|Vabc|} = \begin{pmatrix} 0 \\ 3.79 \\ 3.79 \end{pmatrix} \cdot kV$$

G For the different grounded cases described above, discuss the available quantities to measure for ground fault protection and suggest a scheme to consider (based on voltage, current, etc).

For the high resistance grounded case, there isn't enough current available for doing ground fault protection, but V0 is 1pu, so there is enough voltage available to use that to identify the presense of a ground fault.

For the case with the low inductance grounded, there is sufficient I0 for detecting a fault, although any fault impedance (resistance) may make this too difficult. There is also probably sufficient V0 to use that to detect the fault.

For the solidly grounded case, V0 is pretty small, and it might be hard to discriminate sufficiently to identify a fault. On the other hand, I0 is large.