ECE 523
Symmetrical Components

Session 18

University of Idaho

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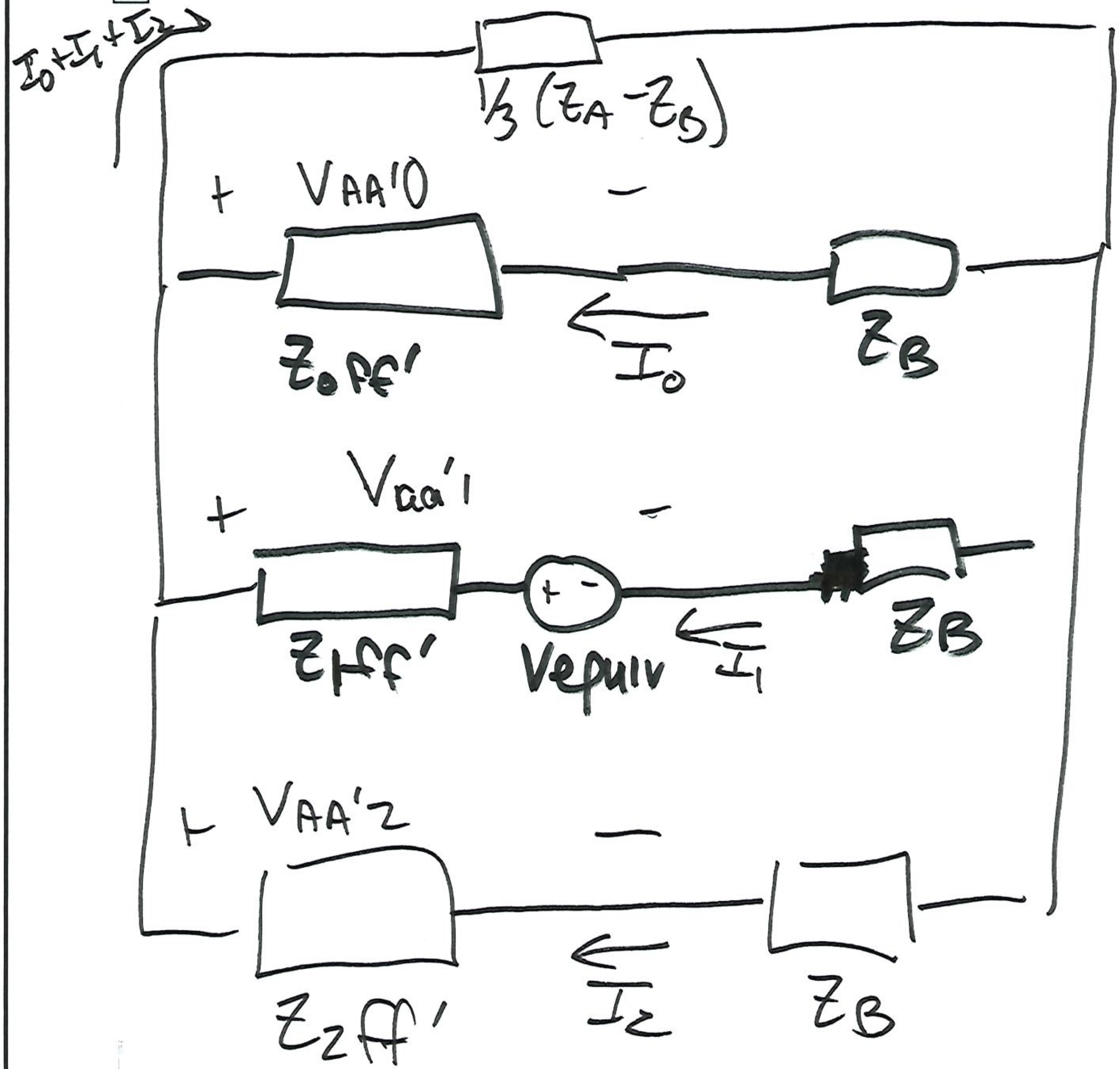
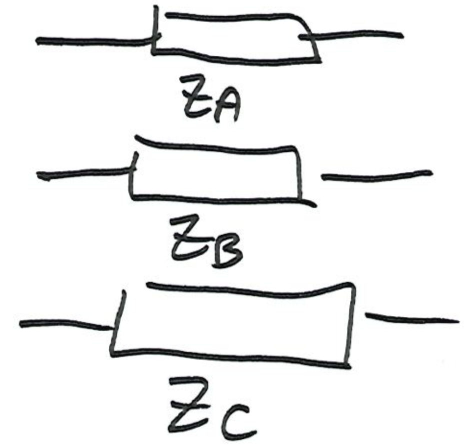




$Z_B = Z_C$

$Z_A \neq Z_B = Z_C$

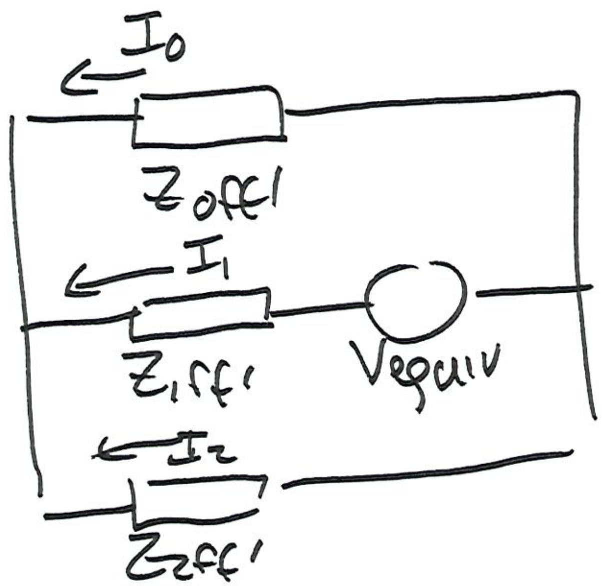
Example

phase A CB is open
(or fuse blown)

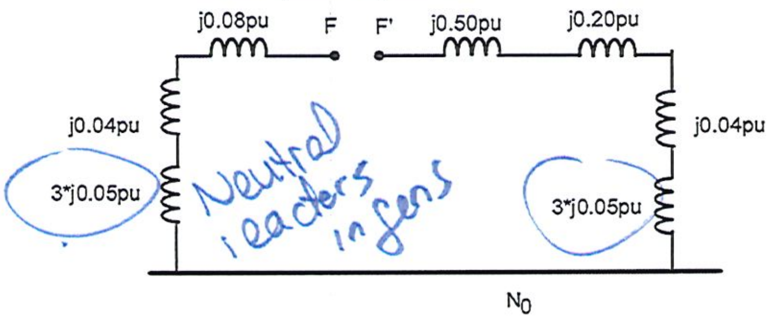
$Z_A = \infty$

$Z_B = Z_C = 0$ (closed CB)

$\frac{1}{3}(Z_A - Z_B) = \infty$



- Zero sequence equivalent:



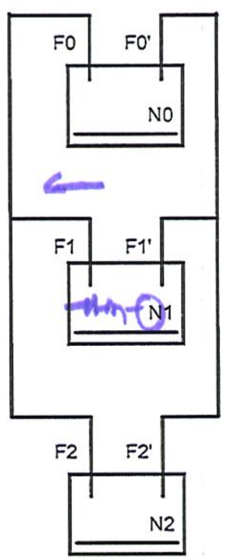
Find total impedance counterclockwise around loop from F to F'

$$Z_{0total} := j \cdot \left(2 \cdot X_{0Mach} + 2 \cdot X_T + X_{L0} + 2 \cdot 3 \cdot X_{nMach}\right)$$

$$Z_{0total} = 1.04i \cdot pu$$

$$Z_{0FF'} := Z_{0total}$$

Now solve for the single phase open circuit currents and voltages:



$$I_1 := \frac{V_{equiv}}{Z_{1FF'} + \left(\frac{1}{Z_{2FF'}} + \frac{1}{Z_{0FF'}}\right)^{-1}}$$

$$I_1 = (0.43 - 0.26i) \cdot pu$$

$$|I_1| = 0.5 \cdot pu \qquad \arg(I_1) = -31.79 \cdot deg$$

$$I_2 := -I_1 \cdot \left(\frac{Z_{0FF'}}{Z_{2FF'} + Z_{0FF'}}\right)$$

$$I_2 = (-0.25 + 0.16i) \cdot pu$$

$$|I_2| = 0.3 \cdot pu \qquad \arg(I_2) = 148.21 \cdot deg$$

$$I_0 := -I_1 \cdot \left(\frac{Z_{2FF'}}{Z_{2FF'} + Z_{0FF'}}\right)$$

$$I_0 = (-0.17 + 0.11i) \cdot pu$$

$$|I_0| = 0.2 \cdot pu \qquad \arg(I_0) = 148.21 \cdot deg$$

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$$I_{abc} := A_{012}\cdot\begin{pmatrix} I_0 \\ I_1 \\ I_2 \end{pmatrix} \qquad \overrightarrow{|I_{abc}|} = \begin{pmatrix} 0 \\ 0.76 \\ 0.76 \end{pmatrix}\cdot pu \qquad arg\left(I_{abc_1}\right) = -145.57\cdot deg \qquad arg\left(I_{abc_2}\right) = 82\cdot deg$$

0.8 prefault

Using the right have the sequence equivalent circuits:

$$V_{3new1} := E_2 + I_1\cdot j\cdot\left(X_{1Mach} + X_T\right) \qquad \left|V_{3new1}\right| = 0.96\cdot pu \qquad arg\left(V_{3new1}\right) = -4.25\cdot deg$$

$$V_{3new2} := 0 + I_2\cdot j\cdot\left(X_{2Mach} + X_T\right) \qquad \left|V_{3new2}\right| = 0.08\cdot pu \qquad arg\left(V_{3new2}\right) = -121.79\cdot deg$$

$$V_{3new0} := 0 + I_0\cdot j\cdot\left(X_{0Mach} + X_T + 3\cdot X_{nMach}\right) \qquad \left|V_{3new0}\right| = 0.05\cdot pu \qquad arg\left(V_{3new0}\right) = -121.79\cdot deg$$

$$V_{3newABC} := A_{012}\cdot\begin{pmatrix} V_{3new0} \\ V_{3new1} \\ V_{3new2} \end{pmatrix} \qquad \overrightarrow{\left|V_{3newABC}\right|} = \begin{pmatrix} 0.903 \\ 0.971 \\ 1.014 \end{pmatrix}\cdot pu \qquad \overrightarrow{arg\left(V_{3newABC}\right)} = \begin{pmatrix} -12.06 \\ -119.95 \\ 118.58 \end{pmatrix}\cdot deg$$

$$\Delta V_{ABC} := 1.0\cdot\begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} - V_{3newABC} \qquad \boxed{\overrightarrow{\left|\Delta V_{ABC}\right|} = \begin{pmatrix} 0.22 \\ 0.03 \\ 0.03 \end{pmatrix}} \qquad \boxed{\overrightarrow{arg\left(\Delta V_{ABC}\right)} = \begin{pmatrix} 58.21 \\ -121.79 \\ -121.79 \end{pmatrix}\cdot deg}$$

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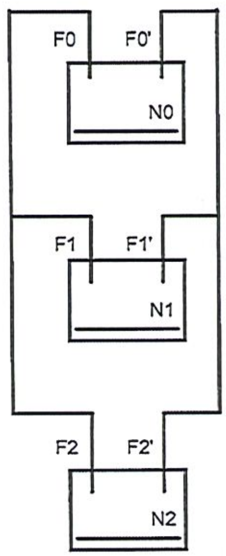
Phase A open analysis:



Equivalent voltage source for phase A open analysis:

$V_{se} := V_S - V_R \qquad V_{se} = (0.06 - 0.34i)\cdot pu$

Norton Equivalent Current: $\quad I_{se} := \dfrac{V_{se}}{Z_{1R} + Z_{1S}} \qquad I_{se} = (-2.28 - 0.4i)\cdot pu$

Equivalent Parallel Impedance: $\quad Z_{eq} := \left(\dfrac{1}{Z_{1L2}} + \dfrac{1}{Z_{1S} + Z_{1R}}\right)^{-1} \qquad Z_{eq} = 0.11i\cdot pu$

Convert back to Thevenin Equivalent Voltage

$V_f := Z_{eq}\cdot I_{se} \qquad |V_f| = 0.25\cdot pu \qquad \arg(V_f) = -80\cdot deg$

Two port thevenin voltage

Positive sequence current in line 1:

$$I_{1L1\_open} := \frac{V_f}{Z_{1equiv} + \left(\dfrac{1}{Z_{2equiv}} + \dfrac{1}{Z_{0equiv}}\right)^{-1}} \qquad |I_{1L1\_open}| = 0.34\cdot pu \qquad \arg(I_{1L1\_open}) = -170\cdot deg$$

Negative sequence current in line 1 (current divider on the line 1 current)

$$I_{2L1\_open} := -I_{1L1\_open}\cdot\frac{Z_{0equiv}}{Z_{2equiv} + Z_{0equiv}} \qquad |I_{2L1\_open}| = 0.27\cdot pu \qquad \arg(I_{2L1\_open}) = 10\cdot deg$$

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Using the sequence diagrams above calculate the positive-, negative-, and zero-sequence currents on Line 2 with VR = 1pu @ 20 degrees.

$V_S := 1\text{pu}\cdot e^{j\cdot 0\text{deg}}$ $\qquad$ $V_R := 1\text{pu}\cdot e^{j\cdot 20\text{deg}}$

Total prefault current:

$$I_{sourceprefault} := \frac{V_S - V_R}{Z_{1S} + Z_{1R} + \left(\frac{1}{Z_{1L1}} + \frac{1}{Z_{1L2}}\right)^{-1}} \qquad \left|I_{sourceprefault}\right| = 1.08\cdot\text{pu} \qquad \arg\left(I_{sourceprefault}\right) = -170\cdot\text{deg}$$

Current dividers to find the current in lines 1 and 2:

$$I_{L1\_prefault} := I_{sourceprefault}\cdot\left(\frac{Z_{1L2}}{Z_{1L1} + Z_{1L2}}\right) \qquad \left|I_{L1\_prefault}\right| = 0.62\cdot\text{pu} \qquad \arg\left(I_{L1\_prefault}\right) = -170\cdot\text{deg}$$

$$I_{L2\_prefault} := I_{sourceprefault}\cdot\left(\frac{Z_{1L1}}{Z_{1L1} + Z_{1L2}}\right) \qquad \left|I_{L2\_prefault}\right| = 0.46\cdot\text{pu} \qquad \arg\left(I_{L2\_prefault}\right) = -170\cdot\text{deg}$$

$$I_{ABCL1\_prefault} := I_{L1\_prefault}\cdot\begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} \qquad \overrightarrow{\left|I_{ABCL1\_prefault}\right|} = \begin{pmatrix} 0.62 \\ 0.62 \\ 0.62 \end{pmatrix}\cdot\text{pu} \qquad \overrightarrow{\arg\left(I_{ABCL1\_prefault}\right)} = \begin{pmatrix} -170 \\ 70 \\ -50 \end{pmatrix}\cdot\text{deg}$$

$$I_{ABCL2\_prefault} := I_{L2\_prefault}\cdot\begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} \qquad \overrightarrow{\left|I_{ABCL2\_prefault}\right|} = \begin{pmatrix} 0.46 \\ 0.46 \\ 0.46 \end{pmatrix}\cdot\text{pu} \qquad \overrightarrow{\arg\left(I_{ABCL2\_prefault}\right)} = \begin{pmatrix} -170 \\ 70 \\ -50 \end{pmatrix}\cdot\text{deg}$$

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Zero sequence current in line 1 (current divider on the line 1 current)

$$I_{0L1\_open} := -I_{1L1\_open}\cdot\frac{Z_{2equiv}}{Z_{2equiv}+Z_{0equiv}} \qquad \left|I_{0L1\_open}\right| = 0.07\cdot pu \qquad \arg\left(I_{0L1\_open}\right) = 10\cdot deg$$

$$I_{ABC\_Line1} := A_{012}\cdot\begin{pmatrix} I_{0L1\_open} \\ I_{1L1\_open} \\ I_{2L1\_open} \end{pmatrix} \qquad \boxed{\overrightarrow{\left|I_{ABC\_Line1}\right|} = \begin{pmatrix} 0 \\ 0.545 \\ 0.545 \end{pmatrix}\cdot pu}$$

$$\boxed{\arg\left(I_{ABC\_Line1_1}\right) = 88.74\cdot deg}$$

$$\boxed{\arg\left(I_{ABC\_Line1_2}\right) = -68.74\cdot deg}$$

Note that the magnitude on phase A is 0 and a little smaller on the unfaulted phases. There is also a phase shift compared to prefault

Now to fine the line 2 current, we need to do another current divider on each of the sequence currents from line 1, since the sequnce currents could either pass through the sources or line to to return to line 1.

Positive sequence load current in line two ignoring open line ? treating line 1 as open

$$I_{LineA2} := \frac{V_S - V_R}{Z_{1S} + Z_{1L2} + Z_{1R}} \qquad \left|I_{LineA2}\right| = 0.631 \qquad \arg\left(I_{LineA2}\right) = -170\cdot deg$$

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load current in Line 2

$$I_{1L2} := -I_{1L1\_open} \cdot \left(\frac{Z_{1S} + Z_{1R}}{Z_{1S} + Z_{1R} + Z_{1L2}} \right) + I_{LineA2}$$

$$\boxed{\left| I_{1L2} \right| = 0.54 \cdot pu} \qquad \boxed{\arg\left(I_{1L2}\right) = -170 \cdot deg}$$

$$I_{2L2} := -I_{2L1\_open} \cdot \left(\frac{Z_{1S} + Z_{1R}}{Z_{1S} + Z_{1R} + Z_{1L2}} \right)$$

$$\boxed{\left| I_{2L2} \right| = 0.07 \cdot pu} \qquad \boxed{\arg\left(I_{2L2}\right) = -170 \cdot deg}$$

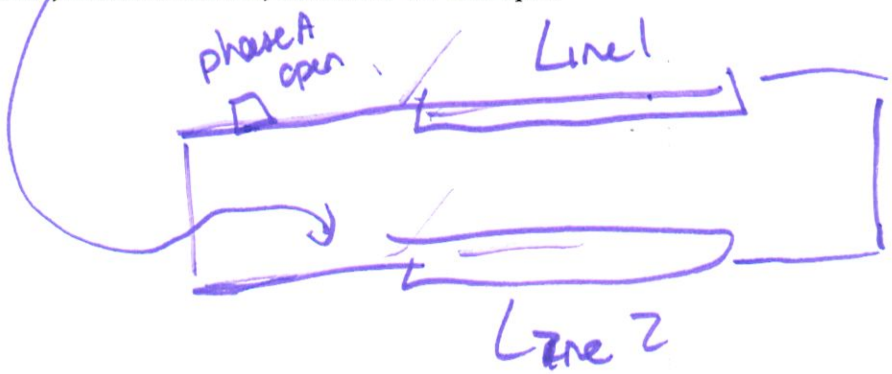
$$I_{0L2} := -I_{0L1\_open} \cdot \left(\frac{Z_{0S} + Z_{0R}}{Z_{0S} + Z_{0R} + Z_{0L2}} \right)$$

$$\boxed{\left| I_{0L2} \right| = 0.02 \cdot pu} \qquad \boxed{\arg\left(I_{0L2}\right) = -170 \cdot deg}$$

$$I_{ABC\_Line2} := A_{012} \cdot \begin{pmatrix} I_{0L2} \\ I_{1L2} \\ I_{2L2} \end{pmatrix}$$

$$\boxed{\overrightarrow{\left| I_{ABC\_Line2} \right|} = \begin{pmatrix} 0.63 \\ 0.494 \\ 0.494 \end{pmatrix} \cdot pu} \qquad \boxed{\overrightarrow{\arg\left(I_{ABC\_Line2}\right)} = \begin{pmatrix} -170 \\ 64.29 \\ -44.29 \end{pmatrix} \cdot deg}$$

- See course web page for ATP, PSCAD/EMTDC, and EMTP-RV examples



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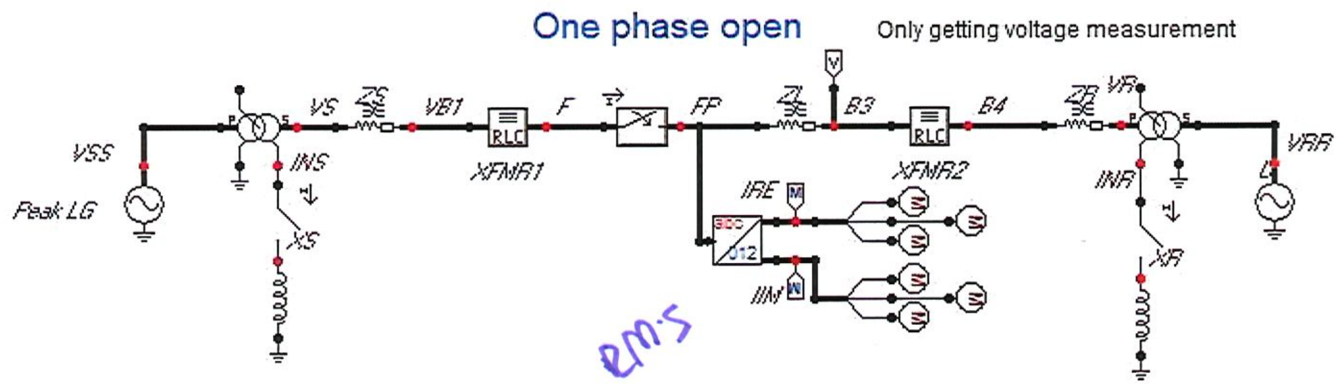
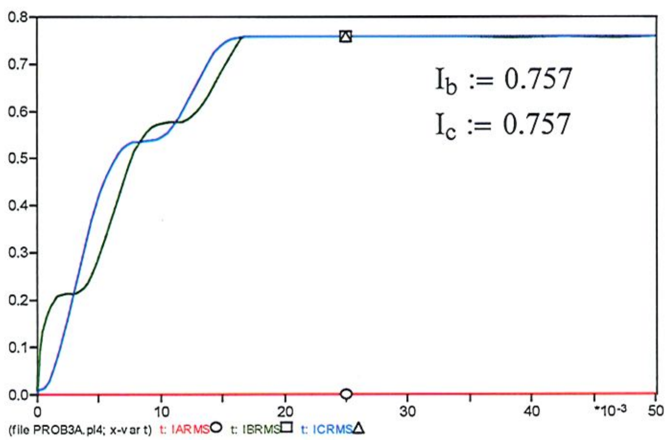
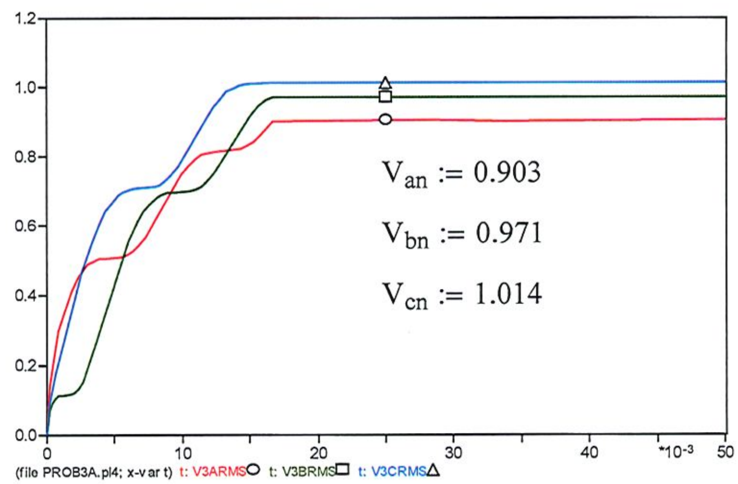
ATP simulation results:



Currents



Voltages



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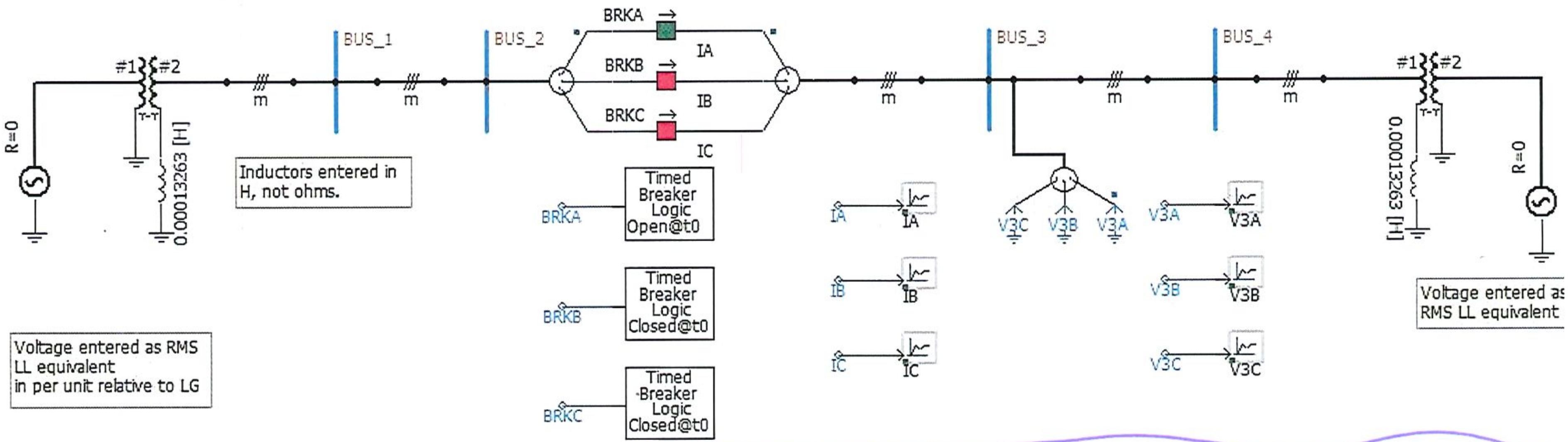
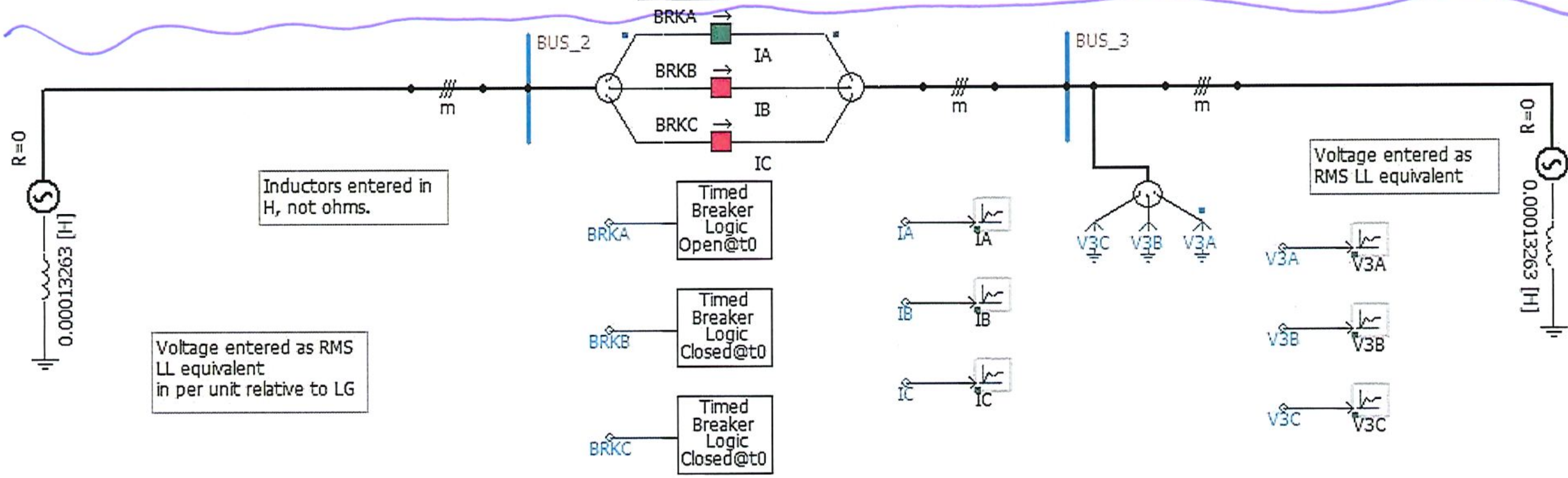
PSCAD/EMTDC implementation





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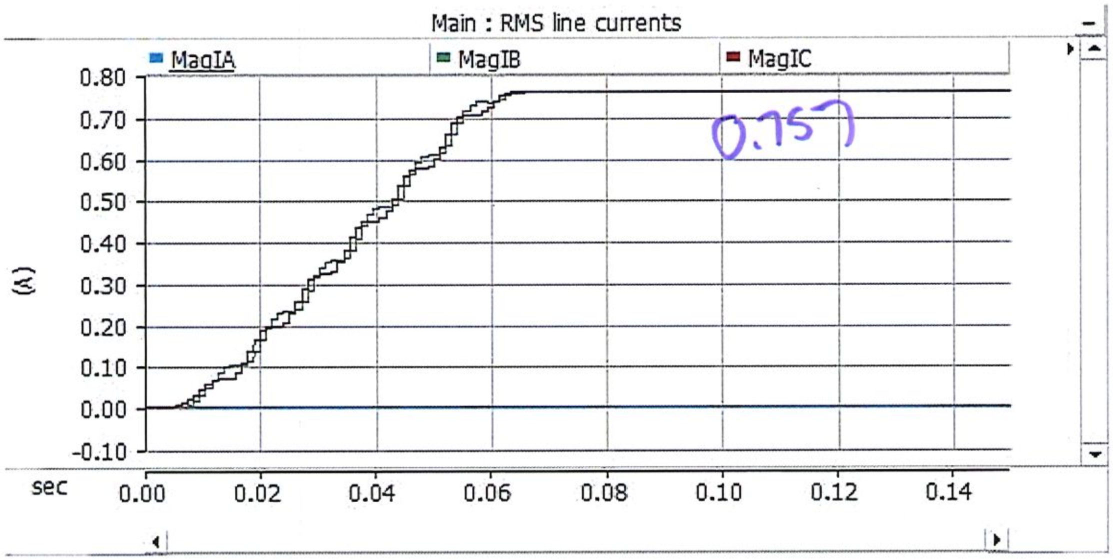
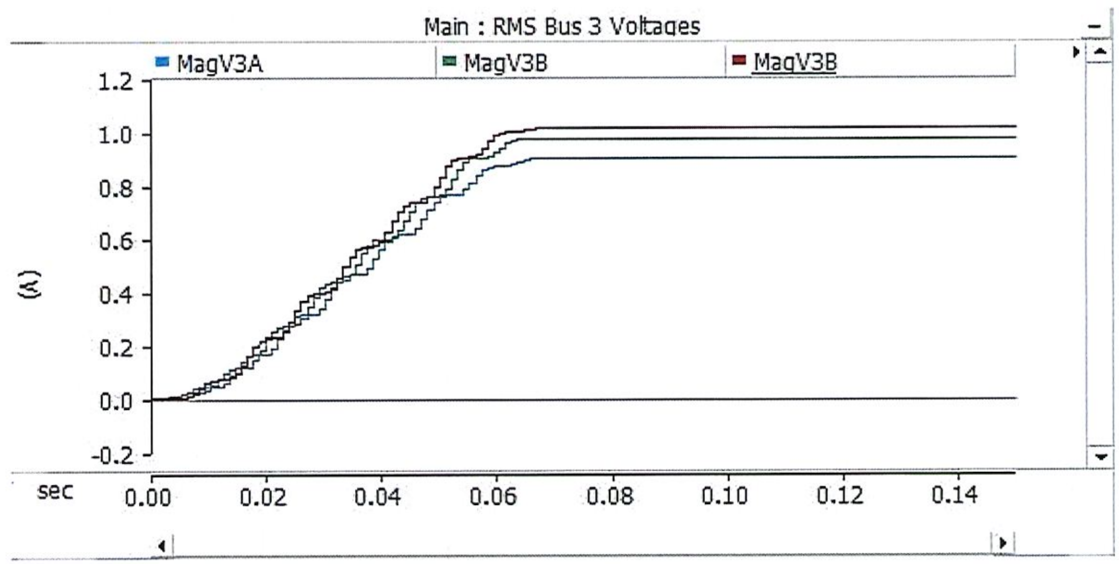

Main : RMS line currents
MagIA
MagIB
MagIC
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
(A)
sec
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.757


Main : RMS Bus 3 Voltages
MagV3A
MagV3B
MagV3B
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
(A)
sec
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14

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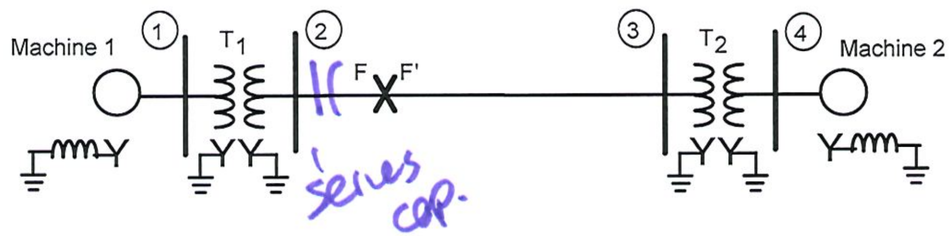
General Series Fault Case

$pu := 1$ $\qquad$ $MVA := 1000kW$

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

Suppose that a series compensated is added to the line at the Bus 2 end with each phase having a capacitive impedance of -j0.1pu. The capacitor on phase A is bypassed by a bypass breaker while phases B and C remaind inserted. Calculate the currents from Bus1 to Bus 2 and the voltage at Bus 3 (assuming the voltage is 1.0 pu before the condition occurs).

- System one-line diagram:



Machines 1 and 2: $\quad S_{Mach} := 100MVA$ $\qquad V_{machine} := 20kV$

$X_{dMach''} := 20\%$ $\qquad X_{1Mach} := X_{dMach''}$ $\qquad X_{2Mach} := X_{1Mach}$

$X_{0Mach} := 4\%$ $\qquad X_{nMach} := 5\%$

Transformers T1 and T2: $\quad S_{Tran} := 1000MVA$ $\qquad V_{HV} := 345kV$ $\qquad V_{LV} := 20kV$ $\qquad X_T := 8\%$

Transmission Line $\quad X_{L1} := 15\%$ $\qquad X_{L2} := X_{L1}$ $\qquad X_{L0} := 50\%$

$X_c := 0.1pu$

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$V_{BLine} := 345kV$ $\quad V_{B\_mach} := V_{BLine} \cdot \left(\frac{V_{LV}}{V_{HV}}\right)$ $\quad V_{B\_mach} = 20 \cdot kV$

No change of base calculations are needed for this system.

Determine internal source voltages:

$magS_{pre} := 100MVA$ $\quad pf_{pre} := 0.85$ lagging $\quad \theta_{pre} := acos(pf_{pre})$ $\quad \theta_{pre} = 31.79 \cdot deg$

$S_{Base} := 100MVA$

$S_{pre} := \frac{magS_{pre}}{S_{Base}} \cdot e^{j \cdot \theta_{pre}}$ $\quad S_{pre} = (0.85 + 0.53i) \cdot pu$ $\quad |S_{pre}| = 1 \cdot pu$

Assume bus 3 voltage is 1.0 pu at and angle of 0 degrees.

$V_3 := 1.0$

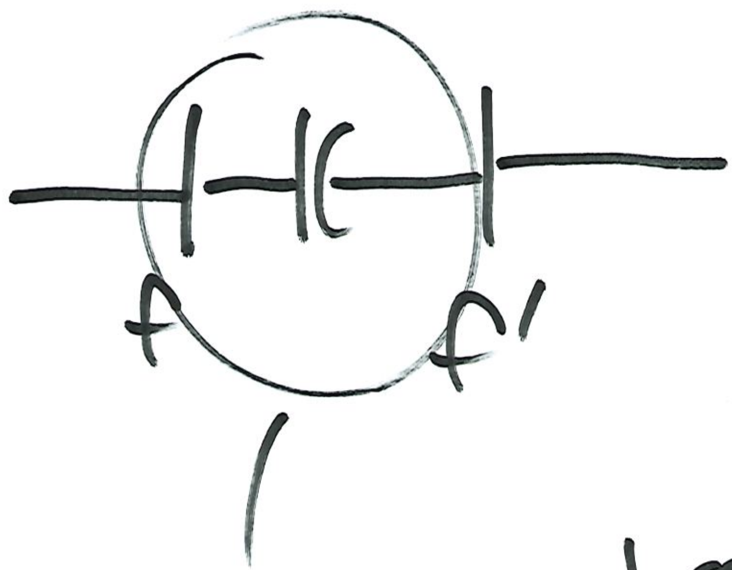
$I_{load} := \overline{\left(\frac{S_{pre}}{V_3}\right)}$ $\quad I_{load} = 0.85 - 0.53i$ $\quad |I_{load}| = 1 \cdot pu$ $\quad arg(I_{load}) = -31.79 \cdot deg$

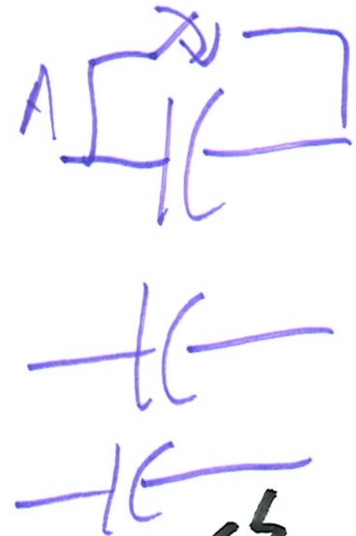
Internal voltage on the motor (since we don't know steady-state synchronous reactance, use X1):

$E_2 := V_3 - I_{load} \cdot j(X_T + X_{1Mach})$ $\quad |E_2| = 0.89$ $\quad \phi_2 := arg(E_2)$ $\quad \phi_2 = -15.6 \cdot deg$

Generator internal voltage:

$E_1 := V_3 + I_{load} \cdot (j \cdot X_{L1} - j \cdot X_c + j \cdot X_T + j \cdot X_{1Mach})$ $\quad |E_1| = 1.21 \cdot pu$ $\quad \phi_1 := arg(E_1)$ $\quad \phi_1 = 13.44 \cdot deg$

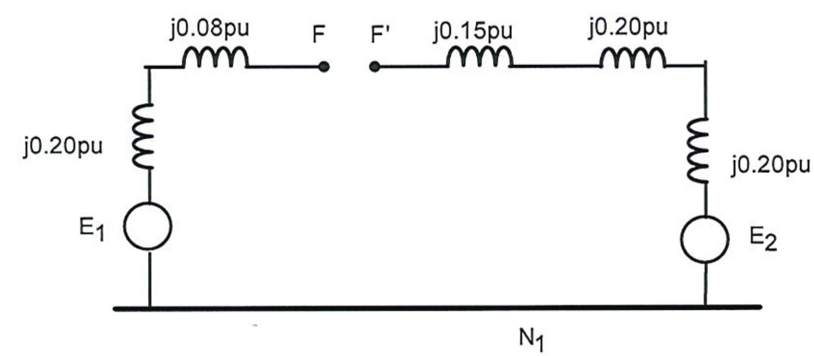




$Z_A = 0$ - closed bypass

$Z_B = Z_C = -jX_C$

- Positive sequence equivalent circuit (with phase open point indicated). Capaictor is not part of the equivalent. It is between F and F'



Find total impedance counterclockwise around loop from F to F'

$Z_{1total} := j\cdot(X_{1Mach} + X_T + X_{L1} + X_T + X_{1Mach})$

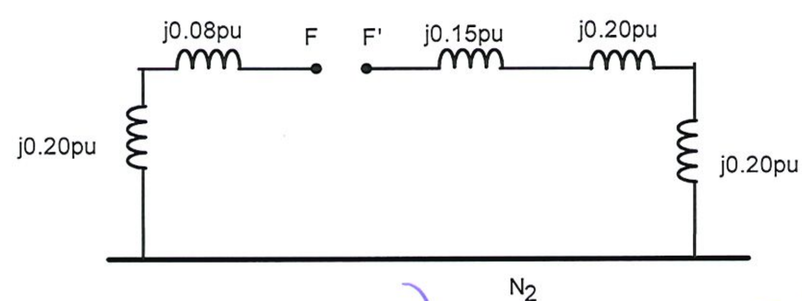
$Z_{1total} = 0.71i\cdot pu$

$Z_{1FF'} := Z_{1total}$

$V_{equiv} := E_1 - E_2$

result did change since E_1 & E_2 different with capacitor

- Negative sequence equivalent circuit:



Find total impedance counterclockwise around loop from F to F'

$Z_{2total} := j\cdot(X_{2Mach} + X_T + X_{L2} + X_T + X_{2Mach})$

$Z_{2total} = 0.71i\cdot pu$

$Z_{2FF'} := Z_{2total}$

Unchanged since cap between f & f'

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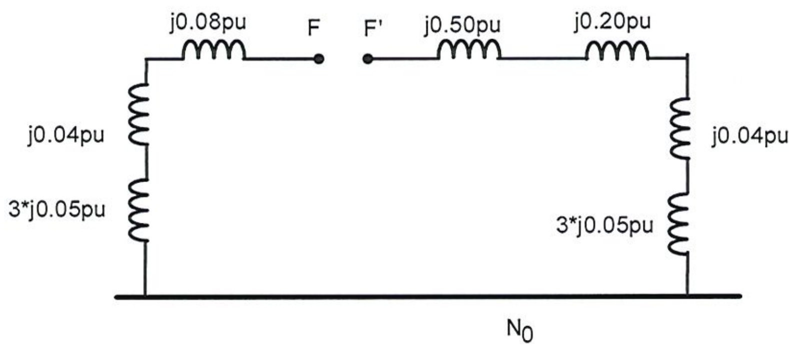
- Zero sequence equivalent:



Find total impedance counterclockwise around loop from F to F'

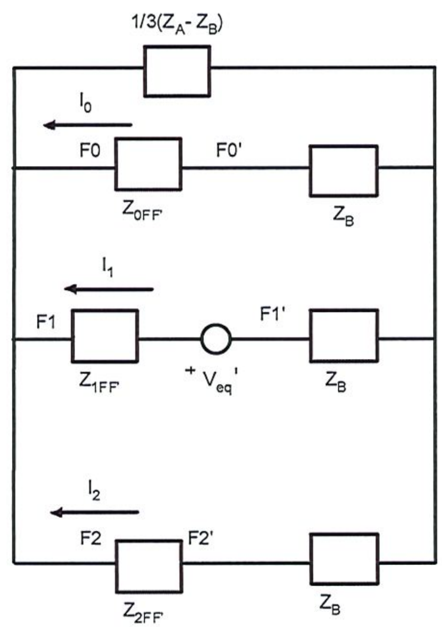
$$Z_{0total} := j\cdot\left(2\cdot X_{0Mach} + 2\cdot X_T + X_{L0} + 2\cdot 3\cdot X_{nMach}\right)$$

$$Z_{0total} = 1.04i\cdot pu$$

$$Z_{0FF'} := Z_{0total}$$

Now solve for the single phase open circuit currents and voltages:

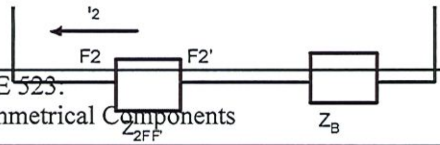
$Z_A := 0pu$ shorted capacitor $Z_B := -j\cdot X_c$



$$I_{1pp'\_f} := \frac{V_{equiv}}{\left(Z_{1FF'} + Z_B\right) + \left[\frac{1}{\left(Z_{2FF'} + Z_B\right)} + \frac{1}{\left(Z_{0FF'} + Z_B\right)} + \frac{1}{\frac{1}{3}\cdot\left(Z_A - Z_B\right)}\right]^{-1}}$$

$$\left|I_{1pp'\_f}\right| = 0.95\cdot pu$$

$$\arg\left(I_{1pp'\_f}\right) = -31.79\cdot deg$$



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$Z_0 \| \frac{1}{3}(Z_A - Z_B)$

$$I_{2pp'\_f} := -I_{1pp'\_f} \cdot \frac{\left[\frac{1}{Z_{0FF'} + Z_B} + \frac{1}{\frac{1}{3}\cdot(Z_A - Z_B)}\right]^{-1}}{(Z_{2FF'} + Z_B) + \left[\frac{1}{Z_{0FF'} + Z_B} + \frac{1}{\frac{1}{3}\cdot(Z_A - Z_B)}\right]^{-1}}$$

$$|I_{2pp'\_f}| = 0.05 \cdot pu$$

$$\arg(I_{2pp'\_f}) = 148.21 \cdot deg$$

$$I_{0pp'\_f} := -I_{1pp'\_f} \cdot \frac{\left[\frac{1}{Z_{2FF'} + Z_B} + \frac{1}{\frac{1}{3}\cdot(Z_A - Z_B)}\right]^{-1}}{(Z_{0FF'} + Z_B) + \left[\frac{1}{Z_{2FF'} + Z_B} + \frac{1}{\frac{1}{3}\cdot(Z_A - Z_B)}\right]^{-1}}$$

$$|I_{0pp'\_f}| = 0.03 \cdot pu$$

$$\arg(I_{0pp'\_f}) = 148.21 \cdot deg$$

- Although we don't use it, here is the current in the $1/3*(Z_A\text{-}Z_B)$ branch

$$I_{a\_b} := -I_{1pp'\_f} \cdot \frac{\left(\frac{1}{Z_{2FF'} + Z_B} + \frac{1}{Z_{0FF'} + Z_B}\right)^{-1}}{\left(\frac{1}{Z_{2FF'} + Z_B} + \frac{1}{Z_{0FF'} + Z_B}\right)^{-1} + \frac{1}{3}\cdot(Z_A - Z_B)}$$

$$|I_{a\_b}| = 0.87 \cdot pu$$

$$\arg(I_{a\_b}) = 148.21 \cdot deg$$

- Notice that is the largest component of the current.

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$$I_{L2\_ABC\_f} := A_{012} \cdot \begin{pmatrix} I_{0pp'\_f} \\ I_{1pp'\_f} \\ I_{2pp'\_f} \end{pmatrix} \qquad \overrightarrow{\left|I_{L2\_ABC\_f}\right|} = \begin{pmatrix} 0.8736 \\ 0.9917 \\ 0.9917 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(I_{L2\_ABC\_f}\right)} = \begin{pmatrix} -31.79 \\ -150.95 \\ 87.37 \end{pmatrix} \cdot deg$$

- Phase A has a smaller current than B and C, but not zero.
- Good match with ATP results

Using the right have the sequence equivalent circuits:

$$V_{3new1} := E_2 + I_{1pp'\_f} \cdot j \cdot \left(X_{1Mach} + X_T\right) \qquad \left|V_{3new1}\right| = 0.99 \cdot pu \qquad \arg\left(V_{3new1}\right) = -0.66 \cdot deg$$

$$V_{3new2} := 0 + I_{2pp'\_f} \cdot j \cdot \left(X_{2Mach} + X_T\right) \qquad \left|V_{3new2}\right| = 0.01 \cdot pu \qquad \arg\left(V_{3new2}\right) = -121.79 \cdot deg$$

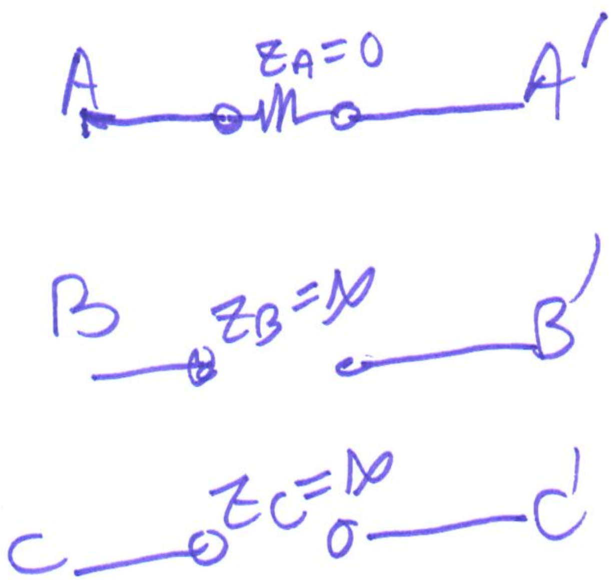
$$V_{3new0} := 0 + I_{0pp'\_f} \cdot j \cdot \left(X_{0Mach} + X_T + 3 \cdot X_{nMach}\right) \qquad \left|V_{3new0}\right| = 0.01 \cdot pu \qquad \arg\left(V_{3new0}\right) = -121.79 \cdot deg$$

$$V_{3newABC} := A_{012} \cdot \begin{pmatrix} V_{3new0} \\ V_{3new1} \\ V_{3new2} \end{pmatrix} \qquad \overrightarrow{\left|V_{3newABC}\right|} = \begin{pmatrix} 0.98 \\ 1 \\ 1 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(V_{3newABC}\right)} = \begin{pmatrix} -1.74 \\ -119.99 \\ 119.75 \end{pmatrix} \cdot deg$$

Equivalent circuit hold for almost all series faults

– except for 2 phases open

$Z_A = 0 \qquad Z_B = Z_C = \infty$



ABC constraints

$Z_B = Z_C = \infty$

$I_B = I_C = 0$

$V_{AA'} = Z_A \cdot I_A$

In sequence domain

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_A \\ 0 \\ 0 \end{bmatrix}$$

$$I_0 = I_1 = I_2 = \frac{I_A}{3}$$

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ECE 523, Lect 17

Two phase open sequence connections

$Z_B = Z_C = \infty$

- Boundary conditions in ABC domain:

$I_b = I_c = 0$

$V_{aa'} = Z_A \cdot I_a$

- Transform boundary conditions to sequence domain

  - Result for currents is similar to that for a SLG fault:

$I_0 = I_1 = I_2 = \dfrac{I_a}{3}$ • implies series connection of sequence blocks

  - voltage equation mapped to sequence domain:

$VAG = V_{aa'0} + V_{aa'1} + V_{aa'2} = Z_A \cdot (I_0 + I_1 + I_2)$

- Rearrange equation grouping terms:

$$\boxed{(V_{aa'0} - Z_A \cdot I_0) + (V_{aa'1} - Z_A \cdot I_1) + (V_{aa'2} - Z_A \cdot I_2) = 0}$$

$V_{aa'0} + V_{aa'1} + V_{aa'2} = 3 Z_A I_0$

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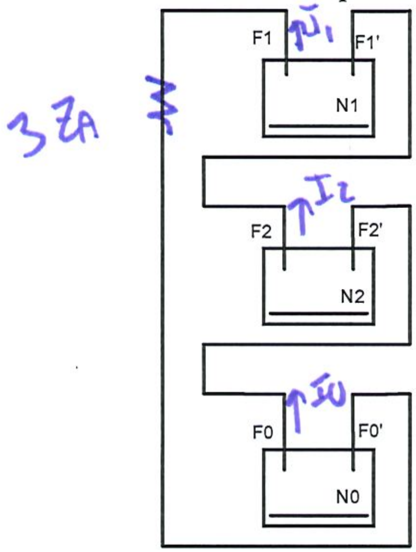
Now solve the two phase open circuit below for the sequence currents:



$$I_1 := \frac{V_{equiv}}{Z_{1FF'} + Z_{2FF'} + Z_{0FF'}}$$ $- E_1 - E_2$

$I_1 = (0.2 - 0.12i)\cdot pu$

$|I_1| = 0.23\cdot pu \qquad \arg(I_1) = -31.79\cdot deg$

$I_2 := I_1 \qquad I_0 := I_1$

prefault was 0.8 at -31.79

$$I_{abc} := A_{012}\cdot\begin{pmatrix} I_0 \\ I_1 \\ I_2 \end{pmatrix} \qquad \overrightarrow{|I_{abc}|} = \begin{pmatrix} 0.69 \\ 0 \\ 0 \end{pmatrix}\cdot pu \qquad \overrightarrow{\arg(I_{abc})} = \begin{pmatrix} -31.79 \\ 81.87 \\ 81.87 \end{pmatrix}\cdot deg$$

$V_{3new1} := E_2 + I_1\cdot j\cdot(X_{1Mach} + X_T) \qquad V_{3new1} = (0.92 - 0.14i)\cdot pu$

$V_{3new2} := 0 + I_2\cdot j\cdot(X_{2Mach} + X_T) \qquad V_{3new2} = (0.03 + 0.05i)\cdot pu$

$V_{3new0} := 0 + I_0\cdot j\cdot(X_{0Mach} + X_T + 3\cdot X_{nMach}) \qquad V_{3new0} = (0.03 + 0.05i)\cdot pu$

$$V_{3newABC} := A_{012}\cdot\begin{pmatrix} V_{3new0} \\ V_{3new1} \\ V_{3new2} \end{pmatrix} \qquad \overrightarrow{|V_{3newABC}|} = \begin{pmatrix} 0.983 \\ 0.905 \\ 0.901 \end{pmatrix}\cdot pu \qquad \overrightarrow{\arg(V_{3newABC})} = \begin{pmatrix} -1.6 \\ -132.16 \\ 107.93 \end{pmatrix}\cdot deg$$

$$\Delta V_{ABC} := 1.0\cdot\begin{pmatrix} 1 \\ a^2 \\ a \end{pmatrix} - V_{3newABC} \qquad \overrightarrow{|\Delta V_{ABC}|} = \begin{pmatrix} 0.03 \\ 0.22 \\ 0.22 \end{pmatrix}\cdot pu \qquad \overrightarrow{\arg(\Delta V_{ABC})} = \begin{pmatrix} 58.21 \\ -61.27 \\ 177.7 \end{pmatrix}\cdot deg$$