University of Idaho

ECE 523
Symmetrical Components

Session 12

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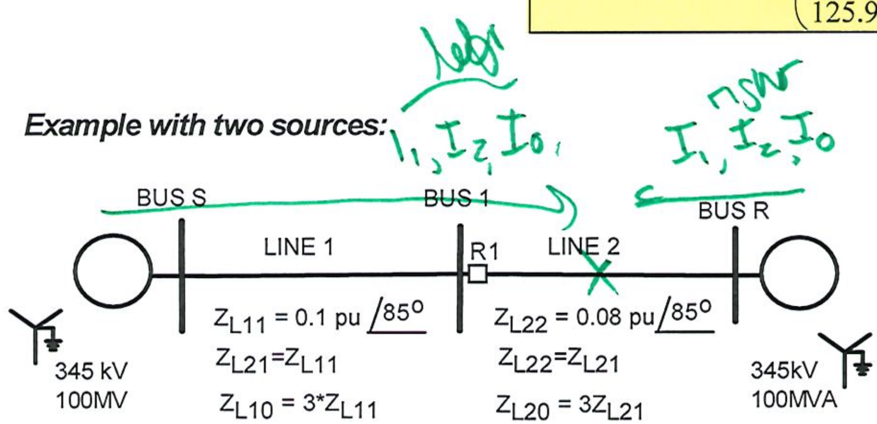
$$V_{abc\_SLGHV} := A_{012} \cdot \begin{pmatrix} V_{0\_SLGHV} \\ V_{1\_SLGHV} \\ V_{2\_SLGHV} \end{pmatrix}$$

$$\overrightarrow{\left|V_{abc\_SLGHV}\right|} = \begin{pmatrix} 0.62 \\ 1 \\ 0.62 \end{pmatrix} \cdot pu$$

$$\overrightarrow{\arg\left(V_{abc\_SLGHV}\right)} = \begin{pmatrix} 54.06 \\ -90 \\ 125.94 \end{pmatrix} \cdot deg$$

- ***Example with two sources:***



V_S = 1.0pu @ 0 deg

Z_{S1} = j0.03 pu
Z_{S2}=Z_{S1}
Z_{S0} = 3*Z_{S1}

Per unit line impedances calculated with SB=100MVA and VB=345kV LL

V_R = 1.0pu at 0 deg

Z_{R1} = j0.06 pu
Z_{R2}=Z_{R1}
Z_{R0} = 3*Z_{R1}

$$Z_{S1} := j \cdot 0.03pu \qquad Z_{L11} := 0.1pu \cdot e^{j \cdot 85deg} \qquad Z_{L21} := 0.08pu \cdot e^{j \cdot 85deg}$$

$$Z_{S2} := Z_{S1} \qquad Z_{L11} = 0.01 + 0.1i \qquad Z_{L21} = 0.01 + 0.08i$$

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$Z_{S0} := 3Z_{S1}$

$Z_{R1} := j\cdot 0.06pu$

$Z_{R2} := Z_{R1}$

$Z_{R0} := 3Z_{R1}$

$Z_{L12} := Z_{L11}$

$Z_{L10} := 3\cdot Z_{L11}$

$Z_{L10} = 0.03 + 0.3i$

$Z_{L22} := Z_{L21}$

$Z_{L20} := 3\cdot Z_{L21}$

$Z_{L20} = 0.02 + 0.24i$

- For faults on Line 2: left of fault   to right of the fault

$$Z_{L2\_1\_thev}(n) := \left[\frac{1}{Z_{S1} + Z_{L11} + n\cdot Z_{L21}} + \frac{1}{(1-n)\cdot Z_{L21} + Z_{R1}}\right]^{-1}$$

$$Z_{L2\_2\_thev}(n) := \left[\frac{1}{Z_{S2} + Z_{L12} + n\cdot Z_{L22}} + \frac{1}{(1-n)\cdot Z_{L22} + Z_{R2}}\right]^{-1}$$

$$Z_{L2\_0\_thev}(n) := \left[\frac{1}{Z_{S0} + Z_{L10} + n\cdot Z_{L20}} + \frac{1}{(1-n)\cdot Z_{L20} + Z_{R0}}\right]^{-1}$$

- ***3 phase faults:*** $V_f := 1$

$$I_{f1}(m) := \frac{V_f}{Z_{L2\_1\_thev}(m)}$$

$$I_{left\_1}(m) := \frac{I_{f1}(m)\cdot\left[(1-m)\cdot Z_{L21} + Z_{R1}\right]}{Z_{S1} + Z_{L11} + m\cdot Z_{L21} + \left[(1-m)\cdot Z_{L21} + Z_{R1}\right]}$$

current divider

total fault current

$$I_{right\_1}(m) = \frac{I_{A}(m)\left(Z_{S1} + Z_{L11} + mZ_{L21}\right)}{Z_{TOT}}$$

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$$V_{R1\_1}(m) := V_f - I_{left\_1}(m)\cdot(Z_{S1} + Z_{L11})$$

$$\left|I_{left\_1}(0.5)\right| = 5.89\cdot pu \qquad \left|V_{R1\_1}(0.5)\right| = 0.24\cdot pu$$

$$\arg(I_{left\_1}(0.5)) = -85.88\cdot deg \qquad \arg(V_{R1\_1}(0.5)) = -0.88\cdot deg$$

- ***SLG faults:***

Total fault current –

$$I_{f0}(m) := \frac{V_f}{Z_{L2\_1\_thev}(m) + Z_{L2\_2\_thev}(m) + Z_{L2\_0\_thev}(m)} \qquad I_{f1}(m) := I_{f0}(m) \qquad I_{f2}(m) := I_{f0}(m)$$

Sequence currents from left

$$I_{left\_1}(m) := \frac{I_{f1}(m)\cdot[(1-m)\cdot Z_{L21} + Z_{R1}]}{Z_{S1} + Z_{L11} + m\cdot Z_{L21} + [(1-m)\cdot Z_{L21} + Z_{R1}]}$$

$$I_{left\_2}(m) := \frac{I_{f2}(m)\cdot[(1-m)\cdot Z_{L22} + Z_{R2}]}{Z_{S2} + Z_{L12} + m\cdot Z_{L22} + [(1-m)\cdot Z_{L22} + Z_{R2}]}$$

$$I_{left\_0}(m) := \frac{I_{f0}(m)\cdot[(1-m)\cdot Z_{L20} + Z_{R0}]}{Z_{S0} + Z_{L10} + m\cdot Z_{L20} + [(1-m)\cdot Z_{L20} + Z_{R0}]}$$

voltage drops to relay location in sequence domain

$$V_{R1\_1}(m) := V_f - I_{left\_1}(m)\cdot(Z_{S1} + Z_{L11})$$

$$V_{R1\_2}(m) := 0 - I_{left\_2}(m)\cdot(Z_{S2} + Z_{L12})$$

$$V_{R1\_0}(m) := 0 - I_{left\_0}(m)\cdot(Z_{S0} + Z_{L10})$$

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$$V_{ABC\_R1}(m) := A_{012} \cdot \begin{pmatrix} V_{R1\_0}(m) \\ V_{R1\_1}(m) \\ V_{R1\_2}(m) \end{pmatrix} \qquad \overrightarrow{\left|V_{ABC\_R1}(0.5)\right|} = \begin{pmatrix} 0.24 \\ 1.18 \\ 1.18 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(V_{ABC\_R1}(0.5)\right)} = \begin{pmatrix} -0.88 \\ -132.89 \\ 132.99 \end{pmatrix} \cdot deg$$

$$I_{ABC\_R1}(m) := A_{012} \cdot \begin{pmatrix} I_{left\_0}(m) \\ I_{left\_1}(m) \\ I_{left\_2}(m) \end{pmatrix} \qquad \overrightarrow{\left|I_{ABC\_R1}(0.5)\right|} = \begin{pmatrix} 3.53 \\ 0 \\ 0 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(I_{ABC\_R1}(0.5)\right)} = \begin{pmatrix} -85.88 \\ 49.05 \\ 49.05 \end{pmatrix} \cdot deg$$

meaningless
magnitude = 0
(10^-13

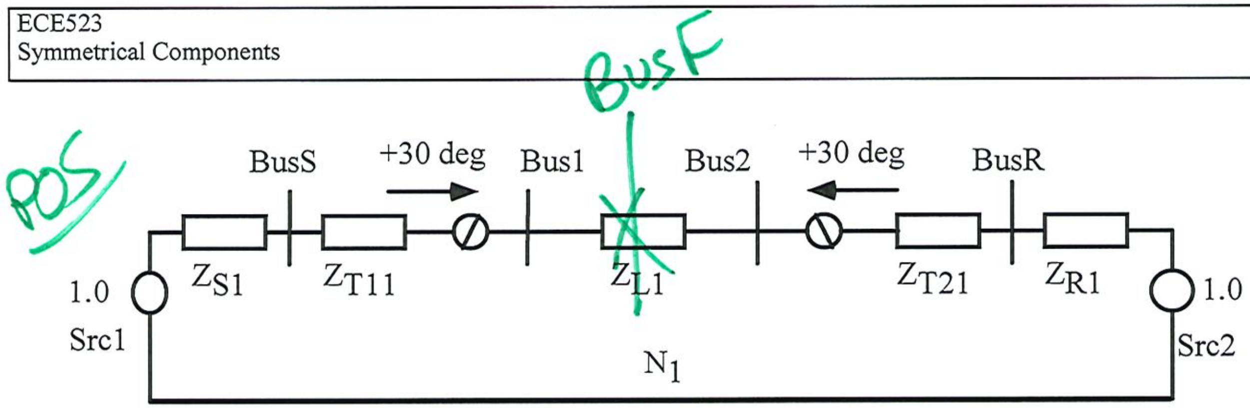
- ***DLG faults:***

$$I_{f1}(m) := \frac{V_f}{Z_{L2\_1\_thev}(m) + \left(\frac{1}{Z_{L2\_2\_thev}(m)} + \frac{1}{Z_{L2\_0\_thev}(m)}\right)^{-1}}$$

$$I_{f2}(m) := -I_{f1}(m) \cdot \left(\frac{Z_{L2\_0\_thev}(m)}{Z_{L2\_2\_thev}(m) + Z_{L2\_0\_thev}(m)}\right)$$

$$I_{f0}(m) := -I_{f1}(m) \left(\frac{Z_{L2\_2\_thev}(m)}{Z_{L2\_2\_thev}(m) + Z_{L2\_0\_thev}(m)}\right)$$

$$I_{left\_1}(m) := \frac{I_{f1}(m) \cdot \left[(1-m) \cdot Z_{L21} + Z_{R1}\right]}{Z_{S1} + Z_{L11} + m \cdot Z_{L21} + \left[(1-m) \cdot Z_{L21} + Z_{R1}\right]}$$



- Positive sequence Ybus

Bus S Bus 1 Bus 2 Bus R Bus F

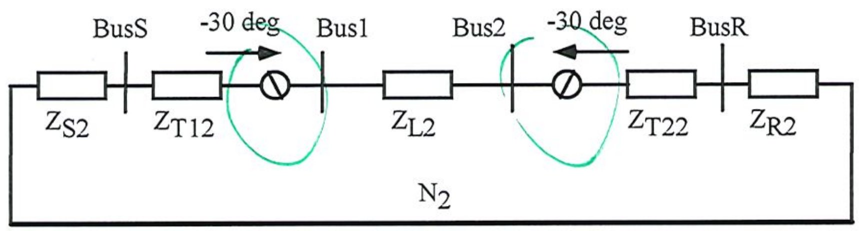
$$Y_1(M) := \begin{bmatrix} \frac{1}{jX_{G11}} + \frac{1}{Z_{T11}} & \frac{-1 \cdot e^{-j \cdot 30deg}}{Z_{T11}} & 0 & 0 & 0 \\ \frac{-1 \cdot e^{j \cdot 30deg}}{Z_{T11}} & \frac{1}{Z_{T11}} + \frac{1}{M \cdot Z_{L11}} & 0 & 0 & \frac{-1}{M \cdot Z_{L11}} \\ 0 & 0 & \frac{1}{Z_{T21}} + \frac{1}{(1-M) \cdot Z_{L11}} & \frac{-1 \cdot e^{j \cdot 30deg}}{Z_{T21}} & \frac{-1}{(1-M) \cdot Z_{L11}} \\ 0 & 0 & \frac{-1 \cdot e^{-j \cdot 30deg}}{Z_{T21}} & \frac{1}{Z_{T21}} + \frac{1}{jX_{G21}} & 0 \\ 0 & \frac{-1}{M \cdot Z_{L11}} & \frac{-1}{(1-M) \cdot Z_{L11}} & 0 & \frac{1}{M \cdot Z_{L11}} + \frac{1}{(1-M) \cdot Z_{L11}} \end{bmatrix}$$

$$Z_1(M) := Y_1(M)^{-1}$$

$V_S := 1.0pu$ $\quad V_R := 1.0pu$ $\quad V_f := 1.0pu$

Negative Sequence Ybus

- All of the impedance values are the same in this case.
- Only change is in the Δ-Y phase shifts.
- Equivalent circuit looks the same, but no sources.

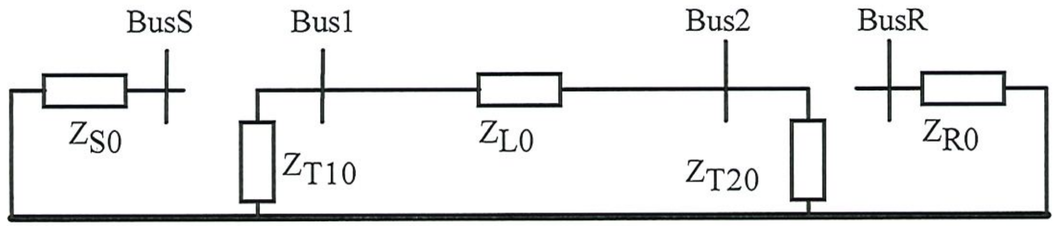


$$Y_2(M) := \begin{bmatrix} \frac{1}{jX_{G12}} + \frac{1}{Z_{T12}} & \frac{-1 \cdot e^{j \cdot 30deg}}{Z_{T12}} & 0 & 0 & 0 \\ \frac{-1 \cdot e^{-j \cdot 30deg}}{Z_{T12}} & \frac{1}{Z_{T12}} + \frac{1}{M \cdot Z_{L12}} & 0 & 0 & \frac{-1}{M \cdot Z_{L12}} \\ 0 & 0 & \frac{1}{Z_{T22}} + \frac{1}{(1-M) \cdot Z_{L12}} & \frac{-1 \cdot e^{-j \cdot 30deg}}{Z_{T22}} & \frac{-1}{(1-M) \cdot Z_{L12}} \\ 0 & 0 & \frac{-1 \cdot e^{j \cdot 30deg}}{Z_{T22}} & \frac{1}{Z_{T22}} + \frac{1}{jX_{G22}} & 0 \\ 0 & \frac{-1}{M \cdot Z_{L12}} & \frac{-1}{(1-M) \cdot Z_{L12}} & 0 & \frac{1}{M \cdot Z_{L12}} + \frac{1}{(1-M) \cdot Z_{L12}} \end{bmatrix}$$

$$Z_2(M) := Y_2(M)^{-1}$$

Zero Sequence Ybus

- Impedance values differ
- Model the transformer zero sequence connections
- Different looking equivalent circuit.



$$Y_0(M) := \begin{bmatrix} \frac{1}{Z_{G10}} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{Z_{T10}} + \frac{1}{M \cdot Z_{L10}} & 0 & 0 & \frac{-1}{M \cdot Z_{L10}} \\ 0 & 0 & \frac{1}{Z_{T20}} + \frac{1}{(1-M) \cdot Z_{L10}} & 0 & \frac{-1}{(1-M) \cdot Z_{L10}} \\ 0 & 0 & 0 & \frac{1}{Z_{G20}} & 0 \\ 0 & \frac{-1}{M \cdot Z_{L10}} & \frac{-1}{(1-M) \cdot Z_{L10}} & 0 & \frac{1}{M \cdot Z_{L10}} + \frac{1}{(1-M) \cdot Z_{L10}} \end{bmatrix}$$

$$Z_0(M) := Y_0(M)^{-1}$$

Unbalanced Fault Analysis Examples

Define units: $MVA := 1000kW$ $\quad MVAR := MVA$

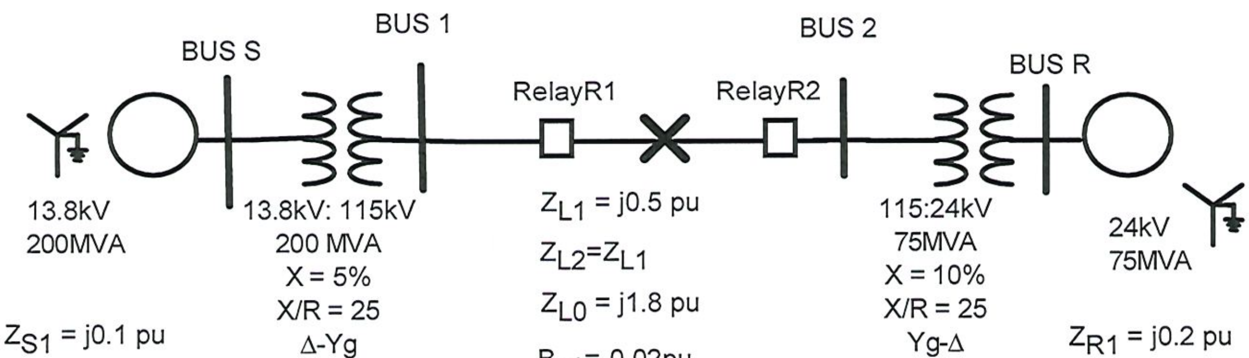
$MW := MVA$ $\quad pu := 1$

$a := 1 \cdot e^{j \cdot 120deg}$

$$A_{012} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$$

$\angle(mag, ang) := mag \cdot \cos(ang \cdot deg) + j \cdot mag \cdot \sin(ang \cdot deg)$

System Description:



$Z_{S1} = j0.1$ pu

$Z_{S2} = Z_{S1}$

$Z_{S0} = 5.0 + j0.05$pu

$Z_{L1} = j0.5$ pu

$Z_{L2} = Z_{L1}$

$Z_{L0} = j1.8$ pu

$B_{c1} = 0.02$pu

$B_{c2} = B_{c1}$

$B_{c0} = 0.0133$ pu

on 100MVA and 115 kV

$Z_{R1} = j0.2$ pu

$Z_{R2} = Z_{R1}$

$Z_{R0} = 10 + j0.05$pu

Per Unit Change of Base Calculations (hidden, to view double click on the arrow)

SLG Fault:

Fault bus

$$I_{0\_SLG}(M,R_f) := \frac{V_f}{Z_1(M)_{4,4} + Z_2(M)_{4,4} + Z_0(M)_{4,4} + 3 \cdot R_f}$$

$$\left|I_{0\_SLG}(0.5,0)\right| = 1.0853$$

$$\arg\left(I_{0\_SLG}(0.5,0)\right) = -90 \cdot deg$$

$$I_{1\_SLG}(M,R_f) := I_{0\_SLG}(M,R_f)$$

$$I_{2\_SLG}(M,R_f) := I_{0\_SLG}(M,R_f)$$

$$I_{ABC\_SLG}(M,R_f) := A_{012} \cdot \begin{pmatrix} I_{0\_SLG}(M,R_f) \\ I_{1\_SLG}(M,R_f) \\ I_{2\_SLG}(M,R_f) \end{pmatrix}$$

$$\overrightarrow{\left|I_{ABC\_SLG}(0.5,0)\right|} = \begin{pmatrix} 3.2558 \\ 0 \\ 0 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(I_{ABC\_SLG}(0.5,0)\right)} = \begin{pmatrix} -90 \\ 18.4349 \\ 18.4349 \end{pmatrix} \cdot deg$$

- Angles meaningless when magnitude is 0

- Now find voltages in each sequence component)

$$\Delta V1_{SLG}(M,R_f) := Z_1(M) \cdot \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -I_{1\_SLG}(M,R_f) \end{pmatrix}$$

$$\overrightarrow{\left|\Delta V1_{SLG}(0.5,0)\right|} = \begin{pmatrix} 0.0362 \\ 0.0543 \\ 0.1447 \\ 0.0965 \\ 0.2351 \end{pmatrix} \qquad \overrightarrow{\arg\left(\Delta V1_{SLG}(0.5,0)\right)} = \begin{pmatrix} 150 \\ 180 \\ -180 \\ 150 \\ 180 \end{pmatrix} \cdot deg$$

$-I_{fault}$

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- Now when we find V1 we need to *include the transformer phase shift* in the prefault voltages

$$V1_{SLG}(M,R_f) := \begin{pmatrix} 1.0e^{-j\cdot 30deg} \\ 1.0 \\ 1.0 \\ 1.0\cdot e^{-j\cdot 30deg} \\ 1.0 \end{pmatrix} + \Delta V1_{SLG}(M,R_f)$$

V1 prefault

$$\overrightarrow{\left|V1_{SLG}(0.5,0)\right|} = \begin{pmatrix} 0.9638 \\ 0.9457 \\ 0.8553 \\ 0.9035 \\ 0.7649 \end{pmatrix} \qquad \overrightarrow{\arg\left(V1_{SLG}(0.5,0)\right)} = \begin{pmatrix} -30 \\ 0 \\ 0 \\ -30 \\ 0 \end{pmatrix}\cdot deg$$

$$\Delta V2_{SLG}(M,R_f) := Z_2(M)\cdot\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -I_{2\_SLG}(M,R_f) \end{pmatrix}$$

−I2 fault

$$\overrightarrow{\left|\Delta V2_{SLG}(0.5,0)\right|} = \begin{pmatrix} 0.0362 \\ 0.0543 \\ 0.1447 \\ 0.0965 \\ 0.2351 \end{pmatrix} \qquad \overrightarrow{\arg\left(\Delta V2_{SLG}(0.5,0)\right)} = \begin{pmatrix} -150 \\ -180 \\ -180 \\ -150 \\ -180 \end{pmatrix}\cdot deg$$

Note the -30 degree shift...

$$V2_{SLG}(M,R_f) := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \Delta V2_{SLG}(M,R_f)$$

- No prefault voltage, so enter 0.

$V_{2\,prefault} = 0$

$V_{1f} + V_{2f} + V_{0f}$
$= 0.7649 - 0.2351 - 0.5297$
$= 0 = I_{Af}\cdot R_f$ (0)

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$$\Delta V0_{SLG}(M,R_f) := Z_0(M)\cdot\begin{pmatrix}0\\0\\0\\0\\-I_{0\_SLG}(M,R_f)\end{pmatrix}$$

Bus S
Bus 1
Bus 2
Bus R
Bus f

$$\Delta V0_{SLG}(0.5,0) = \begin{pmatrix}0\\-0.0143\\-0.0683\\0\\-0.5297\end{pmatrix}$$

$$V0_{SLG}(M,R_f) := \begin{pmatrix}0\\0\\0\\0\\0\end{pmatrix} + \Delta V0_{SLG}(M,R_f)$$

Again, no prefault voltage

- ABC Voltages at Bus 1

corresponds to Bus 1

$$V_{ABCB1.SLG}(M,R_f) := A_{012}\cdot\begin{pmatrix}V0_{SLG}(M,R_f)_1\\V1_{SLG}(M,R_f)_1\\V2_{SLG}(M,R_f)_1\end{pmatrix}$$

$$\left|\overrightarrow{V_{ABCB1.SLG}(0.5,0)}\right| = \begin{pmatrix}0.8772\\0.9806\\0.9806\end{pmatrix}\cdot pu \qquad \arg\left(V_{ABCB1.SLG}(0.5,0)\right) = \begin{pmatrix}0\\-117.9783\\117.9783\end{pmatrix}\cdot deg$$

- ABC Voltages at Bus S

$$V_{ABCBS.SLG}(M,R_f) := A_{012}\cdot\begin{pmatrix}V0_{SLG}(M,R_f)_0\\V1_{SLG}(M,R_f)_0\\V2_{SLG}(M,R_f)_0\end{pmatrix}$$

$$\left|\overrightarrow{V_{ABCBS.SLG}(0.5,0)}\right| = \begin{pmatrix}0.9463\\0.9463\\1\end{pmatrix}\cdot pu \qquad \arg\left(V_{ABCBS.SLG}(0.5,0)\right) = \begin{pmatrix}-31.8973\\-148.1027\\90\end{pmatrix}\cdot deg$$

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- Branch currents

Bus 1 Bus F

  - Relay 1 currents

I fault

$$I_{1\_B1.SLG}(M,R_f) := \frac{V1_{SLG}(M,R_f)_1 - V1_{SLG}(M,R_f)_4}{M \cdot Z_{L11}} \qquad \left|I_{1\_B1.SLG}(0.5,0)\right| = 0.7235 \qquad \arg\left(I_{1\_B1.SLG}(0.5,0)\right) = -90 \cdot deg$$

$$I_{2\_B1.SLG}(M,R_f) := \frac{V2_{SLG}(M,R_f)_1 - V2_{SLG}(M,R_f)_4}{M \cdot Z_{L12}} \qquad \left|I_{2\_B1.SLG}(0.5,0)\right| = 0.7235 \qquad \arg\left(I_{2\_B1.SLG}(0.5,0)\right) = -90 \cdot deg$$

$$I_{0\_B1.SLG}(M,R_f) := \frac{V0_{SLG}(M,R_f)_1 - V0_{SLG}(M,R_f)_4}{M \cdot Z_{L10}} \qquad \left|I_{0\_B1.SLG}(0.5,0)\right| = 0.5727 \qquad \arg\left(I_{0\_B1.SLG}(0.5,0)\right) = -90 \cdot deg$$

$$I_{ABC\_B1.SLG}(M,R_f) := A_{012} \cdot \begin{pmatrix} I_{0\_B1.SLG}(M,R_f) \\ I_{1\_B1.SLG}(M,R_f) \\ I_{2\_B1.SLG}(M,R_f) \end{pmatrix} \qquad \overrightarrow{\left|I_{ABC\_B1.SLG}(0.5,0)\right|} = \begin{pmatrix} 2.0197 \\ 0.1509 \\ 0.1509 \end{pmatrix} \cdot pu \qquad \arg\left(I_{ABC\_B1.SLG}(0.5,0)\right) = \begin{pmatrix} -90 \\ 90 \\ 90 \end{pmatrix} \cdot deg$$

Io - circulating

- LVside of transformer (Bus S)

$$I_{1\_BS.SLG}(M,R_f) := \frac{V_S \cdot e^{-j \cdot 30deg} - V1_{SLG}(M,R_f)_0}{jX_{G11}} \qquad \left|I_{1\_BS.SLG}(0.5,0)\right| = 0.7235 \cdot pu \qquad \arg\left(I_{1\_BS.SLG}(0.5,0)\right) = -120 \cdot deg$$

$$I_{2\_BS.SLG}(M,R_f) := \frac{0 - V2_{SLG}(M,R_f)_0}{jX_{G12}} \qquad \left|I_{2\_BS.SLG}(0.5,0)\right| = 0.7235 \cdot pu \qquad \arg\left(I_{2\_BS.SLG}(0.5,0)\right) = -60 \cdot deg$$

$$I_{0\_BS.SLG} := 0$$

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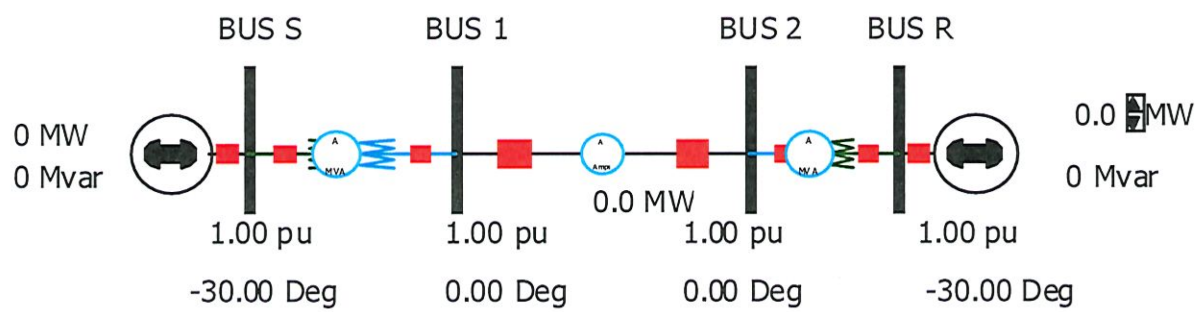
$$I_{ABC\_BS.SLG}(M,R_f) := A_{012} \cdot \begin{pmatrix} I_{0\_BS.SLG} \\ I_{1\_BS.SLG}(M,R_f) \\ I_{2\_BS.SLG}(M,R_f) \end{pmatrix} \qquad \overrightarrow{\left|I_{ABC\_BS.SLG}(0.5,0)\right|} = \begin{pmatrix} 1.2532 \\ 1.2532 \\ 0 \end{pmatrix} \cdot pu \qquad \arg\left(I_{ABC\_BS.SLG}(0.5,0)\right) = \begin{pmatrix} -90 \\ 90 \\ 38.6598 \end{pmatrix} \cdot deg$$

- **Circuit implementation in Powerworld**



- **Powerworld Results**

$I_{AFSLG} := 3.256 \angle (-90deg)$

Fault Data - Buses						
Name	Phase Volt A	Phase Ang A	Phase Volt B	Phase Ang B	Phase Volt C	Phase Ang C
BUS S	0.94625	-31.9	0.94625	-148.1	1	90
BUS 1	0.87716	0	0.98064	-117.98	0.98064	117.98
BUS 2	0.64224	0	0.96409	-116.07	0.96409	116.07
BUS R	0.85937	-35.58	0.85937	-144.42	1	90
FaultPt	0	0	1.1753	-132.54	1.1753	132.54

consistent with calcs above

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Faulted branch - which is replaced

Fault Data - Lines							
From Name	To Name	Phase Cur A From	Phase Ang A From	Phase Cur B From	Phase Ang B From	Phase Cur C From	Phase Ang C From
BUS S	BUS 1	1.25318	-90	1.25318	90	0	0
~~BUS 1~~	~~BUS 2~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
BUS 1	FaultPt	2.0197	-90	0.15086	90	0.15086	90
BUS R	BUS 2	0.62659	-90	0.62659	90	0	0
FaultPt	BUS 2	1.23615	90	0.15086	90	0.15086	90

Good match with calculations above.

LL Fault:

$$I_{1\_LL}(M,R_f) := \frac{V_f}{Z_1(M)_{4,4} + Z_2(M)_{4,4} + R_f}$$

$$\left|I_{1\_LL}(0.5,0)\right| = 2.3077$$

$$\arg\left(I_{1\_LL}(0.5,0)\right) = -90\cdot deg$$

$$I_{2\_LL}(M,R_f) := -I_{1\_LL}(M,R_f)$$

$I_{0\_LL} := 10^{-15}$ Approximately zero, works better with MathCAD.

$$I_{ABC\_LL}(M,R_f) := A_{012}\cdot\begin{pmatrix} I_{0\_LL} \\ I_{1\_LL}(M,R_f) \\ I_{2\_LL}(M,R_f) \end{pmatrix}$$

$$\overrightarrow{\left|I_{ABC\_LL}(0.5,0)\right|} = \begin{pmatrix} 0 \\ 3.997 \\ 3.997 \end{pmatrix}\cdot pu \qquad \overrightarrow{\arg\left(I_{ABC\_LL}(0.5,0)\right)} = \begin{pmatrix} 0 \\ 180 \\ 0 \end{pmatrix}\cdot deg$$

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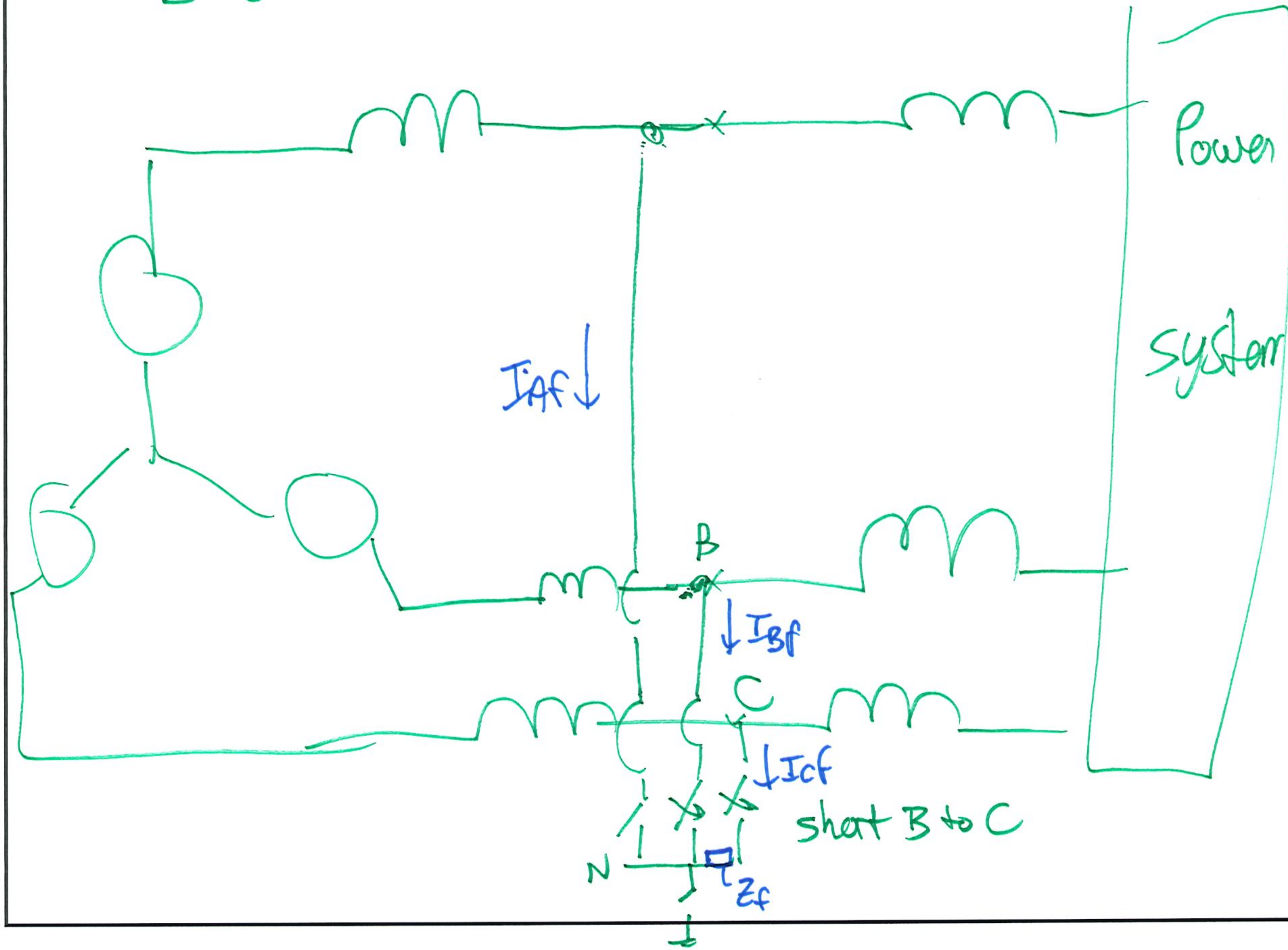
Line to Line Faults



Constraints at fault point

$I_{Af} = 0$

$I_{Bf} = -I_{cf}$

at fault location $V_{BG} - V_{CG} = V_{BC} = I_{Bf} \cdot Z_f$

If $Z_f = 0$ $V_{BG} = V_{CG} \Rightarrow V_{BC} = 0$

In Sepuence Domain

$$\begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 0 \\ I_{BF} \\ -I_{BF} \end{bmatrix} \leftarrow I_{CF}$$

If I say

$I_0 \Rightarrow I_{A0}$

$I_1 \Rightarrow I_{A1}$

$I_2 \Rightarrow I_{A2}$

$$I_0 = \frac{1}{3}\left(0 + I_{BF} - I_{CF}\right) = 0$$

$$I_1 = \frac{1}{3}\left(0 + aI_{BF} - a^2 I_{BF}\right) = \left(\frac{a-a^2}{3}\right) I_{BF}$$

$$I_2 = \frac{1}{3}\left(0 + a^2 I_{BF} - aI_{BF}\right) = \left(\frac{a^2-a}{3}\right) I_{BF}$$

$$I_2 = -I_1$$

voltages

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_{AG} \\ V_{BG} \\ V_{BG} - I_{Bf} Z_f \end{bmatrix}$$

$I_0 = 0 \Rightarrow I_0 \uparrow Z_{THO} \; V_0$

$\Downarrow V_0 = 0$

$V_{BG} - V_{CG} = I_{Bf} Z_f$

$\Rightarrow V_{CG} = V_{BG} - I_{Bf} Z_f$

$$V_1 = \frac{1}{3}\left[V_{AG} + aV_{BG} + a^2(V_{BG} - I_{Bf} Z_f)\right]$$

$$V_2 = \frac{1}{3}\left[V_{AG} + a^2 V_{BG} + a(V_{BG} - I_{Bf} Z_f)\right]$$

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Simplify $\rightarrow Z_f = 0$

$$V_1 = \frac{1}{3}\left[V_{AG} + aV_{BG} + a^2 V_{BG}\right)$$

$$V_2 = \frac{1}{3}\left[V_{AG} + a^2 V_{BG} + aV_{BG}\right) = V_1$$

$$V_1 = V_2$$

$$I_1 = -I_2$$