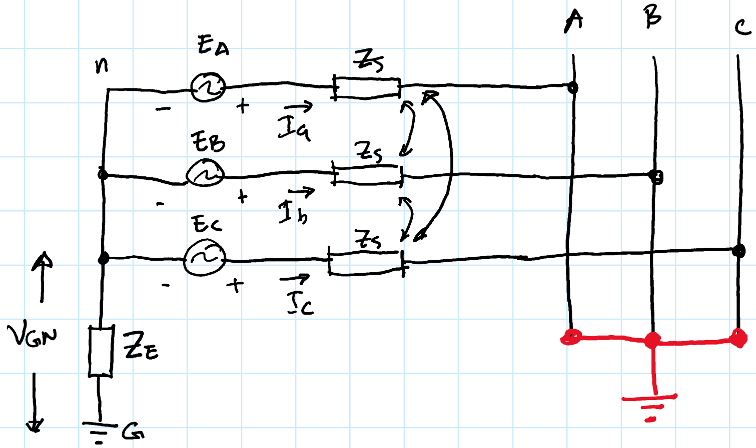
Fault Analysis Using Symmetrical Components

Method to Calculate Unbalanced Short Circuits

1. Determine simulation points
2. Find system sequence networks
3. Calculate for Thevenin equivalent
4. Connect sequence networks and calculate fault currents
5. Calculate sequence voltages and currents
6. Calculate phase quantities

Three-Phase Fault

Simplified Generator



Boundary Conditions:

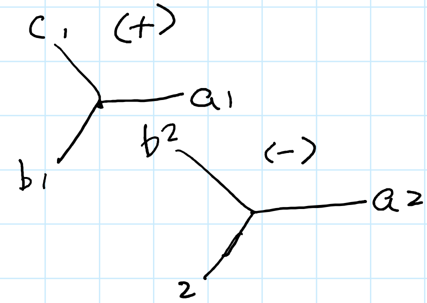
$$I_a + I_b + I_c = 0$$

$$V_a = V_b = V_c = 0$$

$$I_1 = I_a \checkmark$$

$$I_2 = I_0 = 0$$

$$V_1 = V_2 = V_0 = 0$$



$$I_{B1} = a^2 I_{A1} \; ; \; I_{C1} = a I_{A1}$$

$$I_0 = \tfrac{1}{3}(I_A + I_B + I_C) = 0$$

$$I_2 = \tfrac{1}{3}(I_A + a^2 I_B + a I_C) = \tfrac{1}{3}(I_A + a^4 I_A + a^2 I_A)$$

$$= \tfrac{1}{3}(I_A + a I_A + a^2 I_A) = 0$$

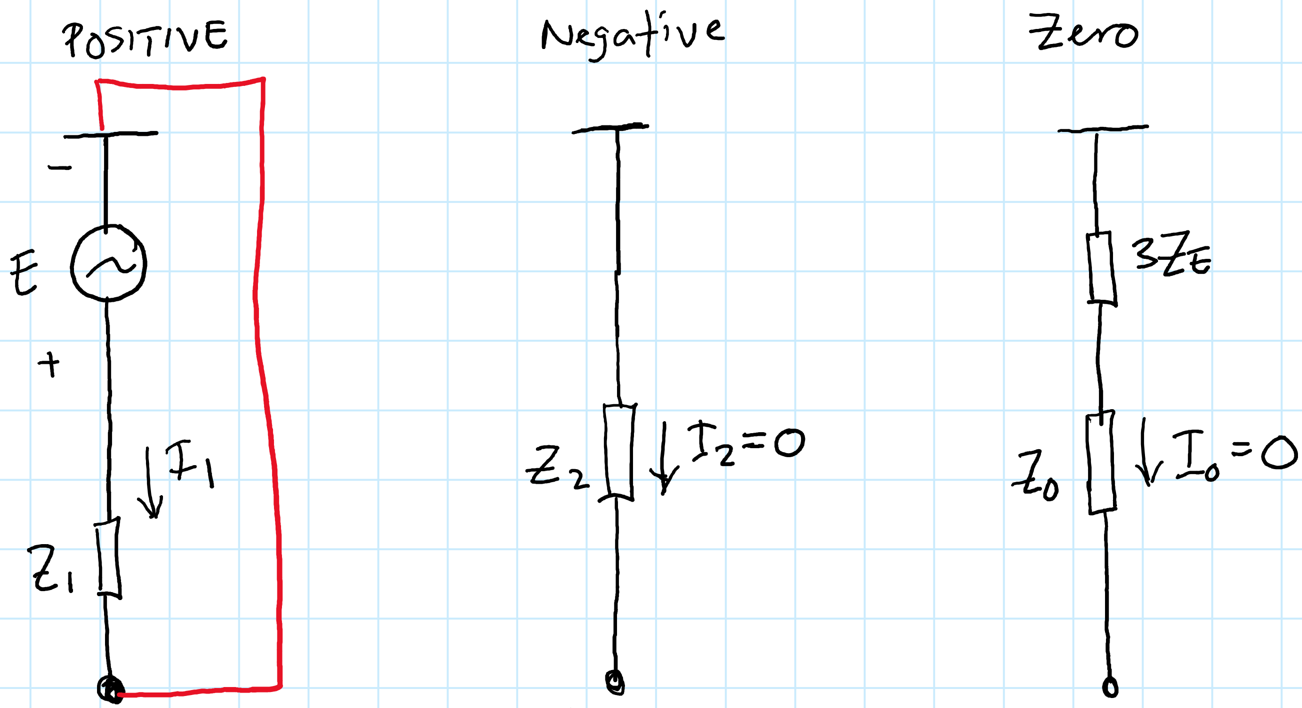
$$\boxed{I_2 = 0}$$

$$\boxed{I_0 = 0}$$

$$I_1 = \tfrac{1}{3}(I_A + a I_B + a^2 I_C) = \tfrac{1}{3}(I_A + a^3 I_A + a^3 I_A) = \tfrac{1}{3}(3 I_A)$$

$$\boxed{I_1 = I_A}$$

Three-Phase Fault (Sequence Network)



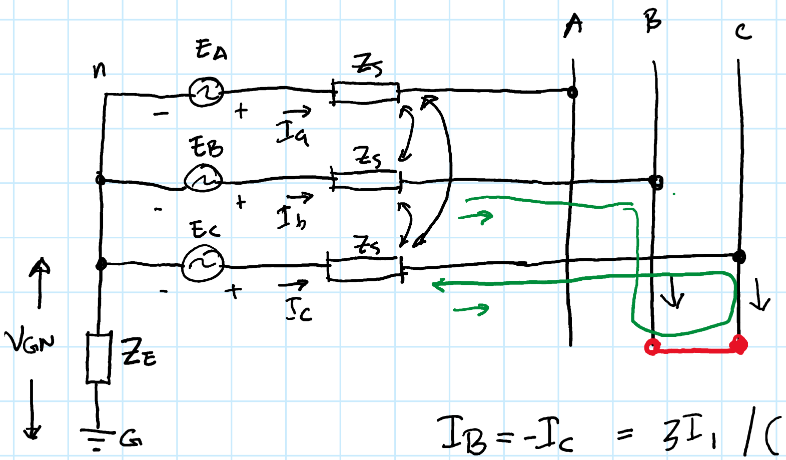
Fault Currents:

$$I_a = I_1 = \frac{E}{Z_1}$$

$$I_b = a^2 I_A$$

$$I_c = a I_A$$

Phase To Phase Faults



$$I_A = I_{A1} + I_{A2} + I_{A0} = I_1 + I_2 + I_0$$
$$I_B = I_{B1} + I_{B2} + I_{B0} = a^2 I_1 + a I_2 + I_0$$
$$I_C = I_{C1} + I_{C2} + I_{C0} = a I_1 + a^2 I_2 + I_0$$

① $3I_1 = I_A + aI_B + a^2 I_C = 0 + aI_B - a^2 I_B = I_B(a - a^2)$

② $3I_2 = I_A + a^2 I_B + a I_C = 0 + a^2 I_B - a I_B = I_B(a^2 - a)$

③ $3I_0 = I_A + I_B + I_C = 0 + I_B - I_B = 0$

$$a - a^2 = \sqrt{3}\angle 90 = -j\sqrt{3}$$

$$I_B = -I_C = 3I_1 / (a - a^2) = \frac{-j\sqrt{3}\,E}{Z_1 + Z_2} = \frac{-j\sqrt{3}\,E}{2Z_1}$$

Boundary Conditions:

$V_b = V_c$

$I_A = 0$

$I_B = -I_C$

Note: $I_{3\phi} = \frac{E}{Z_1}$

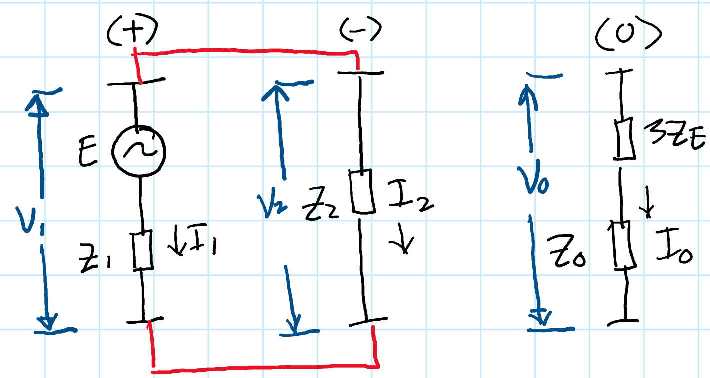
$$I_{LL} = \frac{\sqrt{3}}{2} I_{3\phi}$$

$V_1 = V_2$

$E = I_1 Z_1 + V_1$

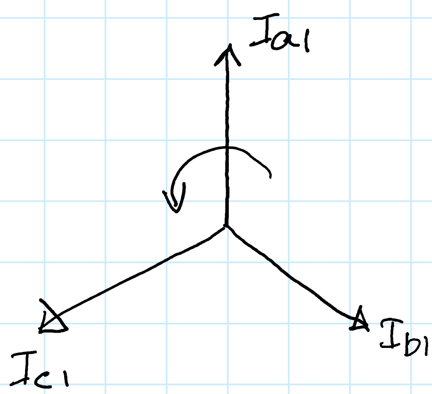
$0 = I_2 Z_2 + V_2$

$I_1 = -I_2$

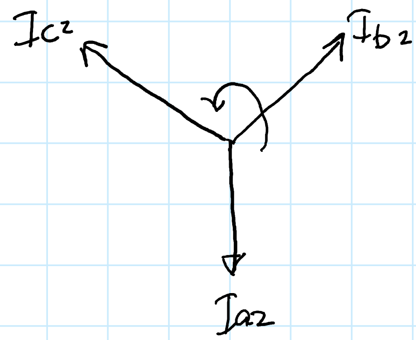


Symmetrical Components for phase To phase Faults

Positive Sequence



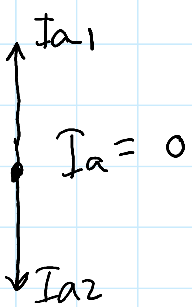
Negative Sequence

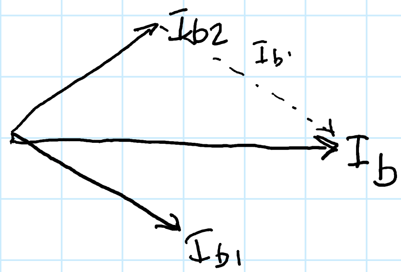


Zero Sequence

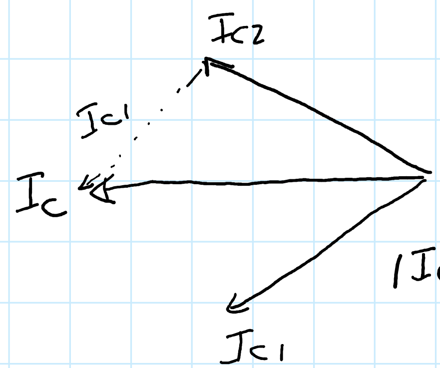
Not Participating (Equal To Zero)

Adding Components



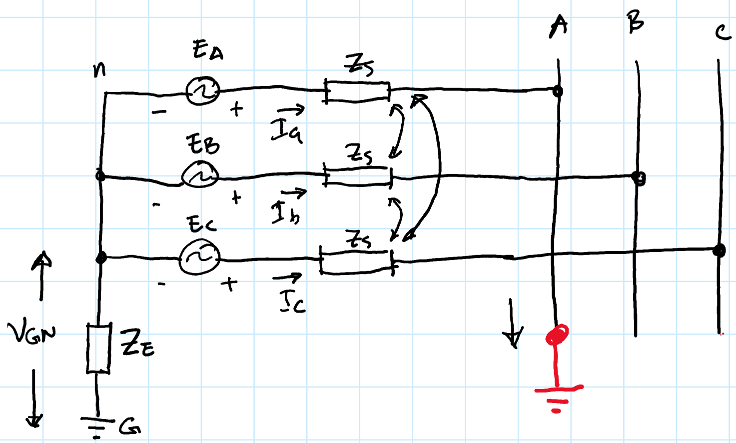


$$|I_b| = \sqrt{3}\,|I_{a1}|$$



$$|I_c| = \sqrt{3}\,|I_{a1}|$$

Single phase To Ground fault



$I_A = I_{A1} + I_{A2} + I_{A0} = I_1 + I_2 + I_0$

$I_B = I_{B1} + I_{B2} + I_{B0} = a^2 I_1 + a I_2 + I_0$

$I_C = I_{C1} + I_{C2} + I_{C0} = a I_1 + a^2 I_2 + I_0$

$3I_1 = I_A + a I_B + a^2 I_C = I_A$

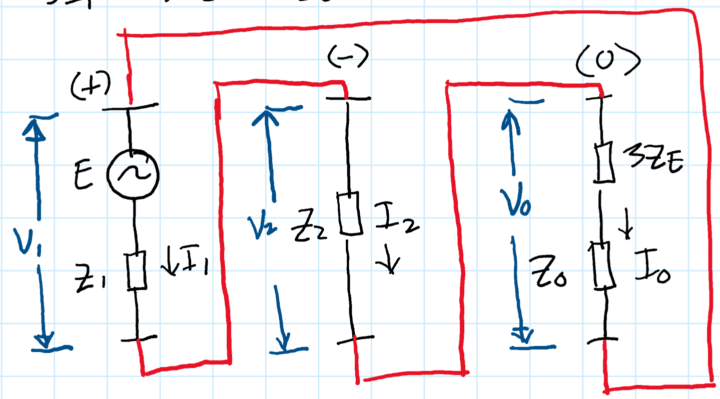
$3I_2 = I_A + a^2 I_B + a I_C = I_A$

$3I_0 = I_A + I_B + I_C = I_A$

$3I_1 = 3I_2 = 3I_0 = I_A$

$$I_1 = I_2 = I_0 = \frac{E}{Z_1 + Z_2 + Z_0 + 3Z_E}$$

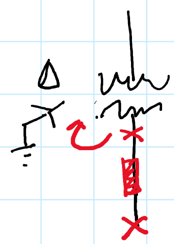
$$I_A = 3I_0 = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_E}$$



Boundary Conditions:

$V_a = 0$; $I_b = I_c = 0$

3-Leg Core Type : $Z_0 \cong 0.8 - 0.9\, Z_1$



Fault near Xfmr Neutral

$$I_A = 3I_0 = \frac{3E}{Z_1 + Z_2 + Z_0}$$

Shell Type
Four leg core Type
Five leg Core Typ
Banks of 3× 1Φ

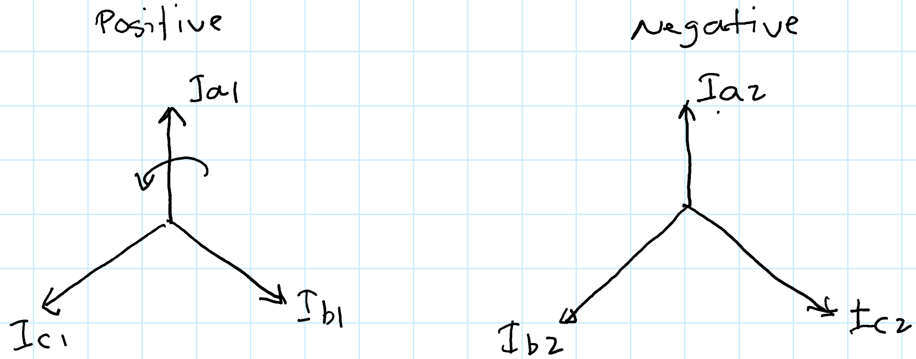
} $Z_0 = Z_1 = Z_2$

For core Type (3-leg)

SLG-$I_A = \dfrac{3E}{2.8 Z_1}$; $I_{3\Phi} = \dfrac{E}{Z_1}$

Therefore $I_{1\Phi} = 107\% I_{3\Phi}$

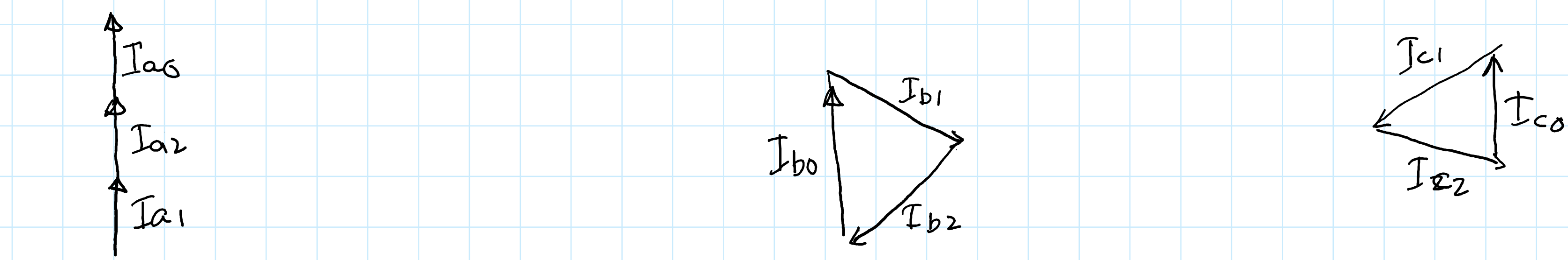
Symmetrical Components for A-Phase-To-Ground Fault



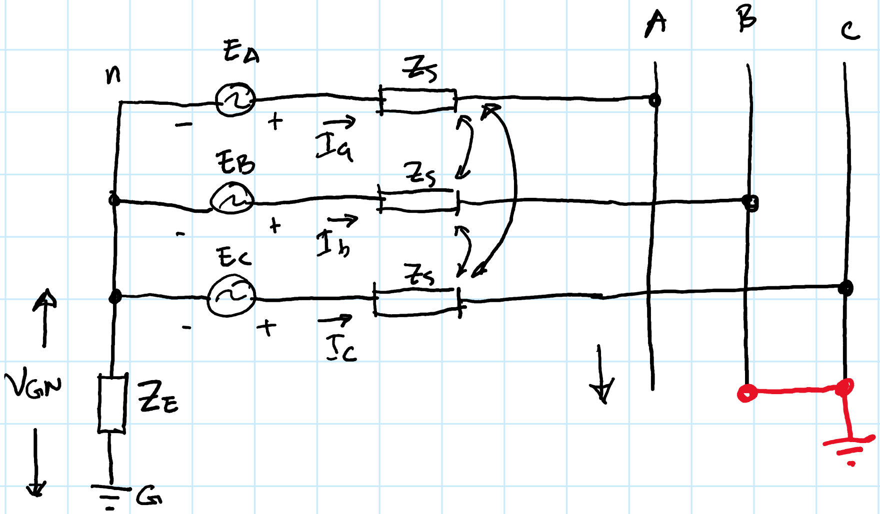
$I_A = I_{a1} + I_{a2} + I_{a0}$

$I_B = I_{b1} + I_{b2} + I_{b0} = 0$

$I_C = I_{c1} + I_{c2} + I_{c0} = 0$



Phase To Phase To Ground



$I_{A0} = 1/3(I_A + I_B + I_C) = 1/3(I_B + I_C)$

$V_B = V_C = 3 I_{A0} Z_E$

$V_0 = 1/3(V_A + V_B + V_C) \rightarrow ②$

$V_1 = 1/3(V_A + aV_B + a^2 V_C)$ } ①

$V_2 = 1/3(V_A + a^2 V_B + a V_C)$ }

Since $V_B = V_C$

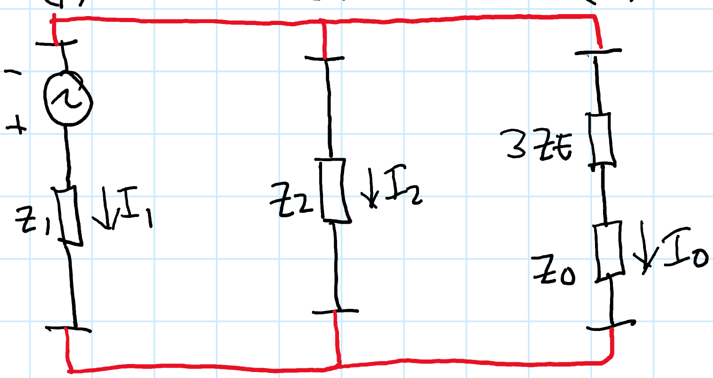
① $V_1 = V_2 = 1/3(V_A + aV_B + a^2 V_B) = 1/3(V_A + aV_C + a^2 V_C)$

② $3V_0 = V_A + 2V_B = (V_0 + V_1 + V_2) + 2(3 I_0 Z_E)$

Boundary Conditions:

$I_A = 0 \quad V_B = V_C = (I_A + I_B) Z_E$

(+) (-) (0)



$3V_0 = (V_0 + 2V_1) + 2(3 I_0 Z_E)$

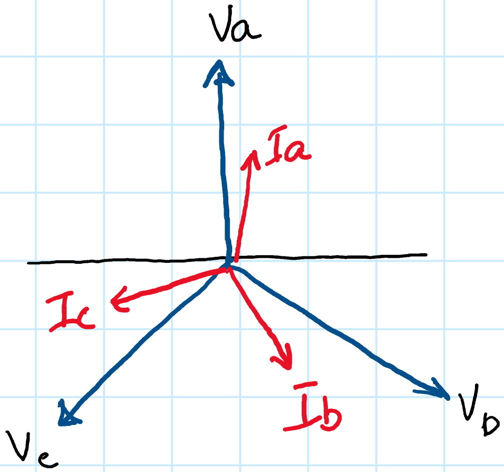
$2V_1 = 2V_0 - 2(3 I_0 Z_E)$

$V_1 = V_0 - 3 I_0 Z_E$

$V_1 = V_2 = V_0 - 3 I_0 Z_E$

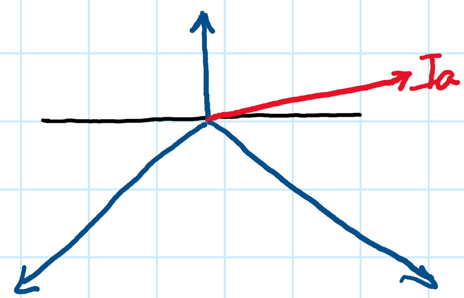
$I_1 + I_2 + I_0 = 0$ (Taking Phase A as reference)

Phasor Voltage and Current Behaviour During Fault

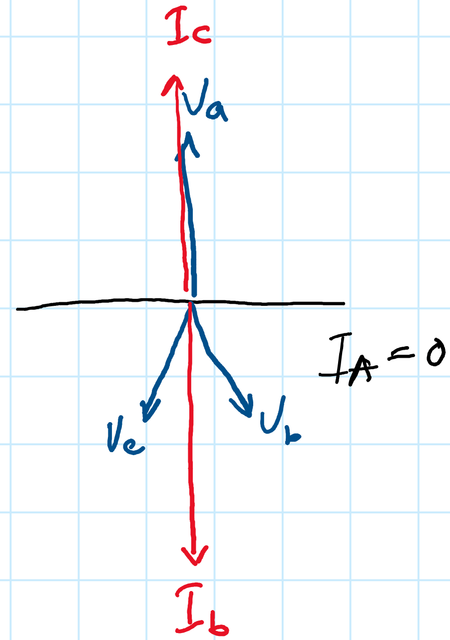


Normal

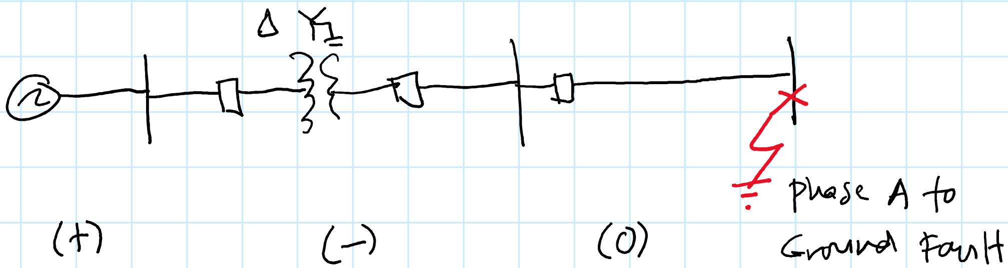
SLG

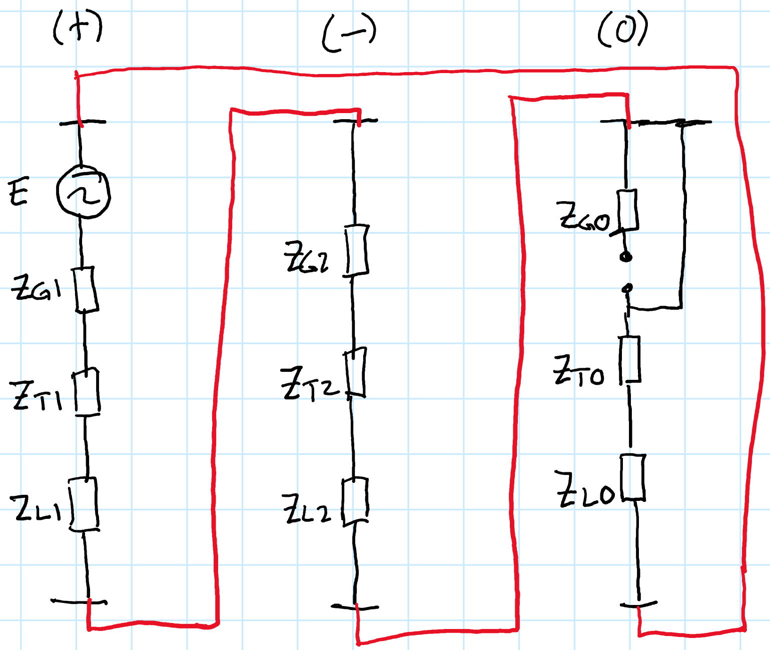


$I_b = I_c = 0$



Single-Phase Phase To Ground Fault (Radial System)





$$Z_{TOTAL} = Z_{G1} + Z_{T1} + Z_{L1} + Z_{G2} + Z_{L2} + Z_{T0} + Z_{L0}$$

$$I_{FAULT} = \frac{E}{Z_{TOTAL}}$$

Sequence Networks of Two-Source Power System

3Φ Fault: $Z_{TOTAL} = \left(\frac{1}{Z_{S1}+Z_{L1}} + \frac{1}{Z_{R1}}\right)^{-1}$