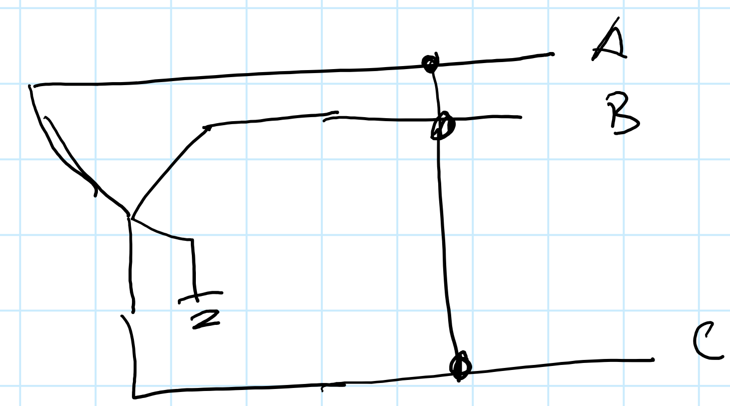
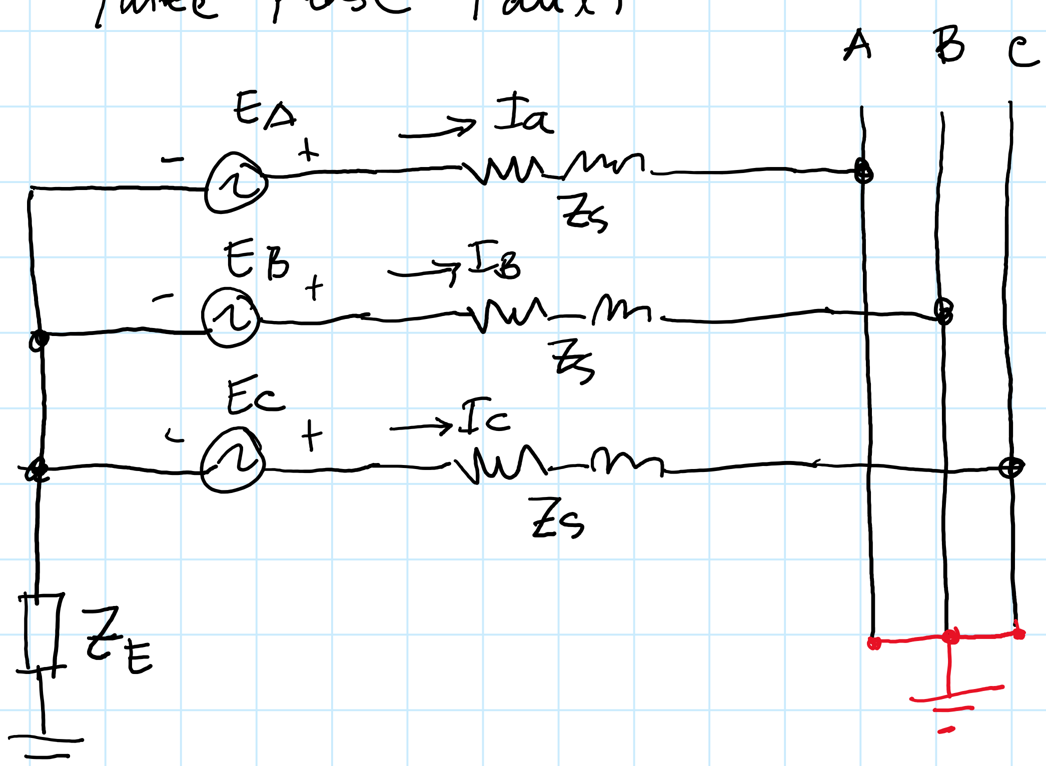
Fault Analysis Using Symmetrical Components

Method to Calculate Unbalanced Short Circuits

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



Three Phase Fault



$$I_A = I_0 + I_1 + I_2 \quad (1)$$
$$I_B = I_0 + a^2 I_1 + a I_2 \quad (2)$$
$$I_C = I_0 + a I_1 + a^2 I_2 \quad (3)$$

$$3I_0 = I_A + I_B + I_C \quad (4)$$
$$3I_1 = I_A + a I_B + a^2 I_C \quad (5)$$
$$3I_2 = I_A + a^2 I_B + a I_C \quad (6)$$

BOUNDARY CONDITIONS

$I_A + I_B + I_C = 0$ ✓✓

$V_A = V_B = V_C = 0$

FROM EQ (4)

$3I_0 = I_A + I_B + I_C = 0$; $\boxed{I_0 = 0}$

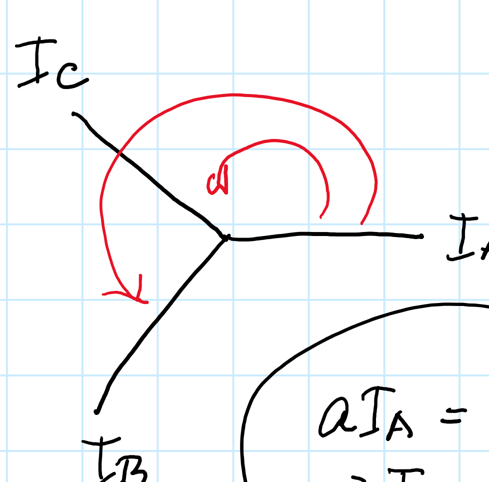
FROM EQ (5)

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

$3I_1 = I_A + a^3 I_A + a^3 I_A = 3 I_A$

$\boxed{I_1 = I_A}$

$\cancel{a^3} \cdot a =$ 1



$a I_A = I_C$

$a^2 I_A = I_B$

FROM EQ (6)

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

$= I_A + a^4 I_A + a^2 I_A$

$= I_A + a I_A + a^2 I_A$

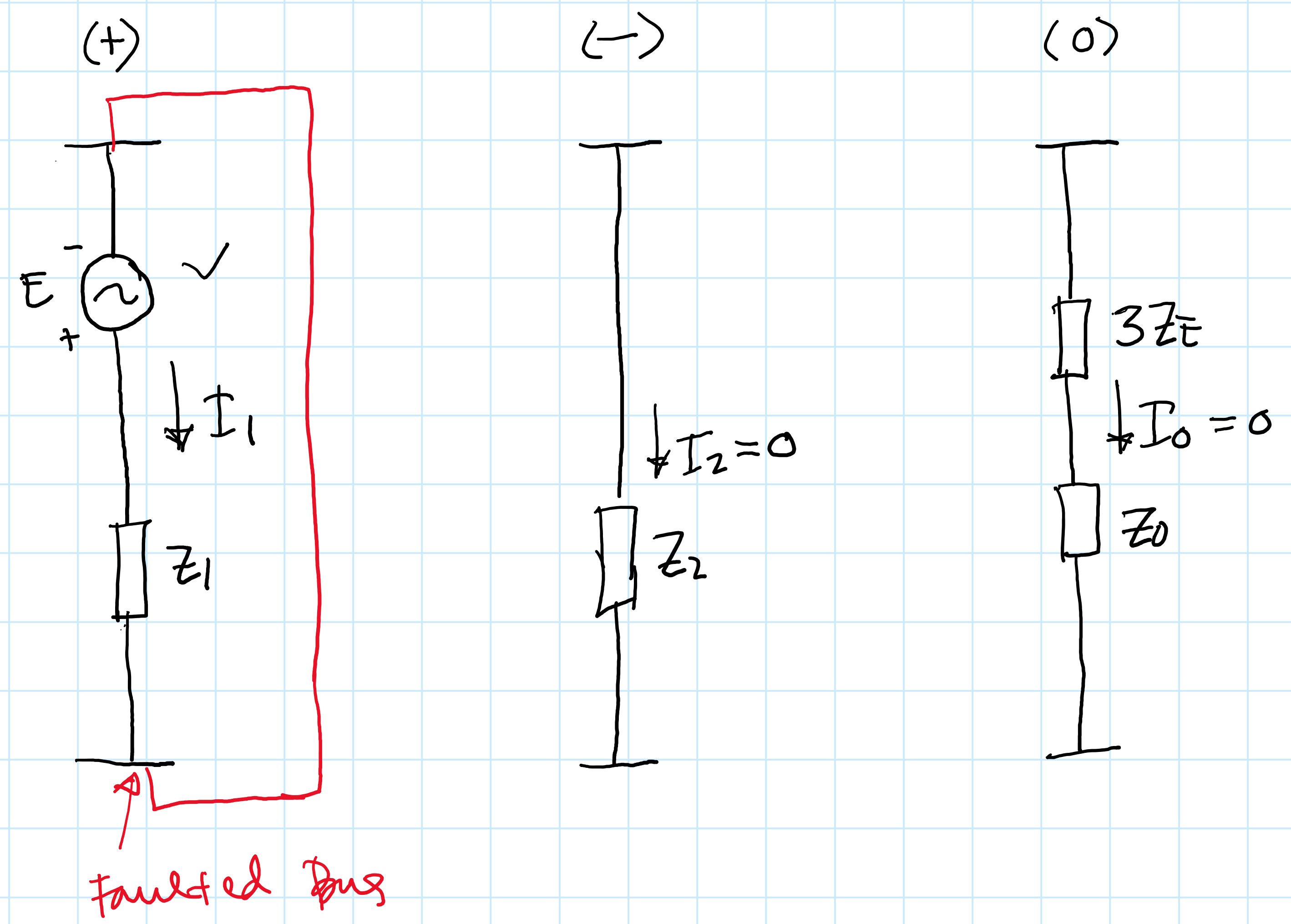
$= I_A \cancel{(1 + a + a^2)}^{0}$

$3I_2 = 0$

$\boxed{I_2 = 0}$

CONCLUSION: For Three-Phase Fault, there are no zero and negative sequence currents present.

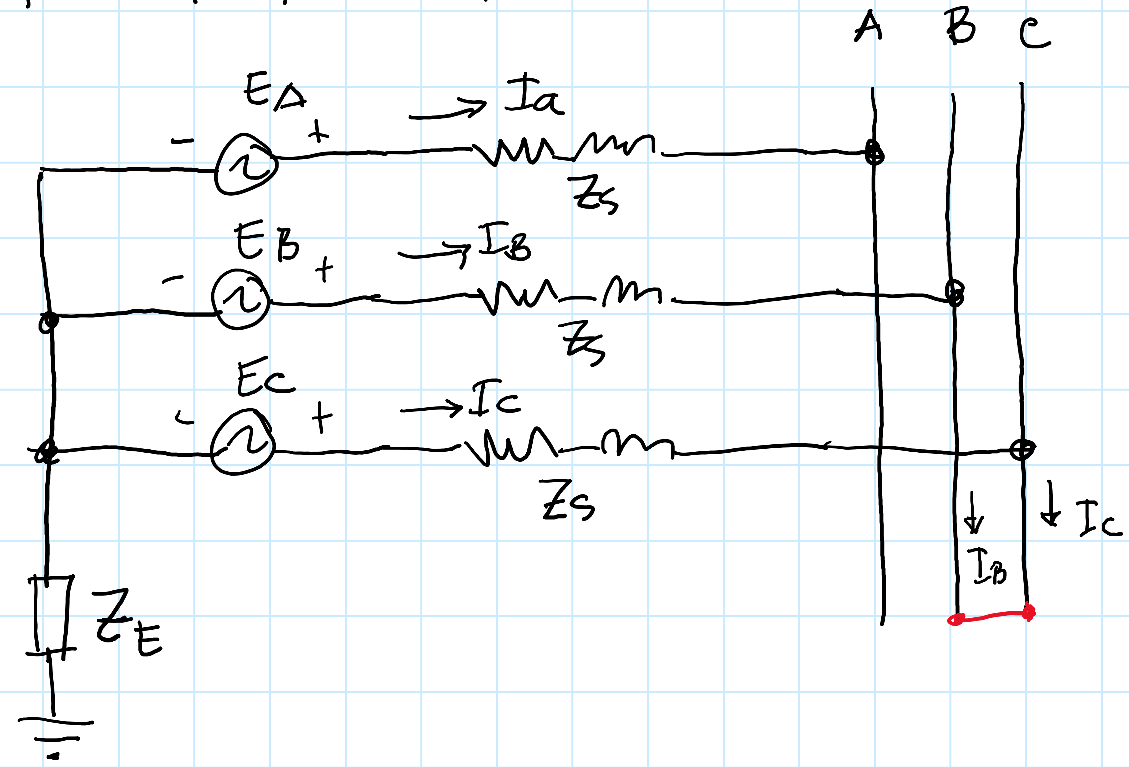
SEQUENCE NETWORK CONNECTION (THREE PHASE FAULT)



FAULT CURRENTS:

$$I_A = I_1 = \frac{E}{Z_1} \; ; \; I_B = a^2 I_A \; ; \; I_C = a I_A$$

Phase To phase Fault



$$I_A = I_0 + I_1 + I_2 \quad (1)$$
$$I_B = I_0 + a^2 I_1 + a I_2 \quad (2)$$
$$I_C = I_0 + a I_1 + a^2 I_2 \quad (3)$$

$$3I_0 = I_A + I_B + I_C \quad (4)$$
$$3I_1 = I_A + a I_B + a^2 I_C \quad (5)$$
$$3I_2 = I_A + a^2 I_B + a I_C \quad (6)$$

BOUNDARY CONDITIONS:

$V_B = V_C$; $I_B = -I_C$; $I_A = 0$

FROM EQ (4)

$$3I_0 = I_A + I_B + I_C = 0 + I_B + (-I_B) = 0$$
$$\boxed{I_0 = 0}$$

FROM EQ (5)

$$3I_1 = I_A + aI_B + a^2 I_C = 0 + aI_B + a^2(-I_B)$$
$$\checkmark \; 3I_1 = (a - a^2) I_B = (\sqrt{3}\angle 90) I_B$$
$$I_1 = \left(\frac{\sqrt{3}\angle 90}{3}\right) I_B = \left(\frac{1\angle 90}{\sqrt{3}}\right) I_B$$

$I_2 = -I_1$

$$I_B = a^2 I_1 + a I_2 = (a^2 - a) I_1$$
$$= (a^2 - a)\left[\frac{E}{Z_1 + Z_2}\right]$$
$$= (\sqrt{3}\angle 90)\frac{E}{2Z_1}$$
$$= \left(\frac{\sqrt{3}\angle 90}{2}\right)\frac{E}{Z_1}$$

3ϕ

$$\boxed{I_{LL} = 0.866\, I_{3\phi}}$$

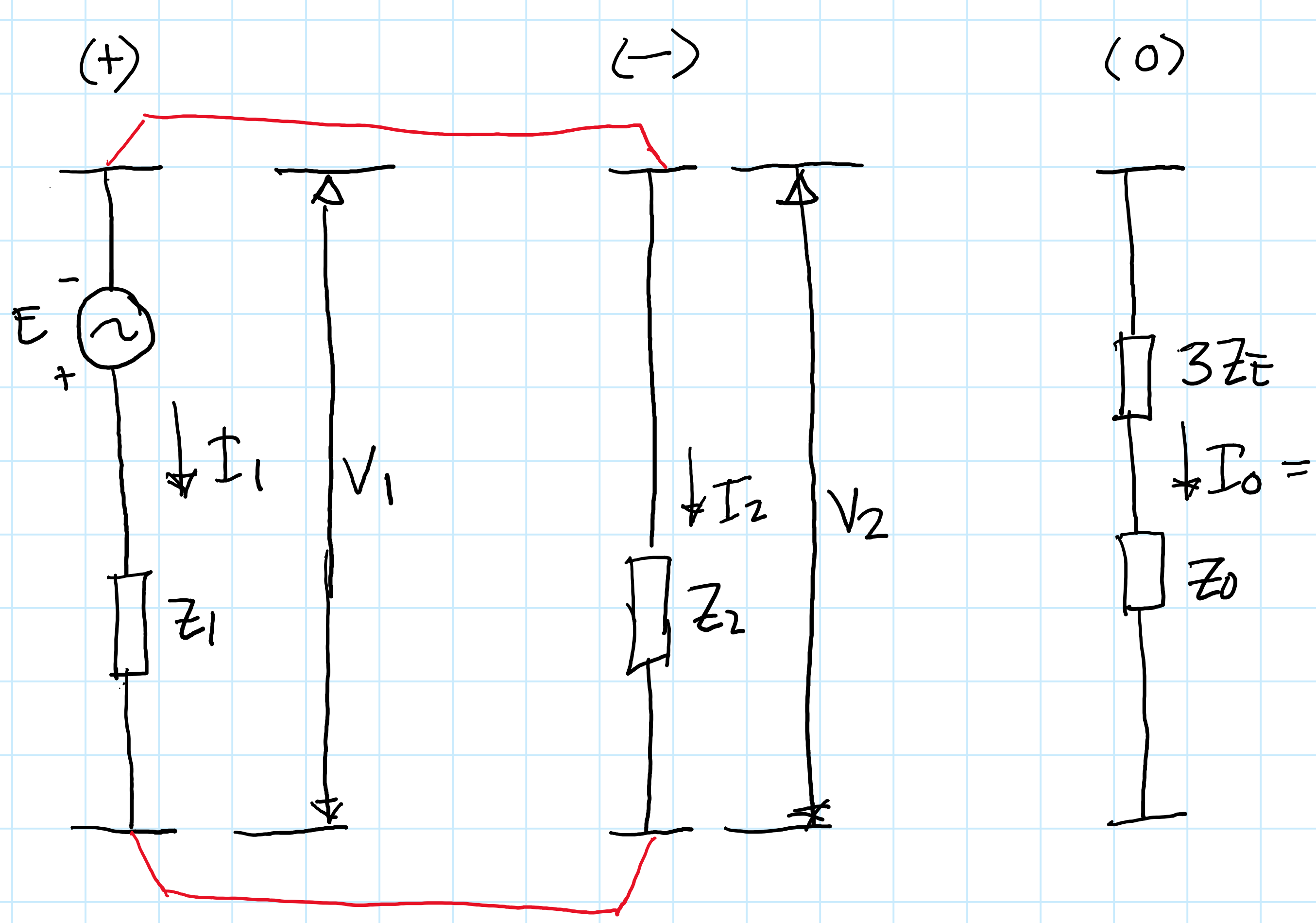
FROM EQ (6)

$$3I_2 = I_A + a^2 I_B + a I_C = 0 + a^2 I_B + a(-I_B)$$
$$\checkmark \; 3I_2 = (a^2 - a) I_B = (\sqrt{3}\angle -90) I_B$$

$\boxed{I_1 = -I_2}$ FROM EQ (5) AND (6)

$|I_2| / |I_1| = 1$

SEQUENCE NETWORK CONNECTIONS (LINE TO LINE FAULT)

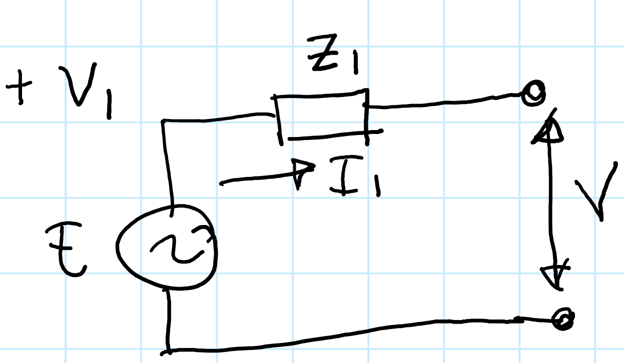


CONCLUSION: There is no zero-sequence current present in a line to line fault.

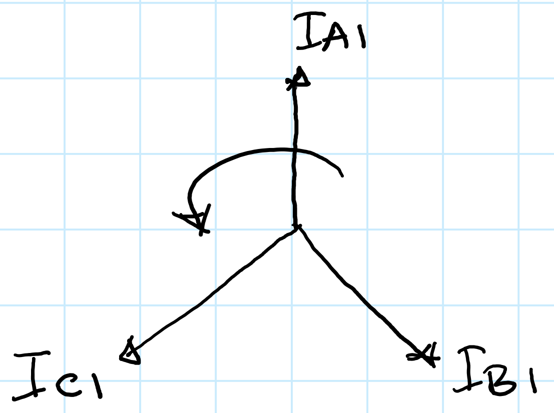
$$I_1 = \frac{E}{Z_1 + Z_2} = -I_2 = \frac{E}{2(Z_1)}$$

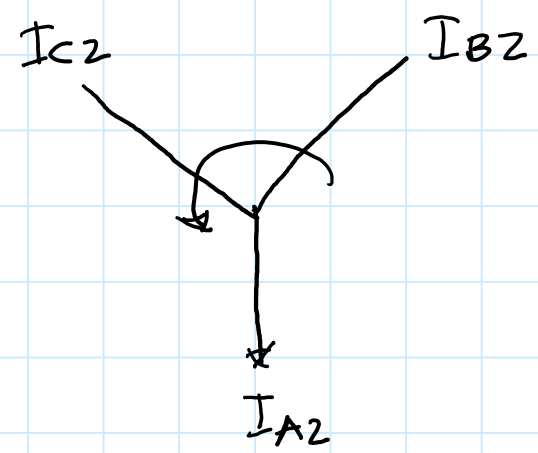
$$V_1 = V_2$$

$$E = I_1 Z_1 + V_1$$



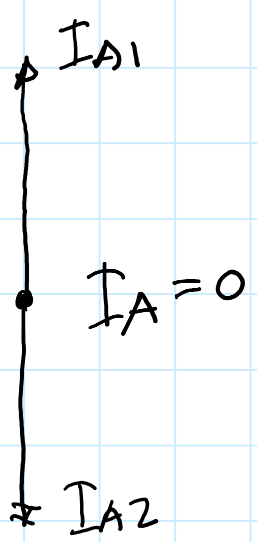
Phase To Phase Fault (Phasors)

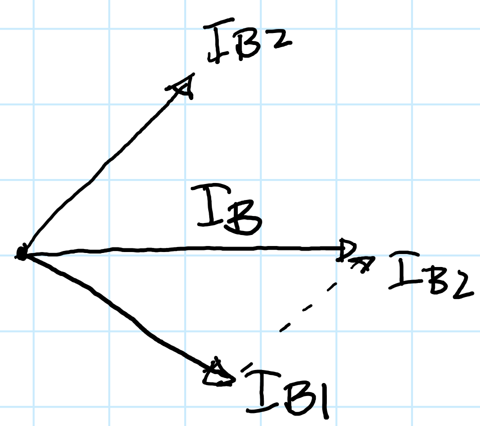


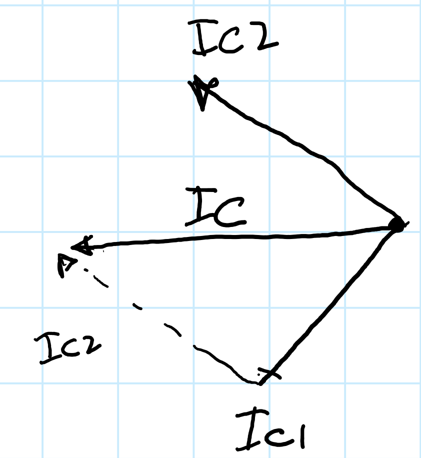


NO ZERO SEQUENCE

$I_1 = -I_2$







$I_A = I_{A1} + I_2 + \cancelto{0}{I_{A0}}$

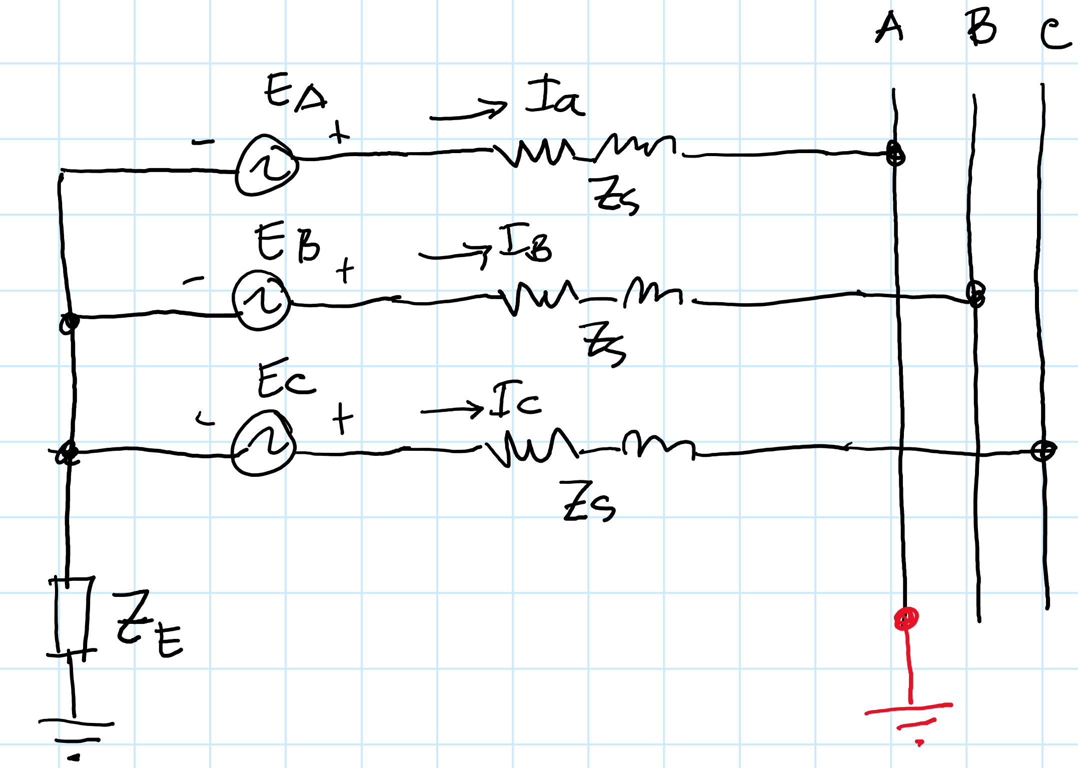
$I_B = I_{B1} + I_{B2} + \cancelto{0}{I_{B0}}$

$I_B = \sqrt{3}\,|I_{B1}|$

$I_C = I_{C1} + I_{C2} + \cancelto{0}{I_{C0}}$

$I_C = \sqrt{3}\,|I_{C1}|$

SINGLE LINE TO GROUND FAULT



$$I_A = I_0 + I_1 + I_2 \quad (1)$$
$$I_B = I_0 + a^2 I_1 + a I_2 \quad (2)$$
$$I_C = I_0 + a I_1 + a^2 I_2 \quad (3)$$

$$3I_0 = I_A + I_B + I_C \quad (4)$$
$$3I_1 = I_A + a I_B + a^2 I_C \quad (5)$$
$$3I_2 = I_A + a^2 I_B + a I_C \quad (6)$$

BOUNDARY CONDITIONS:

$V_A = 0$; $I_B = I_C = 0$

FROM EQ (4)

$$3I_0 = I_A + \cancel{I_B}^{0} + \cancel{I_C}^{0} = I_A$$
$$\boxed{3I_0 = I_A}$$

FROM EQ (5)

$$3I_1 = I_A + a\cancel{I_B}^{0} + a^2\cancel{I_C}^{0}$$
$$\boxed{3I_1 = I_A}$$

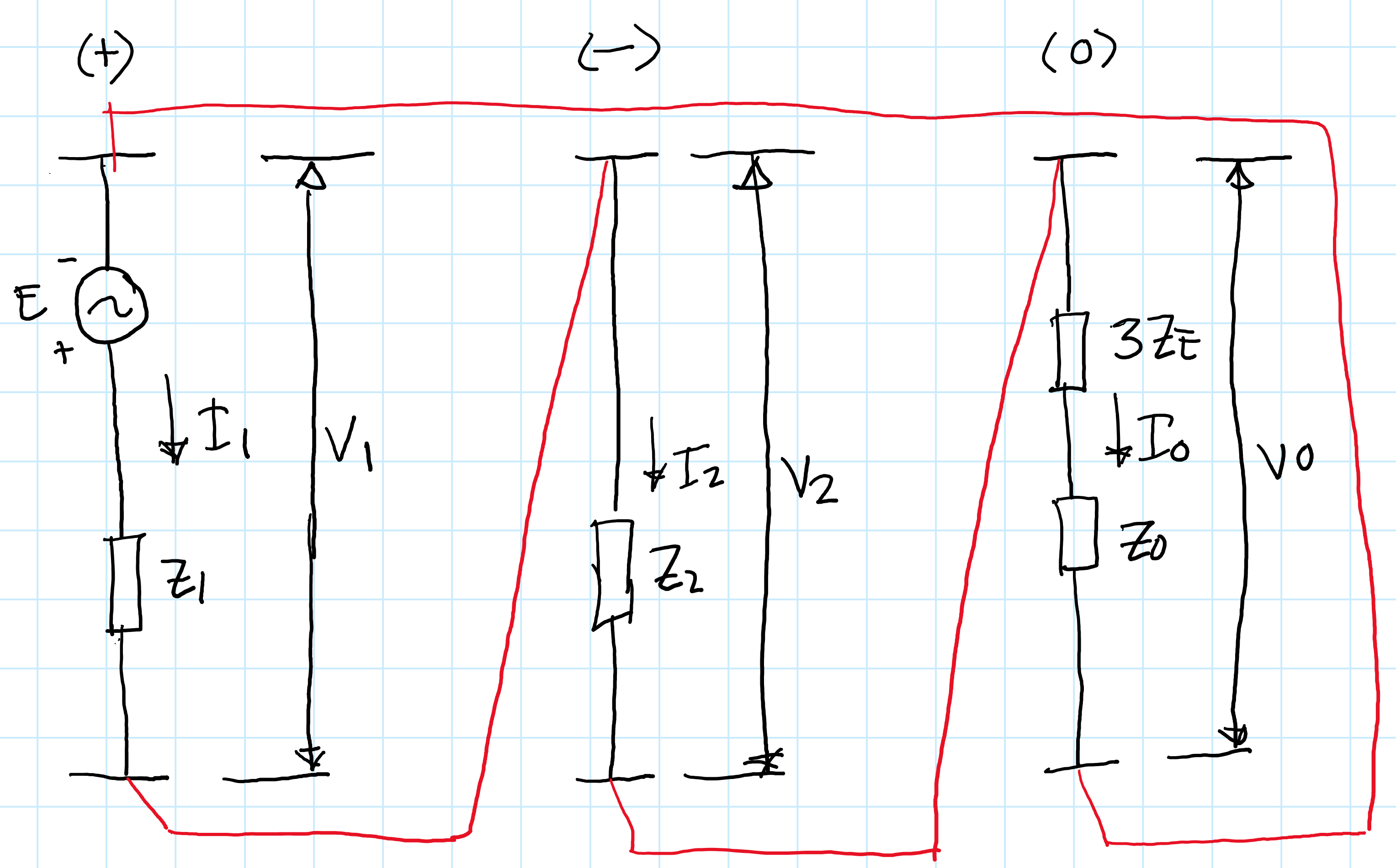
FROM EQ (6)

$$3I_2 = I_A + a^2\cancel{I_B}^{0} + a\cancel{I_C}^{0}$$
$$\boxed{3I_2 = I_A}$$

FROM EQ (4), (5) & (6)

$$\checkmark\ \boxed{I_A = 3I_1 = 3I_2 = 3I_0} \; ; \; \boxed{I_1 = I_2 = I_0 = \tfrac{1}{3} I_A}$$

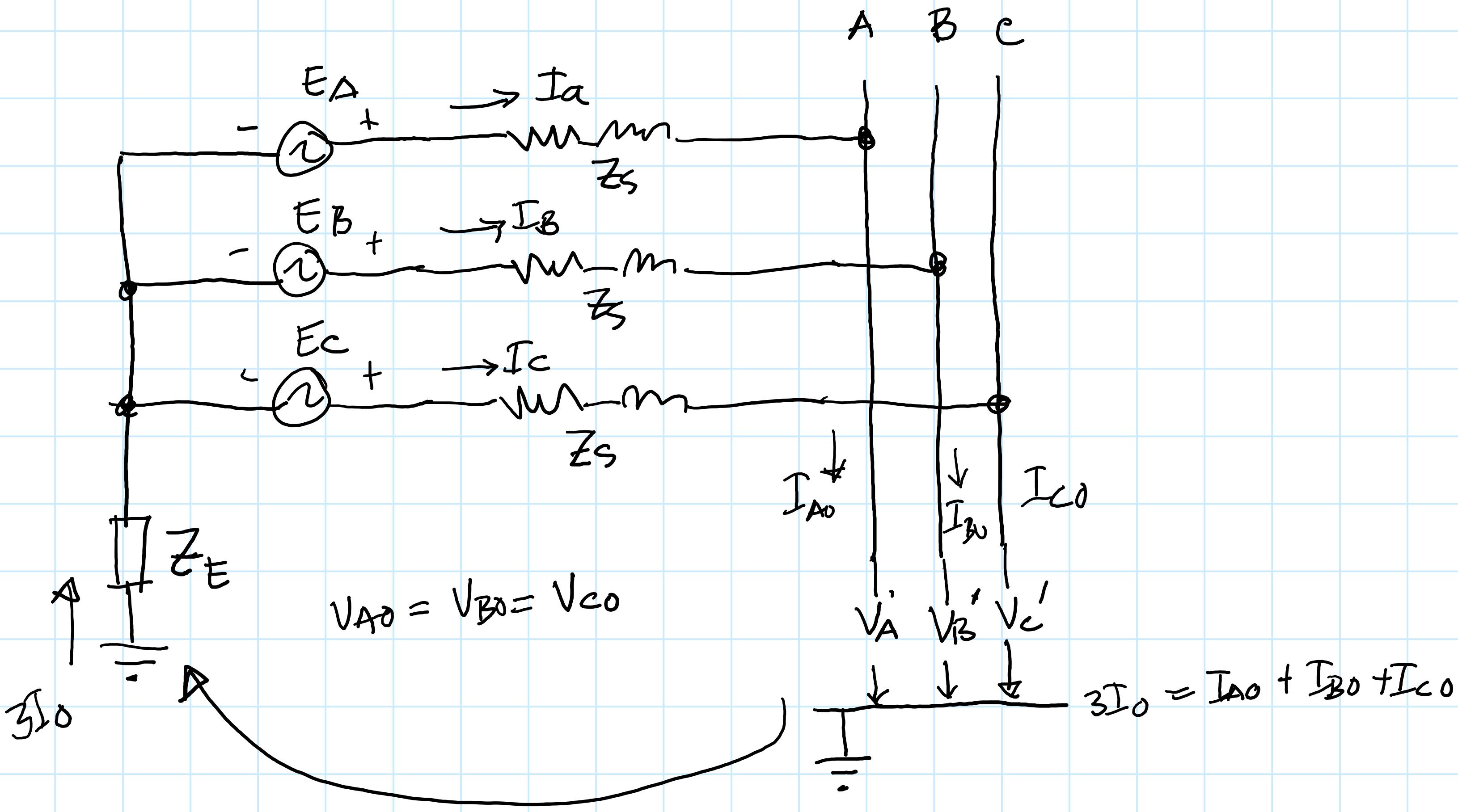
$$I_0 / I_1 = 1$$

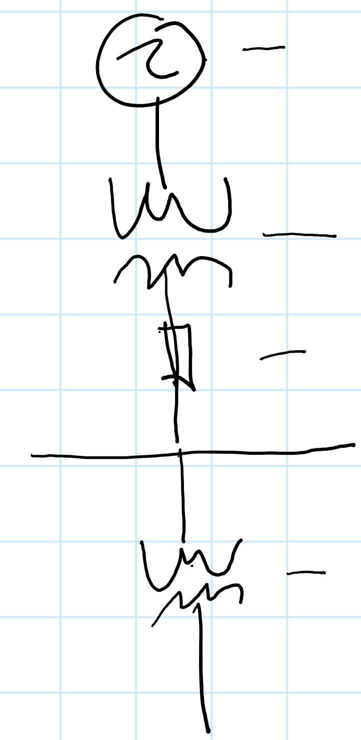


$$I_0 = \frac{E}{Z_1 + Z_2 + Z_0 + 3Z_E}$$

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

SEQUENCE IMPEDANCE OF A GENARATOR



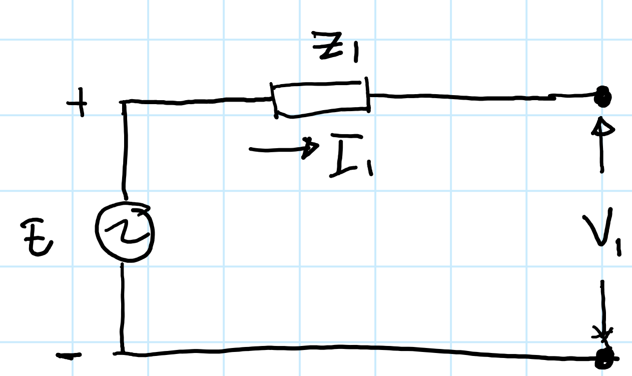


$$E_A = Z_S I_A + Z_M I_B + Z_M I_C + V_A$$

$$E_B = Z_M I_A + Z_S I_B + Z_M I_C + V_B$$

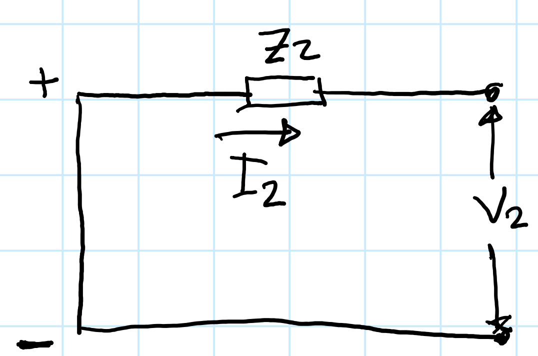
$$E_C = Z_M I_A + Z_M I_B + Z_S I_C + V_C$$

POS SEQ NETWORK



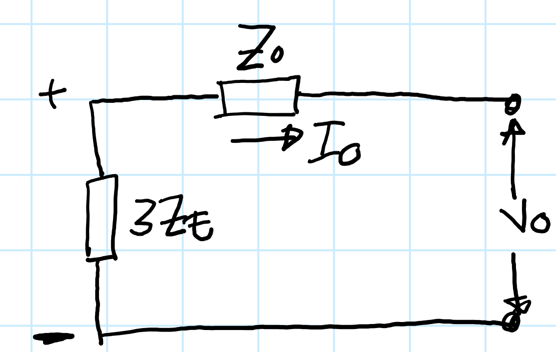
$$E = I_1 Z_1 + V_1$$

NEG SEQ NETWOR



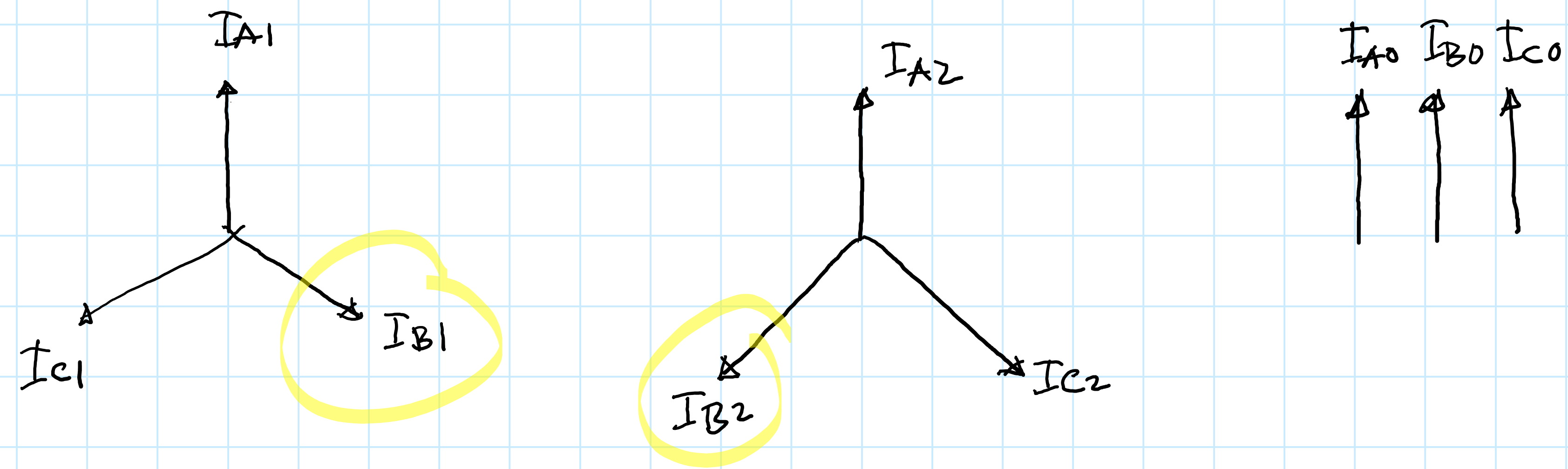
$$0 = I_2 Z_2 + V_2$$

ZERO SEQ NETWORK

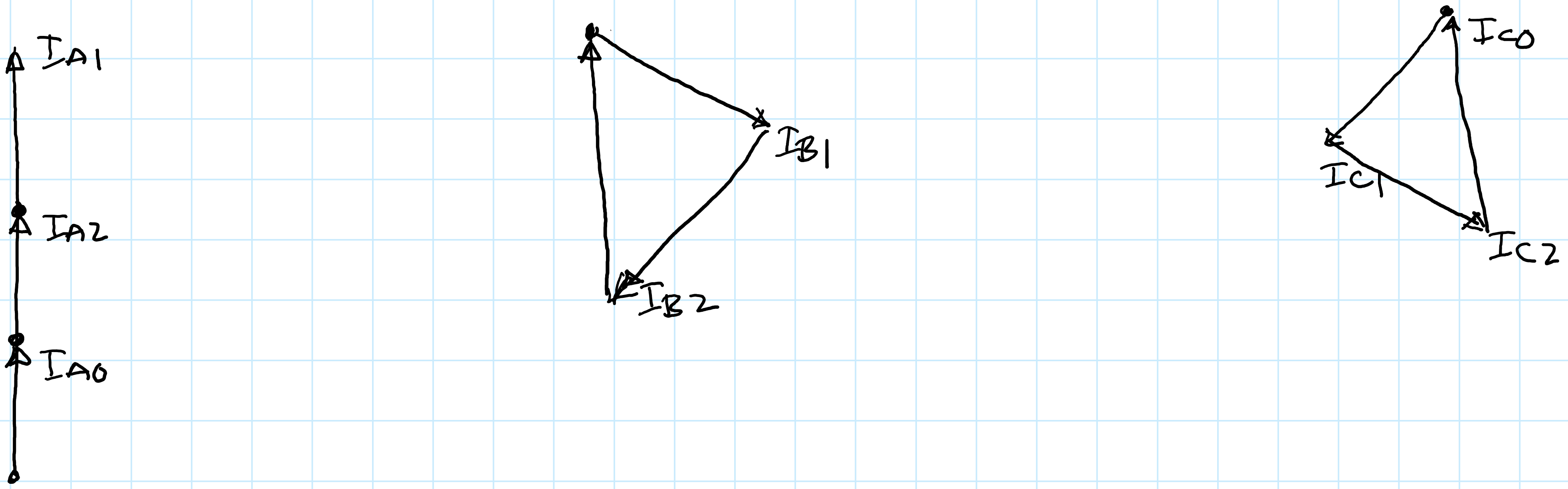


$$0 = I_0 Z_0 + 3 Z_E I_0 + V_0$$

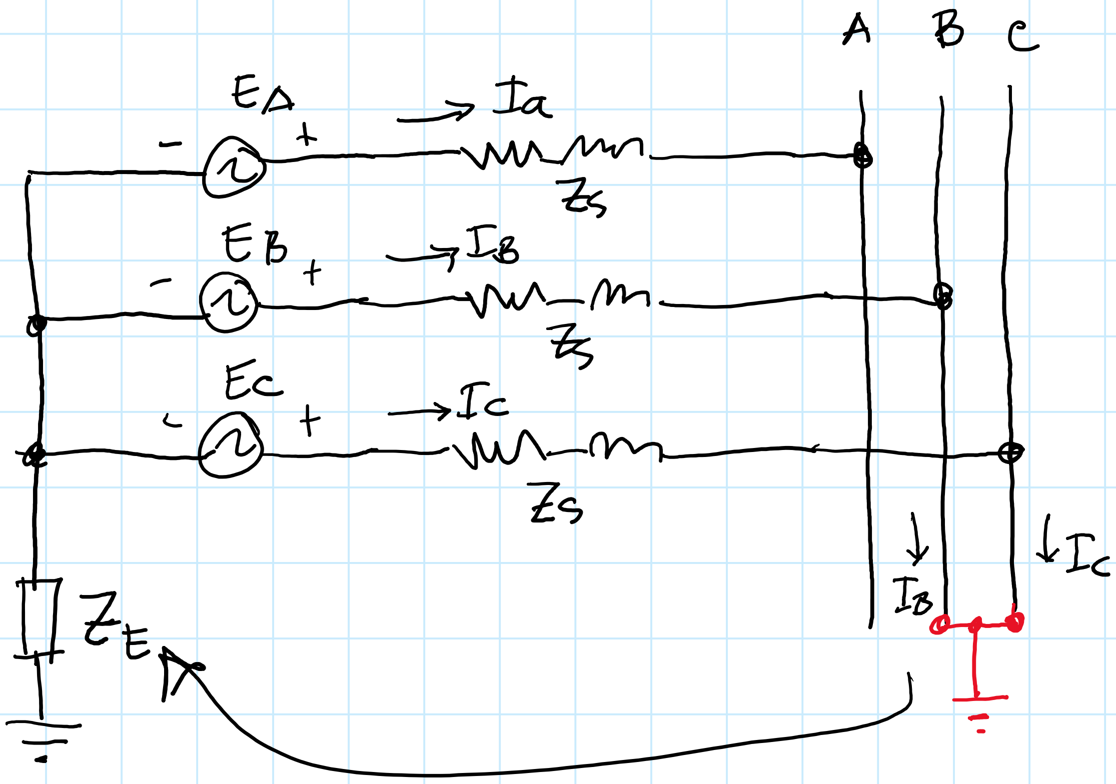
SINGLE LINE TO GROUND (PHASOR)



$I_A = I_{A1} + I_{A2} + I_{A0}$ $\quad$ $I_B = I_{B1} + I_{B2} + I_{B0} = 0$ $\quad$ $I_C = I_{C1} + I_{C2} + I_{C0} = 0$



PHASE TO PHASE TO GROUND



BOUNDARY CONDITIONS

$I_A = 0$; $V_B = V_C = (I_B + I_C) Z_E$

Taking phase A as reference (healthy phase):

$I_{A0} = \frac{1}{3}(I_A + I_B + I_C)$ (4)

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

$3I_0 = I_A + I_B + I_C$ (4)

$3I_1 = I_A + aI_B + a^2 I_C$ (5)

$3I_2 = I_A + a^2 I_B + aI_C$ (6)

$3V_0 = V_A + V_B + V_C$ (7)

$3V_1 = V_A + aV_B + a^2 V_C$ (8)

$3V_2 = V_A + a^2 V_B + aV_C$ (9)

FROM EQ (7)

$3V_0 = V_A + 2V_B$

$3V_1 = V_A + (a + a^2) V_B$

$3V_2 = V_A + (a + a^2) V_B$

$3V_0 = V_A + 2V_B = (V_{A0} + V_{A1} + V_{A2}) + 2(I_{A0} Z_E)$

$2V_0 = V_1 + V_2 + 2I_0 Z_E$

(1) $V_1 = V_2 = \frac{1}{3}(V_A + aV_A + a^2 V_B) = \frac{1}{3}(V_A + aV_C + a^2 V_C)$

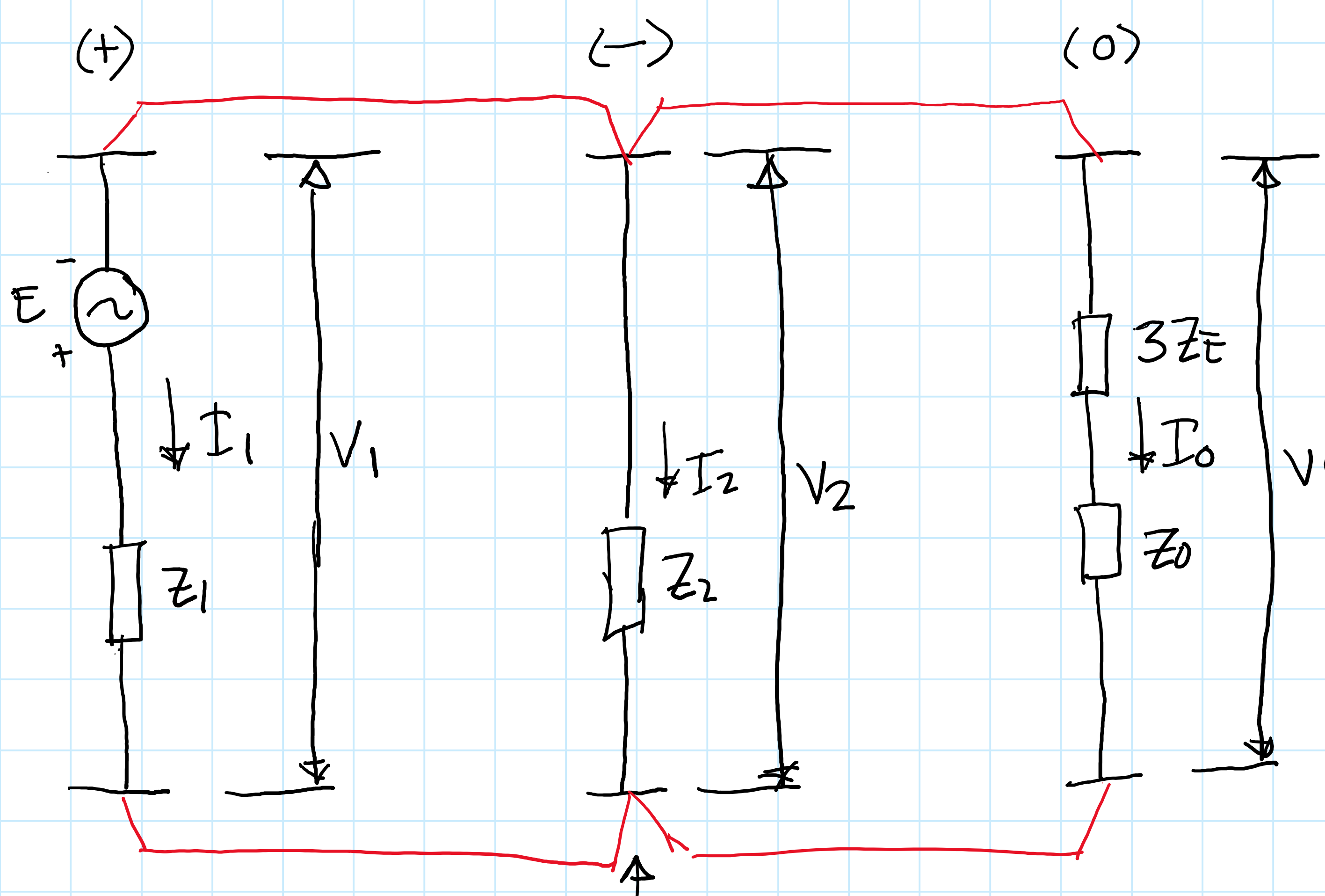
(2) $3V_0 = V_A + 2V_B = (V_0 + V_1 + V_2) + 2(3I_0 Z_E)$

(1)+(2) $\rightarrow 3V_0 = (V_0 + 2V_1) + 2(3I_0 Z_E)$

$2V_1 = 2V_0 - 2\, 3I_0 Z_E$

$V_1 = V_0 - 3I_0 Z_E$

$V_1 = V_2 = V_0 - 3I_0 Z_0$

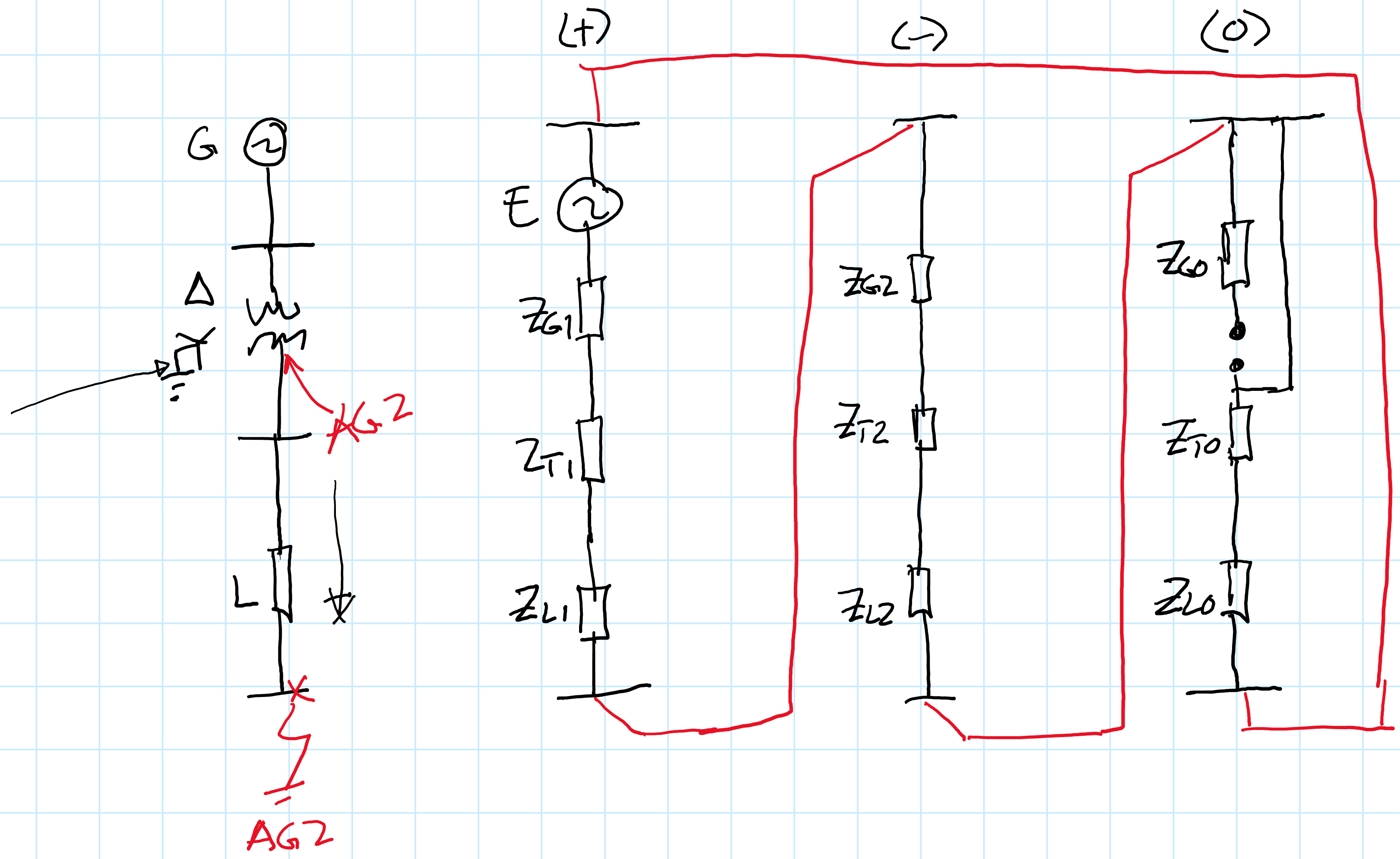


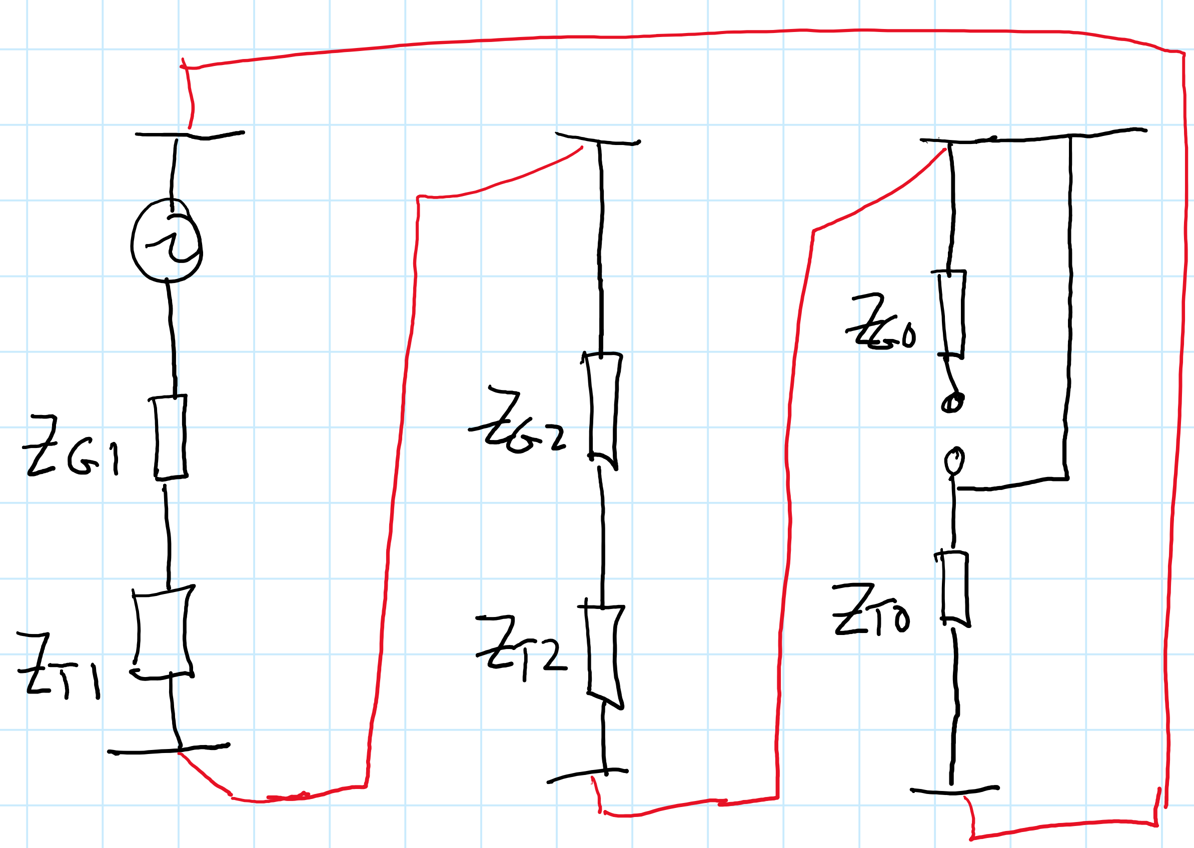
$$I_1 = \frac{E}{Z_1 + Z_2 // Z_0}$$

$I_1 + I_2 + I_0 = 0$

$I_1 = -(I_2 + I_0)$

SEQUENCE NETWORK CONNECTIONS





FOR 3φ FAULT NEAR SEC SIDE OF XFMR

$$I_A = I_1 = \frac{E}{Z_{G1} + Z_{T1}}$$

$$Z_1 = Z_2 = Z_0$$

FOR SLG FAULT NEAR SEC SIDE OF XFMR

$$I_A = 3I_0 = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_F} = \frac{3E}{Z_{G1} + Z_{T1} + Z_{G2} + Z_{T2} + Z_{T0}}$$

$$= \frac{3E}{2Z_{G1} + 2Z_{T1} + Z_{T0}}$$

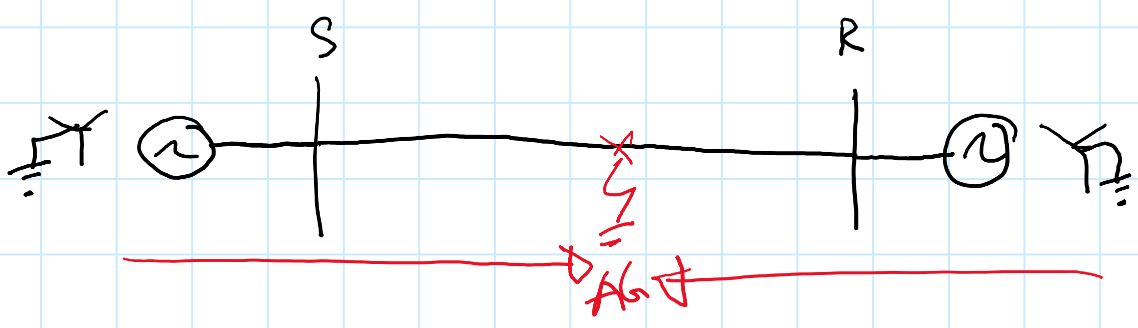
SOURCES OF FAULT CURRENTS

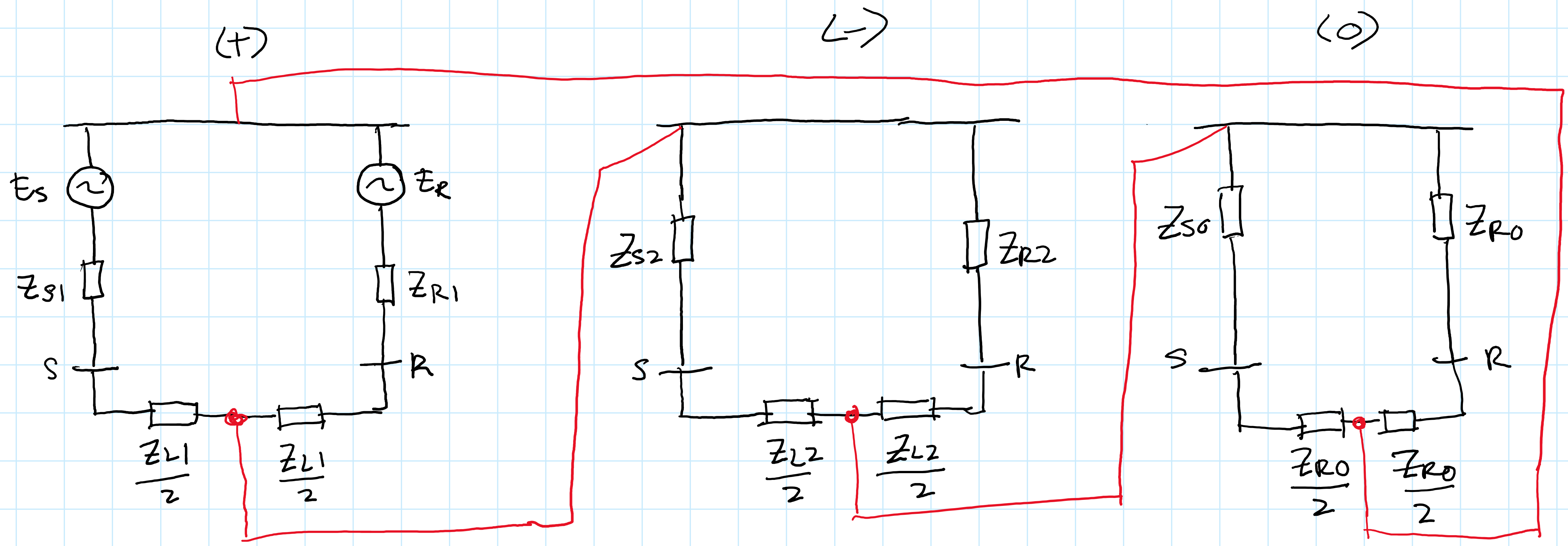
1. UTILITY
2. LOCAL GENERATORS
3. INDUCTION MOTORS
4. SYNCHRONOUS MOTORS

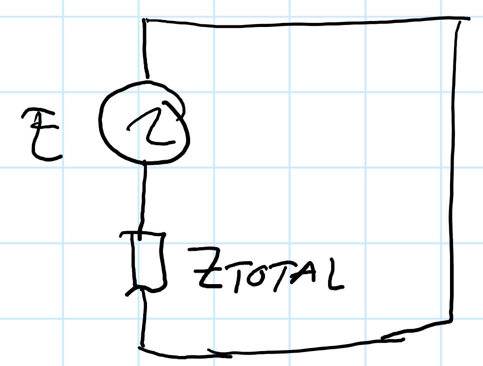
1/8 cycle

Interrupting
Asymmetrical RMS
Asymmetrical Peak

TWO SOURCE POWER SYSTEM







FOR MODERN RELAYS (a_0 and a_2 FACTORS)

$a_0 = |I_0| / |I_1| \geq 0.10$ declare SLG fault $\quad V_A = 0$

$a_2 = |I_2| / |I_1| \geq 0.10$ declare LL fault $\quad V_B = V_C$