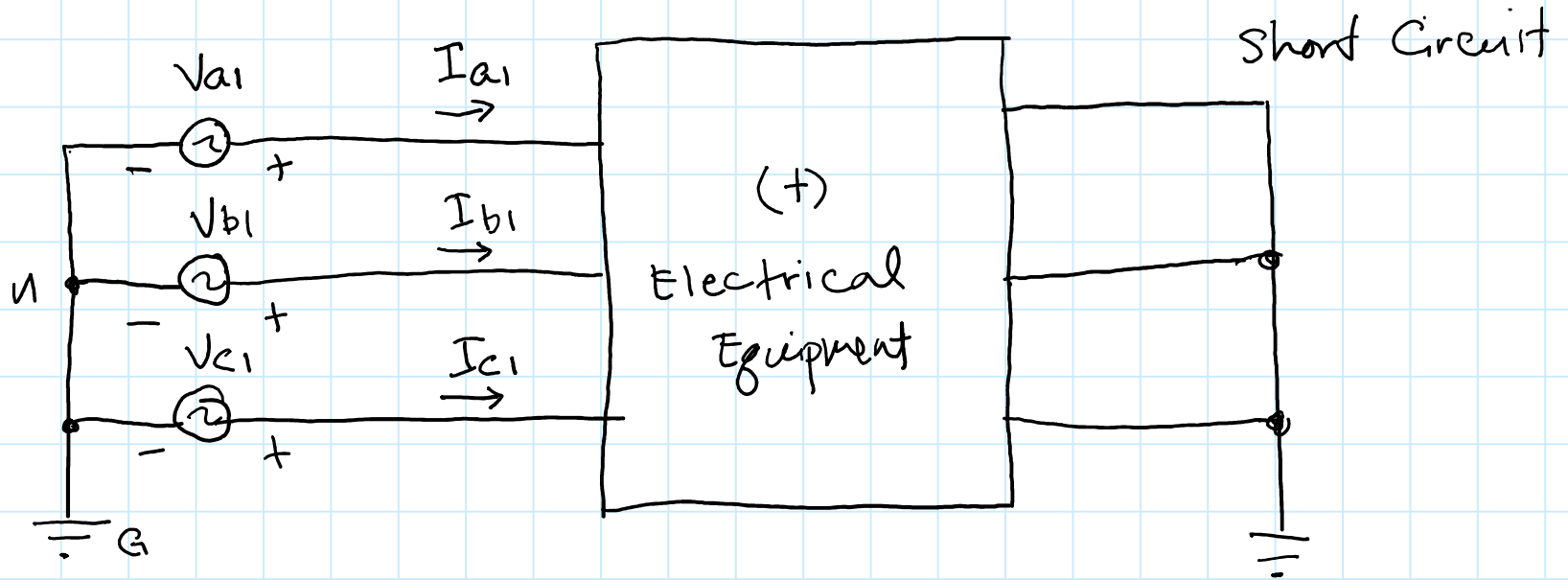


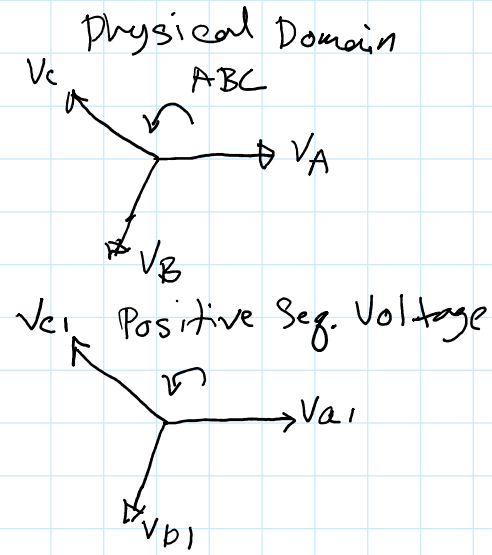
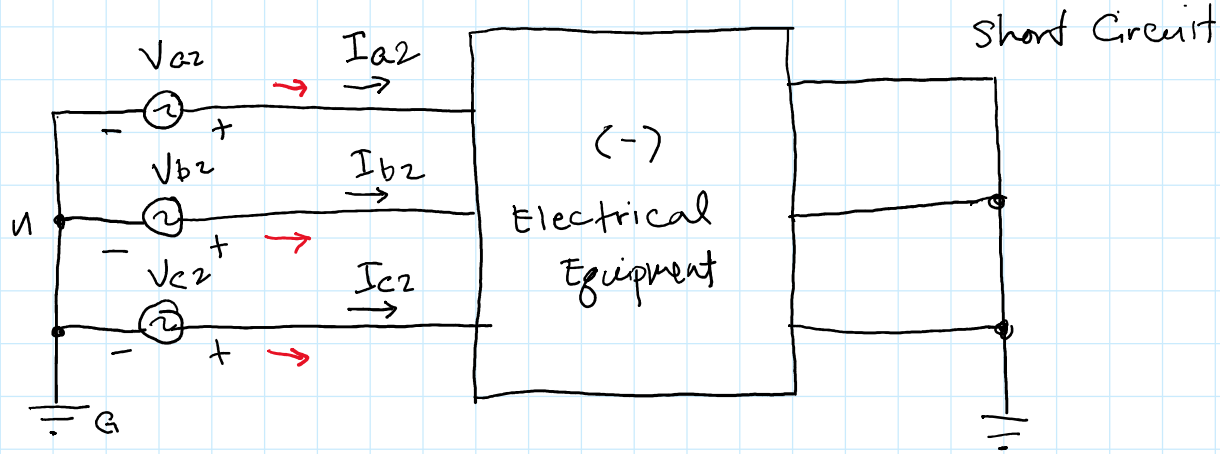
Test Setup for Positive Sequence



Positive Sequence

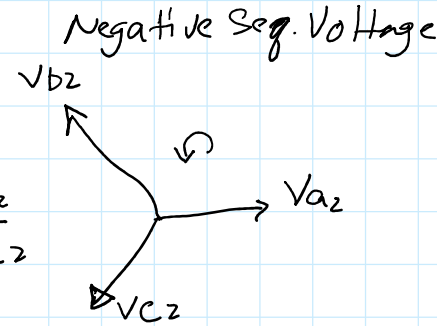
$$\text{Impedance : } Z_1 = R_1 + jX_1 = \frac{V_{a1}}{I_{a1}} = \frac{V_{b1}}{I_{b1}} = \frac{V_{c1}}{I_{c1}}$$

Test Setup for Negative Sequence

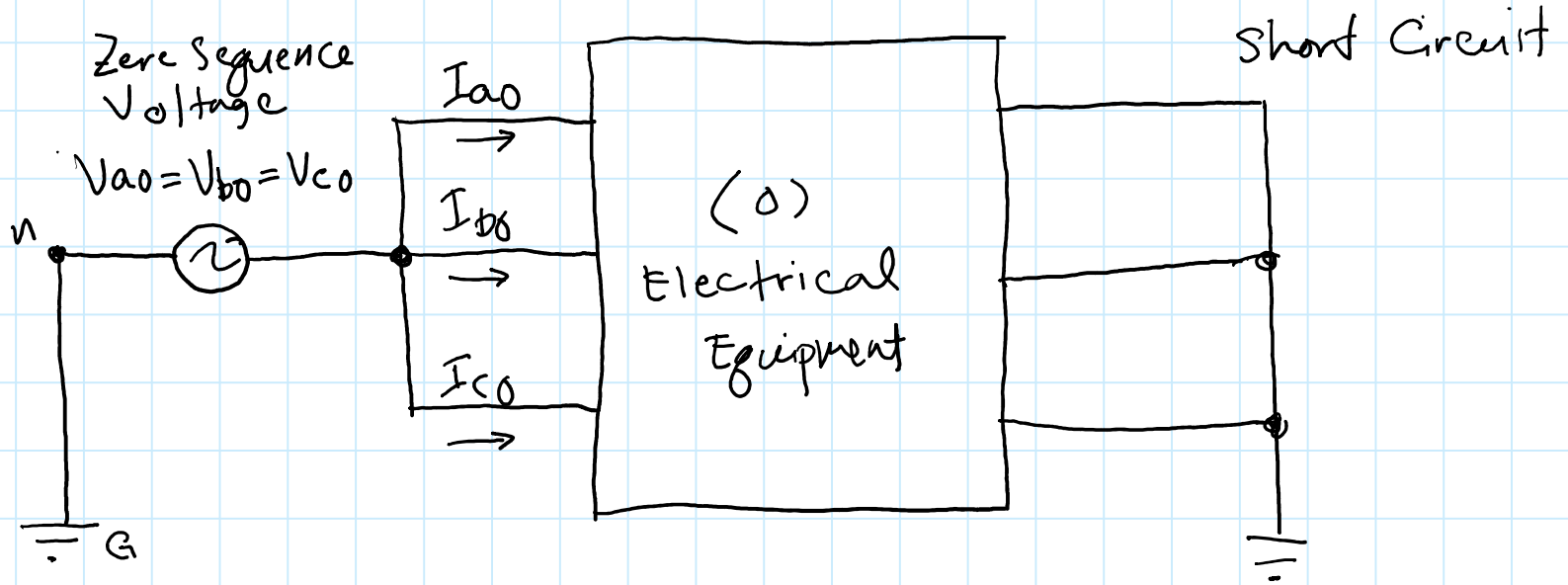


Negative Sequence

Impedance : $Z_2 = R_2 + jX_2 = \frac{V_{a2}}{I_{a2}} = \frac{V_{b2}}{I_{b2}} = \frac{V_{c2}}{I_{c2}}$



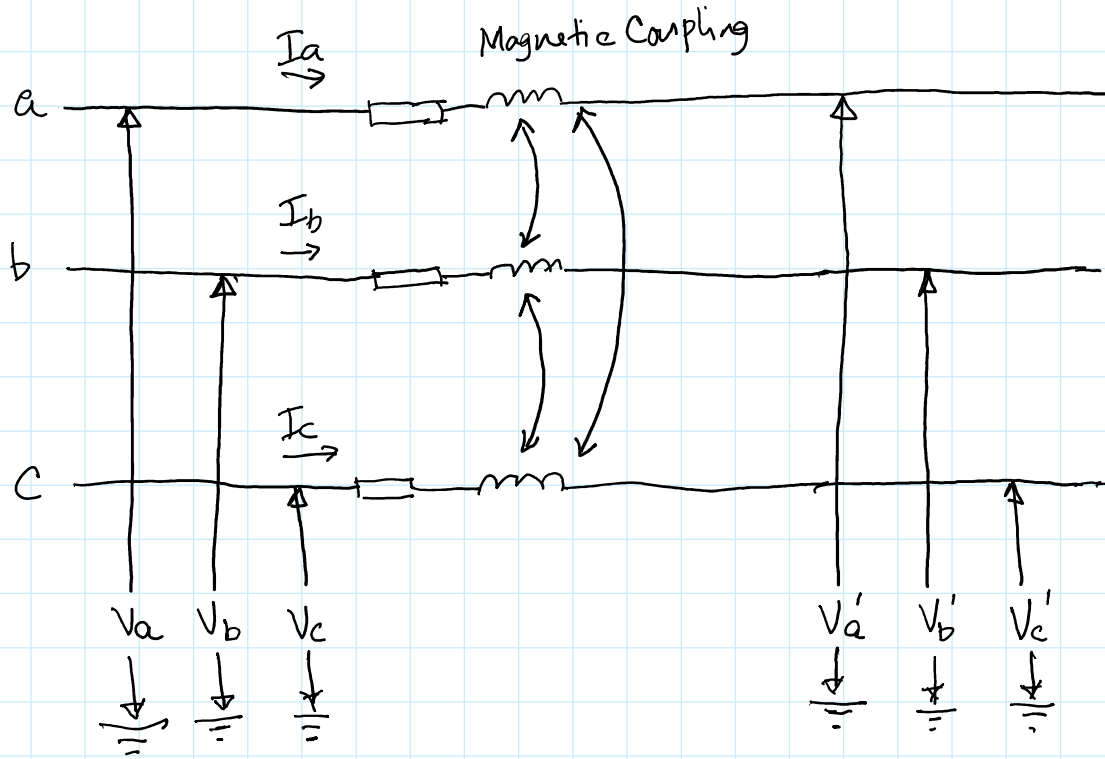
Test Setup for Zero Sequence



Zero Sequence

Impedance : $Z_0 = R_0 + jX_0 = \frac{V_{a0}}{I_{a0}} = \frac{V_{b0}}{I_{b0}} = \frac{V_{c0}}{I_{c0}}$

Transmission Line (Physical Domain)



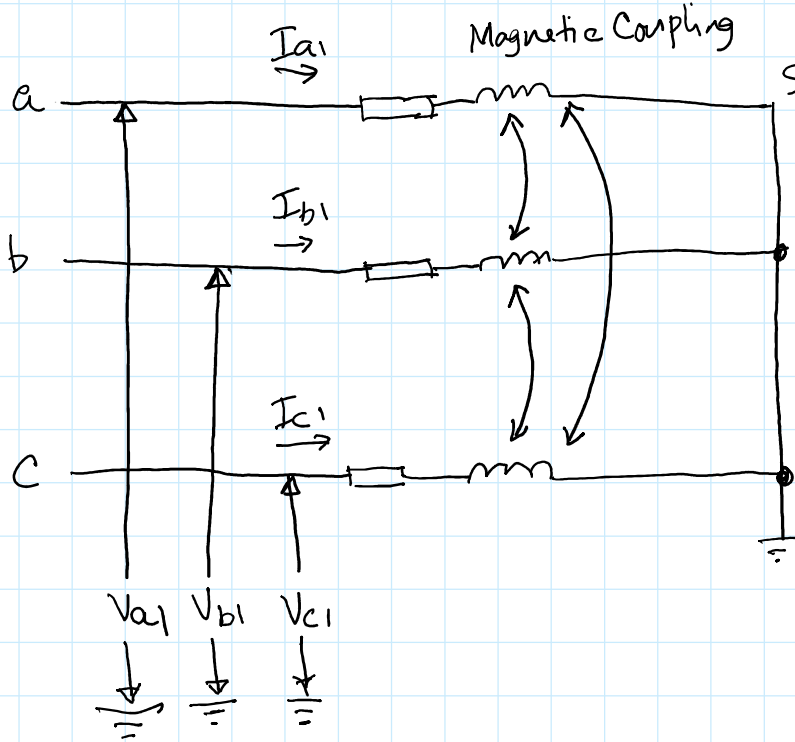
$$V_a = Z_s I_a + Z_m I_b + Z_m I_c + V_a'$$

$$V_b = Z_s I_b + Z_m I_a + Z_m I_c + V_b'$$

$$V_c = Z_s I_c + Z_m I_a + Z_m I_b + V_c'$$

Transmission Line (Positive Sequence)

Positive
Sequence
Source



$$-I_{b1} = I_{a1} + I_{c1}$$

$$I_{a1} + I_{b1} + I_{c1} = 0 \Rightarrow I_{b1} + I_{c1} = -I_{a1}$$

Short Circuit

$$\left. \begin{aligned} V_{a1}' &= 0 \\ V_{b1}' &= 0 \\ V_{c1}' &= 0 \end{aligned} \right\}$$

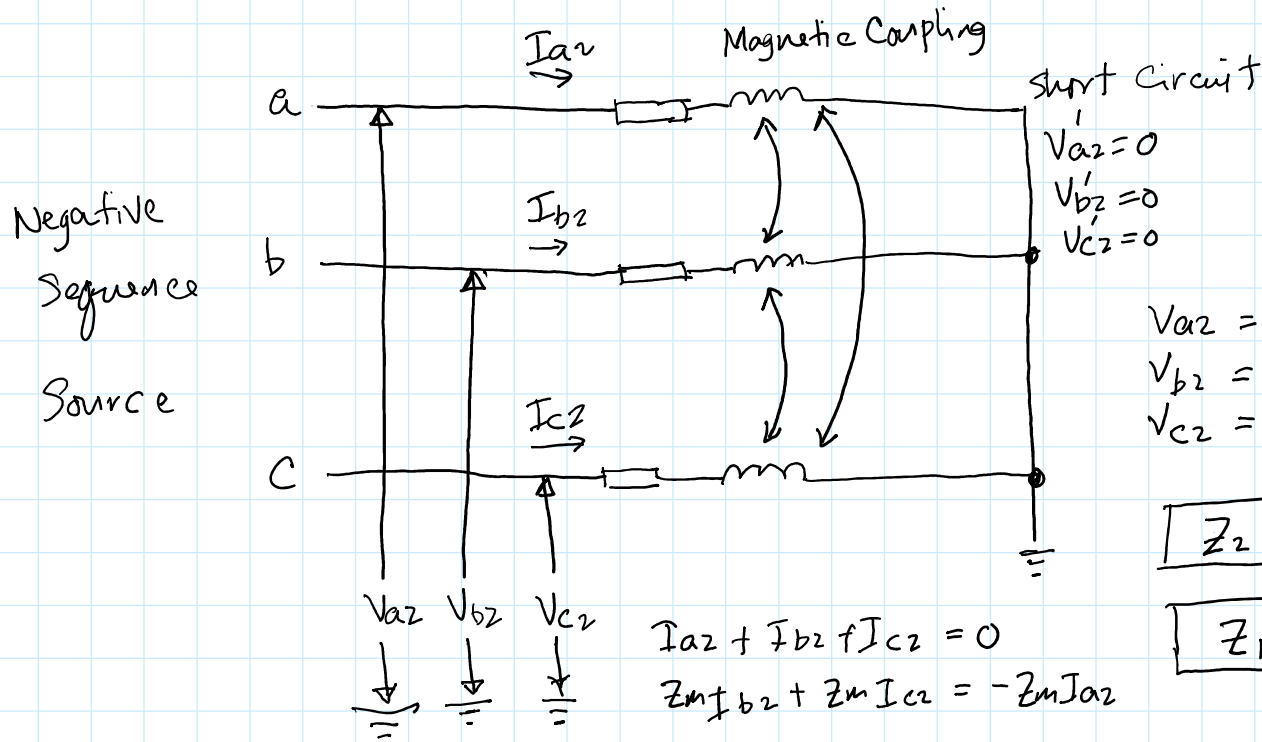
$$\begin{aligned} V_a &= Z_s I_a + Z_m I_b + Z_m I_c + V_a' \\ V_b &= Z_s I_b + Z_m I_a + Z_m I_c + V_b' \\ V_c &= Z_s I_c + Z_m I_a + Z_m I_b + V_c' \end{aligned}$$

- ① $V_{a1} = Z_s I_{a1} + Z_m I_{b1} + Z_m I_{c1} + V_{a1}'$
- ② $V_{b1} = Z_s I_{b1} + Z_m I_{a1} + Z_m I_{c1} + V_{b1}'$
- ③ $V_{c1} = Z_s I_{c1} + Z_m I_{a1} + Z_m I_{b1} + V_{c1}'$

- ① $V_{a1} = Z_s I_{a1} + Z_m (I_{b1} + I_{c1}) = (Z_s - Z_m) I_{a1}$
- ② $V_{b1} = Z_m I_{a1} + Z_s I_{b1} + Z_m I_{c1} = (Z_s - Z_m) I_{b1}$
- ③ $V_{c1} = Z_s I_{c1} + Z_m I_{a1} + Z_m I_{b1} = (Z_s - Z_m) I_{c1}$

$$Z_1 = Z_s - Z_m$$

Transmission Line (Negative Sequence)



$$V_a = Z_s I_a + Z_m I_b + Z_m I_c + V_a'$$

$$V_b = Z_s I_b + Z_m I_a + Z_m I_c + V_b'$$

$$V_c = Z_s I_c + Z_m I_a + Z_m I_b + V_c'$$

$$V_{a2} = Z_s I_{a2} + Z_m I_{b2} + Z_m I_{c2} = (Z_s - Z_m) I_{a2}$$

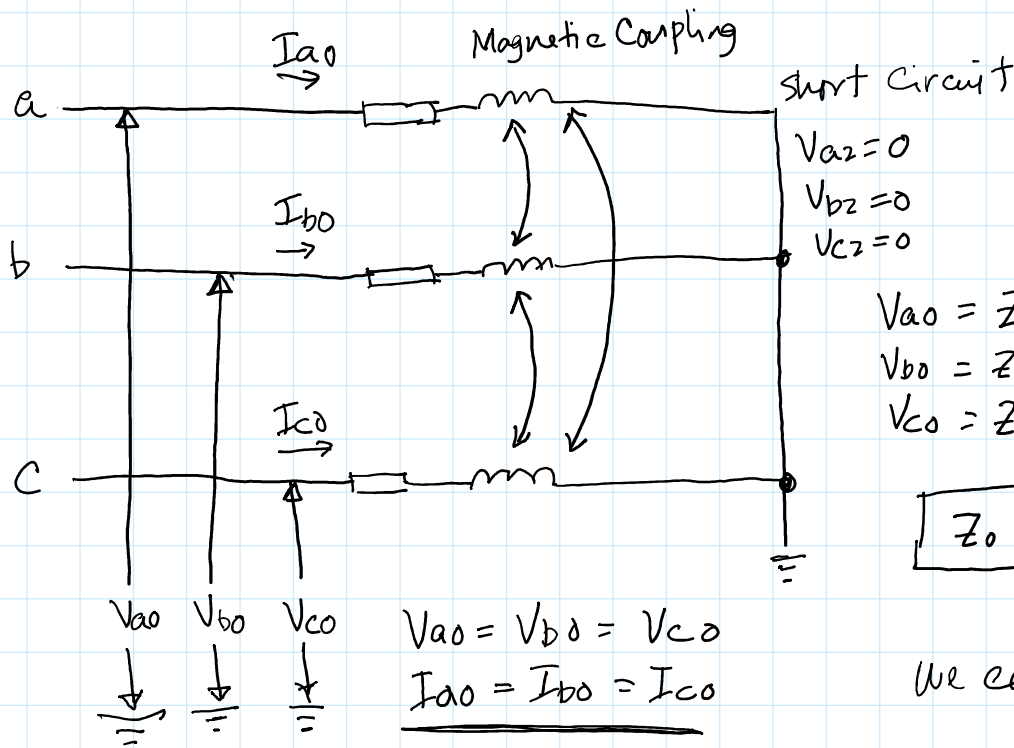
$$V_{b2} = Z_s I_{b2} + Z_m I_{a2} + Z_m I_{c2} = (Z_s - Z_m) I_{b2}$$

$$V_{c2} = Z_s I_{c2} + Z_m I_{a2} + Z_m I_{b2} = (Z_s - Z_m) I_{c2}$$

$$Z_2 = Z_s - Z_m$$

$$Z_1 = Z_2$$

Zero
Sequence
Source
(Single Phase)



$$V_a = Z_s I_a + Z_m I_b + Z_m I_c + V_a'$$

$$V_b = Z_s I_b + Z_m I_a + Z_m I_c + V_b'$$

$$V_c = Z_s I_c + Z_m I_a + Z_m I_b + V_c'$$

$$V_{a0} = Z_s I_{a0} + Z_m I_{b0} + Z_m I_{c0} = (Z_s + 2Z_m) I_{a0}$$

$$V_{b0} = Z_s I_{b0} + Z_m I_{a0} + Z_m I_{c0} = (Z_s + 2Z_m) I_{b0}$$

$$V_{c0} = Z_s I_{c0} + Z_m I_{a0} + Z_m I_{b0} = (Z_s + 2Z_m) I_{c0}$$

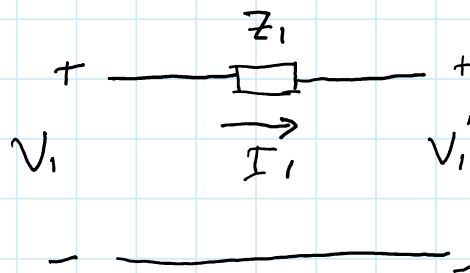
$$Z_0 = Z_s + 2Z_m$$

We can say that $Z_0 > Z_1$; $Z_0 > Z_2$

Typical $\frac{Z_0}{Z_1} \geq 4$

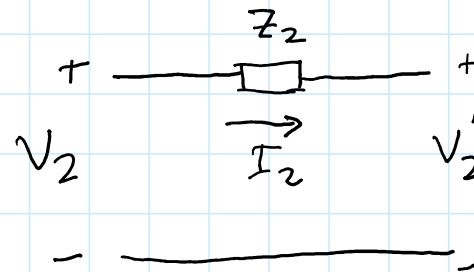
Transmission Line (Sequence Networks)

Positive



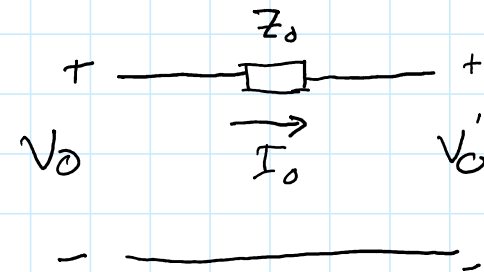
$$V_1 = Z_1 I_1 + V_1'$$

Negative



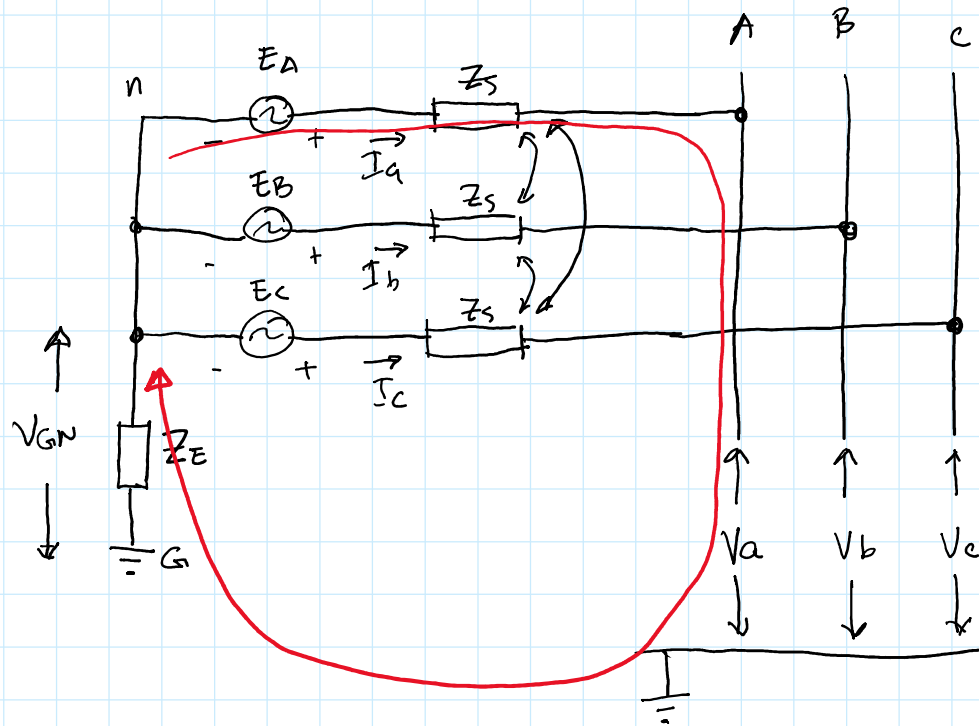
$$V_2 = Z_2 I_2 + V_2'$$

Zero



$$V_0 = Z_0 I_0 + V_0'$$

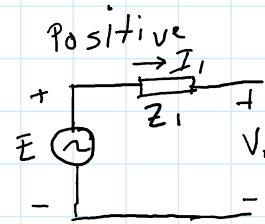
Simplified Generator



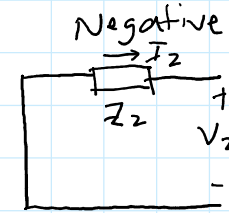
$$E_a = Z_s I_a + Z_m I_b + Z_m I_c + V_a + V_{GN}$$

$$E_b = Z_s I_b + Z_m I_a + Z_m I_c + V_b + V_{GN}$$

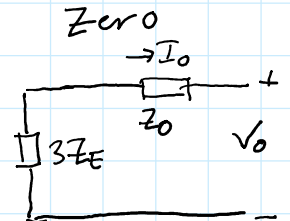
$$E_c = Z_s I_c + Z_m I_a + Z_m I_b + V_c + V_{GN}$$



$$E = Z_1 I_1 + V_1$$



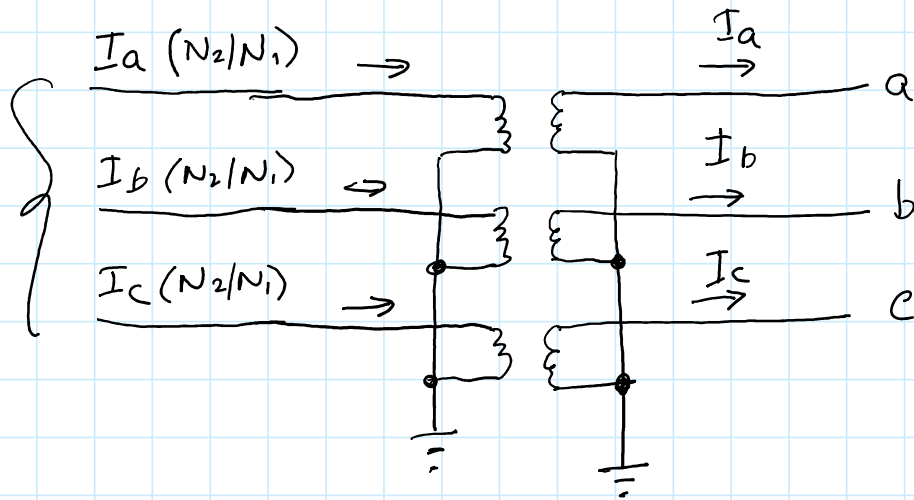
$$0 = Z_2 I_2 + V_2$$



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

Transformer (Wye-Wye)

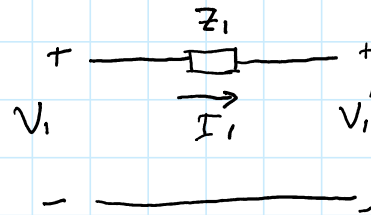
$$\text{Transformer Ratio} = \left(\frac{V_{1LL}}{V_{2LL}} \right) = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$



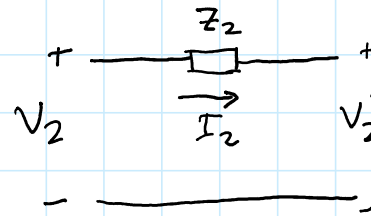
Positive

Negative

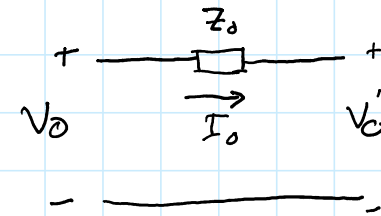
Zero



$$V_1 = Z_1 I_1 + V_1'$$

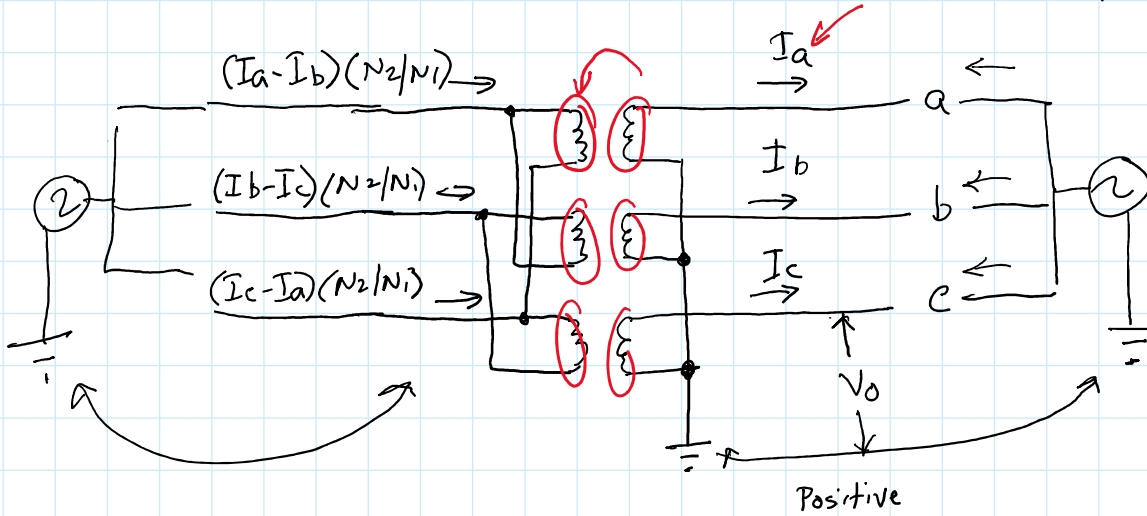


$$V_2 = Z_2 I_2 + V_2'$$



$$V_0 = Z_0 I_0 + V_0'$$

Transformer (Delta-Wye)



$$\text{Transformer Ratio} = \left| \frac{V_{1LL}}{V_{2LL}} \right| = \frac{N_1}{\sqrt{3}N_2} = \frac{I_2}{\sqrt{3}I_1}$$

$$\begin{aligned} I_a &= I_{a1} + I_{a2} + I_{a0} \\ I_b &= I_{b1} + I_{b2} + I_{b0} \\ I_c &= I_{c1} + I_{c2} + I_{c0} \end{aligned}$$

$$\begin{aligned} (I_a - I_b) &= (I_{a1} + I_{a2} + I_{a0}) - (I_{b1} + I_{b2} + I_{b0}) \\ &= (I_{a1} + I_{a2}) - (I_{b1} + I_{b2}) + (I_{a0} - I_{b0}) \end{aligned}$$

