✓ Momentary = ½ cycle → Utility, local generators, motors → Bus bracing, Fast acting Fuses, ✓

✓ Interrupting = 1.5 - 4 cycle → Utility, local generators → Breakers, Relays (Instantaneous)

Steady state = 30 cycle → Utility → Breaker, Relays (time-delayed)

X'' - subtransient reactance

X' - transient reactance

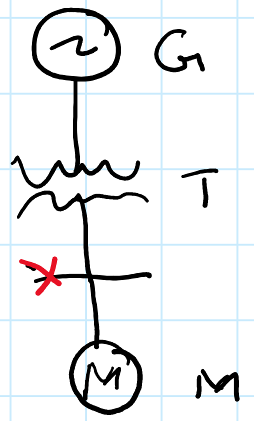
momentary

$X'' < X'$

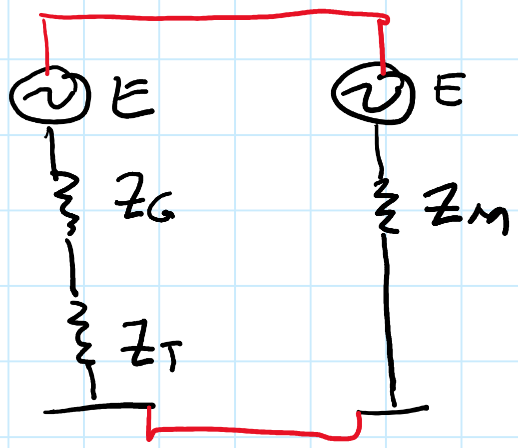
Interrupting

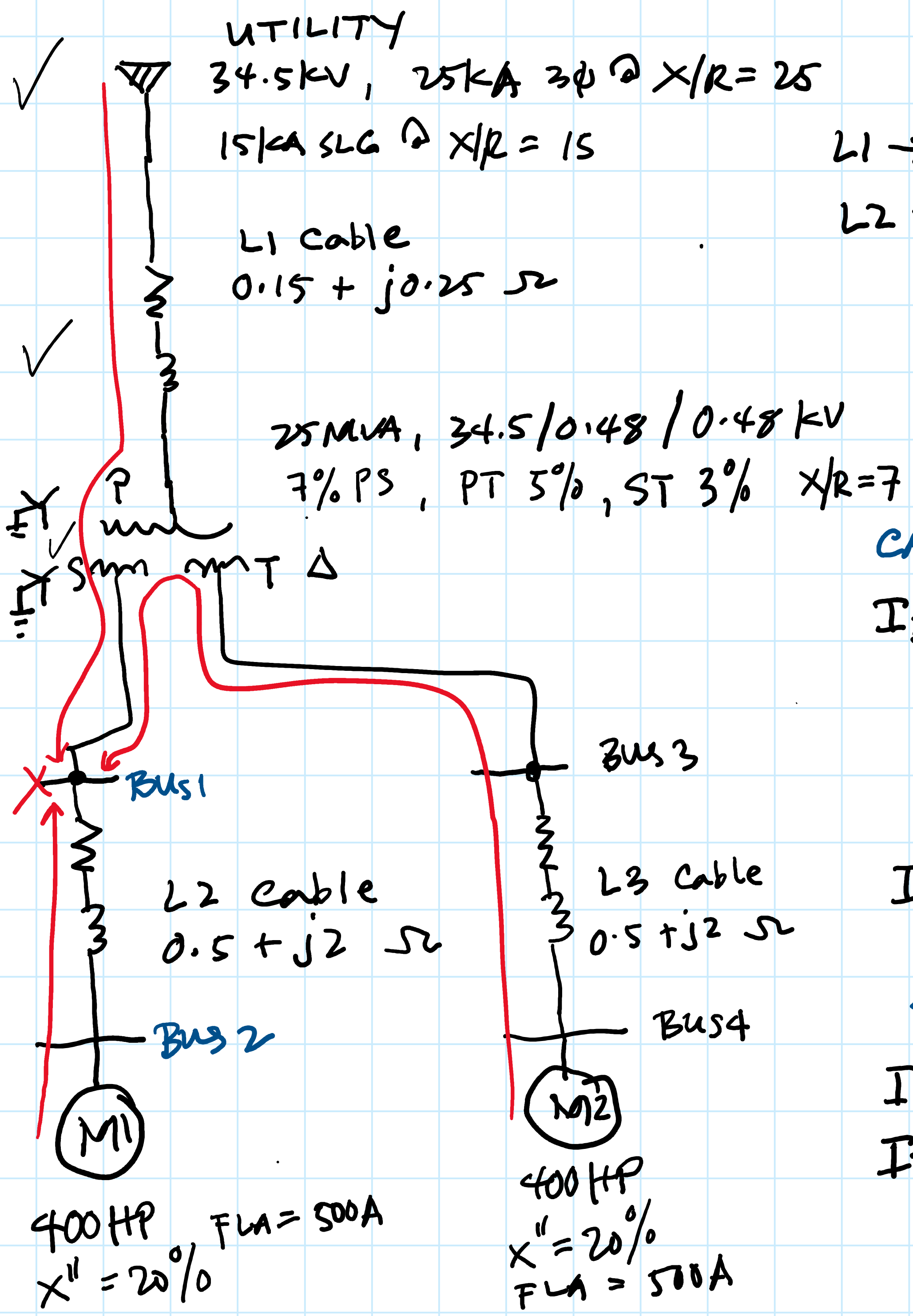
$X'' = 20\% = 0.2$ pu → ½ cycle

$X' = 50\% = 0.5$ pu → 1.5 - 4 cycle



POSITIVE





CABLE IMPEDANCES

L1 → $Z_1 = Z_2 = Z_0 = (0.15 + j0.25)/119.025 = 0.002449 \angle 59.04^\circ$ pu

L2 → $Z_1 = Z_2 = Z_0 = (0.5 + j2)/0.02304 = 89.4771 \angle 75.96^\circ$ pu

TRANSFORMER IMPEDANCE

$Z_1 = Z_2 = Z_0 = 0.07\,(10/25) = \underline{0.028 \angle 81.87^\circ}$

CALCULATE FOR A 3ϕ FAULT CURRENT @ BUS 2

$$I_{3\phi} = E/Z_{1TH} = 1.0\angle 0^\circ / (Z_{1U} + Z_{1L1} + Z_{1T} + Z_{1L2})$$

$$= 1.0\angle 0^\circ / (0.006694 \angle 87.71^\circ + 0.002449 \angle 59.04^\circ + 0.028 \angle 81.87^\circ + 89.4771 \angle 75.96^\circ)$$

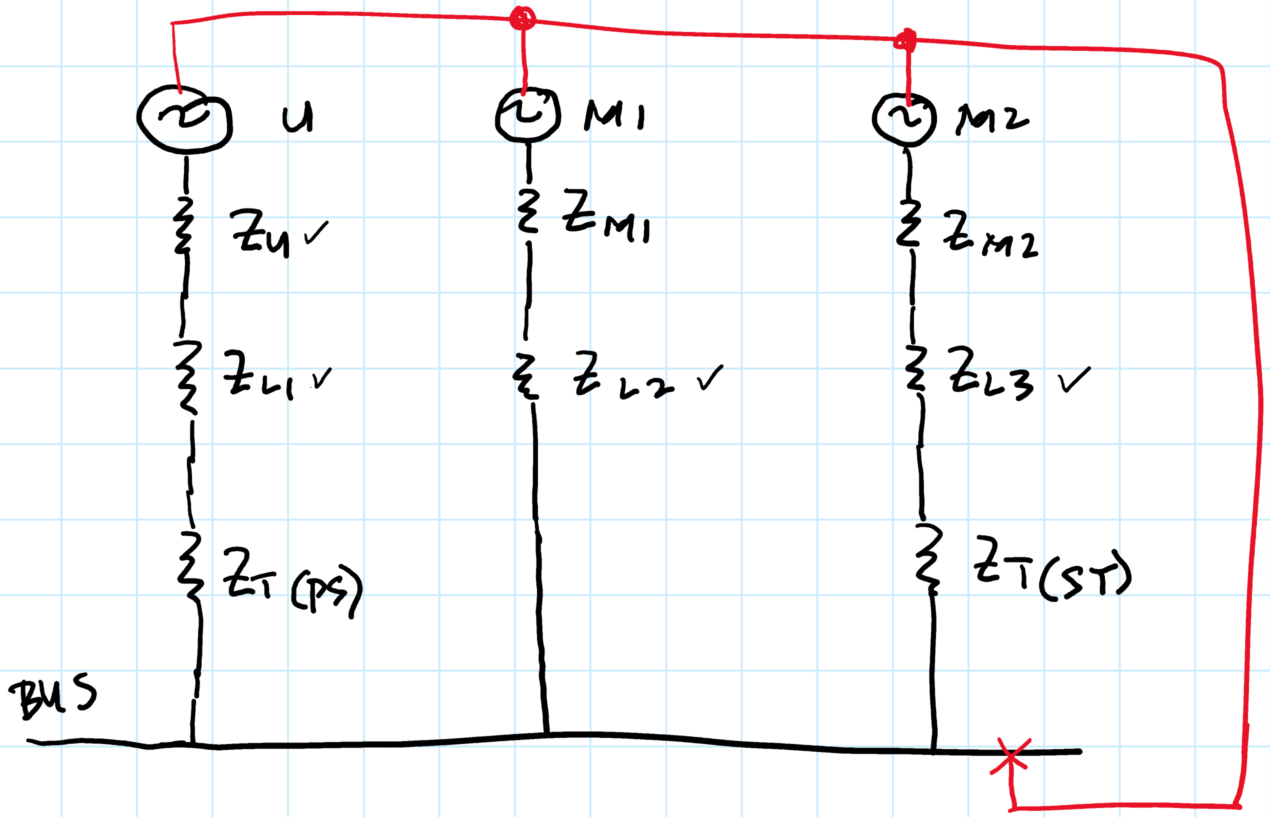
$$= 0.01117 \angle -75.96^\circ \text{ pu}$$

$$I_{3\phi} = 0.01117 \angle -75.96^\circ \times \underline{12028.13} = \boxed{134.35 \angle 75.96^\circ \text{ A}}$$

3ϕ FAULT @ BUS 1

$$I_{3\phi} = E/Z_{1TH} = 1.0\angle 0^\circ / (Z_{1U} + Z_{1L1} + Z_{1T}) = 27.0875 \angle -81.45^\circ \text{ pu}$$

$$I_{3\phi} = 270875 \angle -81.45 \times 12028.13 = \boxed{325{,}811.97 \angle 85.45^\circ \text{ A}}$$



$Z_{1U} = 0.006694 \angle 87.71^\circ \rightarrow A$

$Z_{1L1} = 0.002449 \angle 59.04^\circ \longrightarrow B$

$Z_{1L2} = Z_{1L3} = 89.4771 \angle 75.96^\circ \longrightarrow C$

$Z_{T(PS)} = 0.028 \angle 81.87^\circ \longrightarrow D$

$Z_{T(ST)} = 0.03\,(10/25) = 0.012 \angle 81.87^\circ \longrightarrow E$

$Z_{M1} = Z_{M2} = 0.2\,(10/0.4) = j5\ pu \longrightarrow F$

$$Z_{TH} = \left[\left(\overset{A}{Z_U} + \overset{B}{Z_{1L1}} + \overset{P}{Z_{T(PS)}}\right)^{-1} + \left(\overset{F}{Z_{M1}} + \overset{C}{Z_{1L2}}\right)^{-1} + \left(\overset{F}{Z_{1M2}} + \overset{C}{Z_{1L3}} + \overset{E}{Z_{1T(ST)}}\right)^{-1} \right]^{-1}$$

$Z_{TH} = 0.036889 \angle 81.45^\circ$

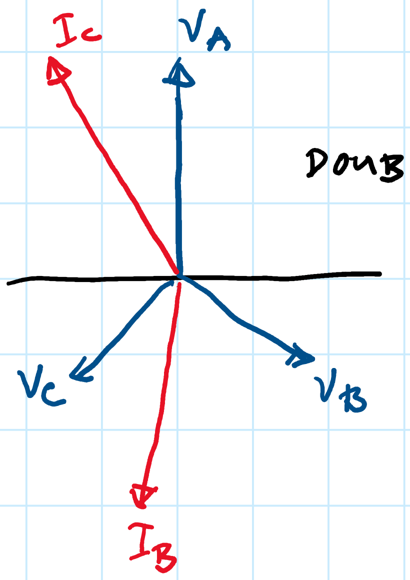
$I_{pu} = 1\angle 0^\circ / Z_{TH} = 27.1086 \angle -81.45^\circ$

$I_F = I_{pu} \times I_b = 27.1086 \times 12028.13$

$= 326{,}065.77\ A$

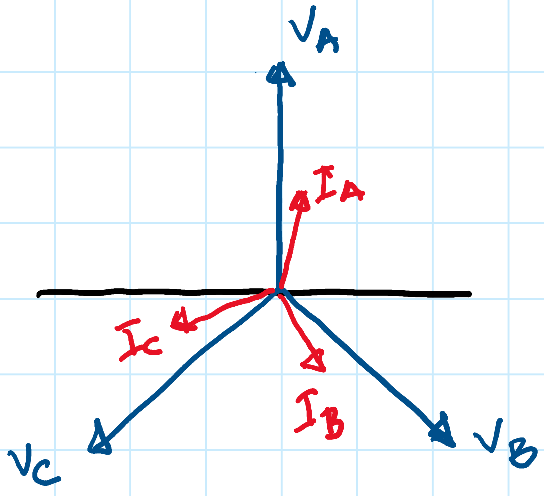
PHASOR VOLTAGE & CURRENT BEHAVIOR DURING FAULTS

DOUBLE LINE TO GROUND

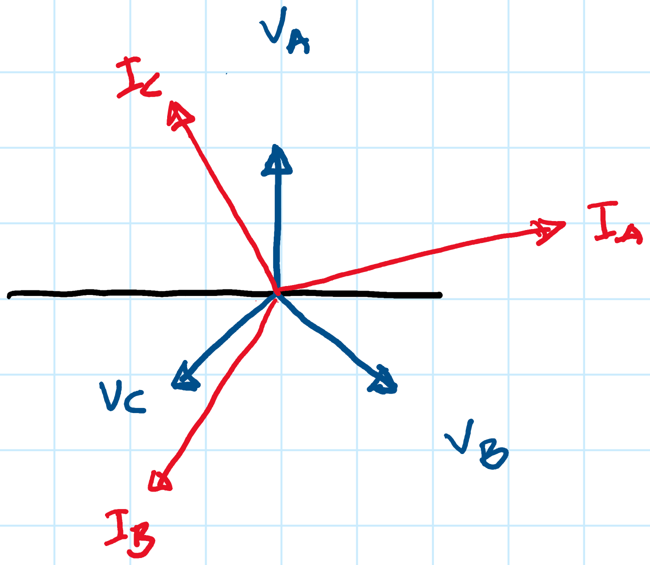


THREE PHASE FAULTS

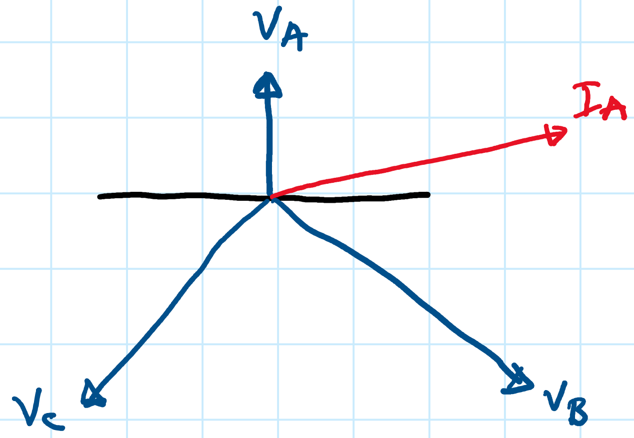
NORMAL OPERATION



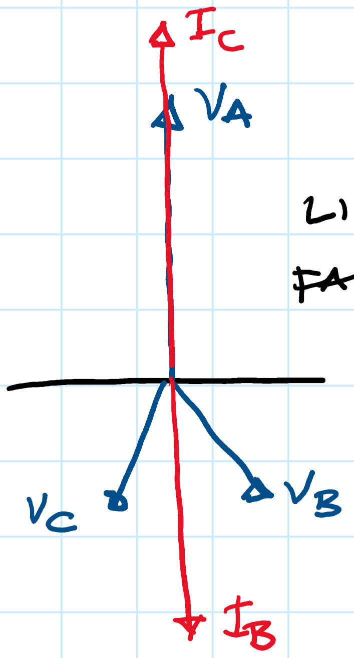
3-PHASE FAULT



SLG

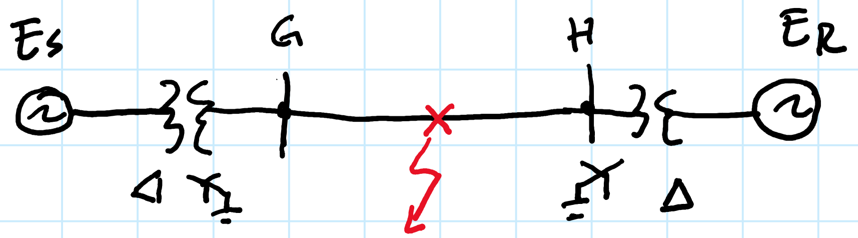


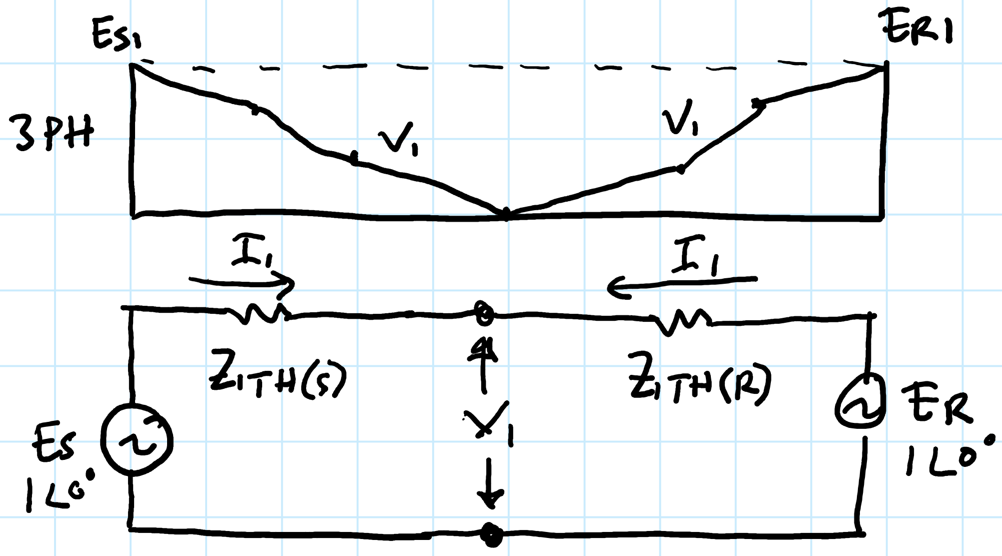
LINE-LINE FAULT

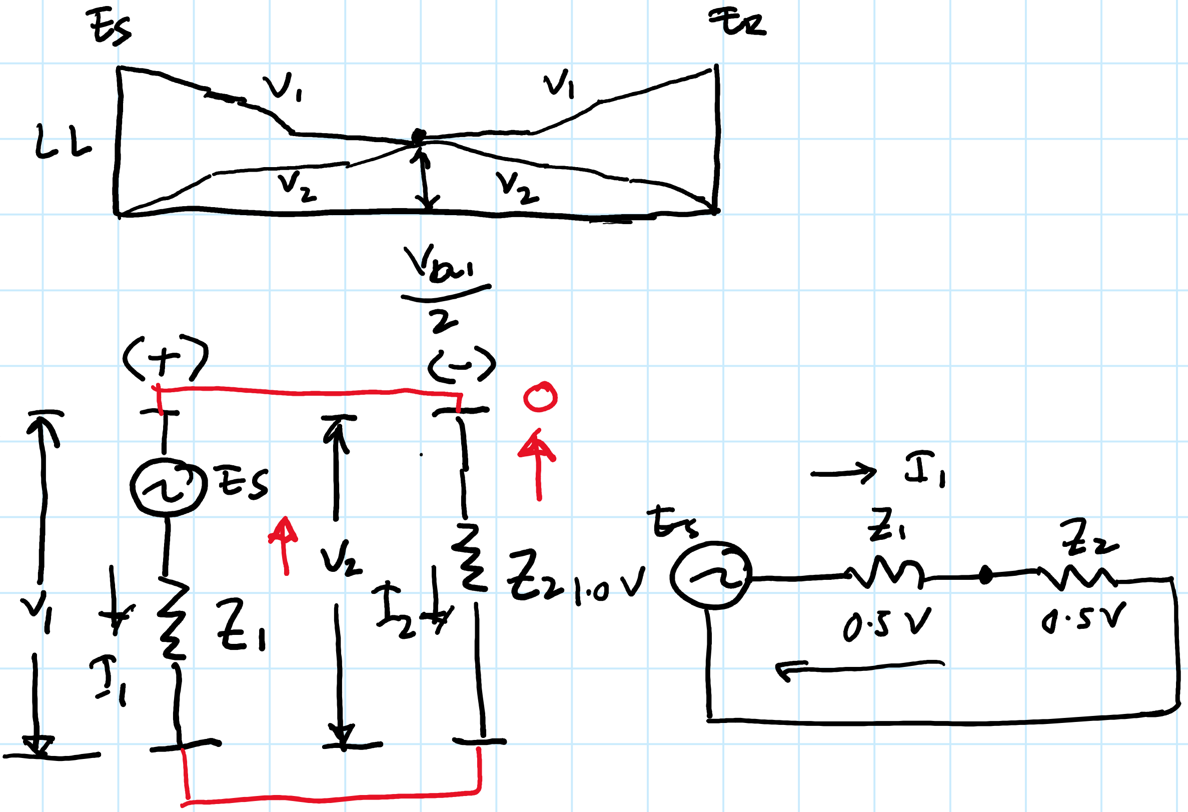


① Voltage decrease
② Current Increase
③ Phase angle b/w V and I increase

SEQUENCE VOLTAGE BEHAVIOR DURING FAULTS

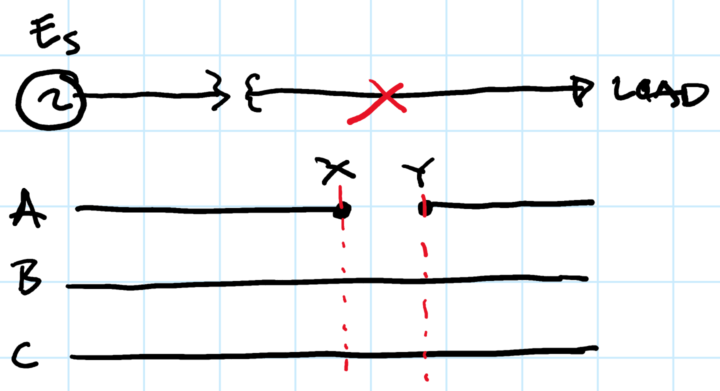


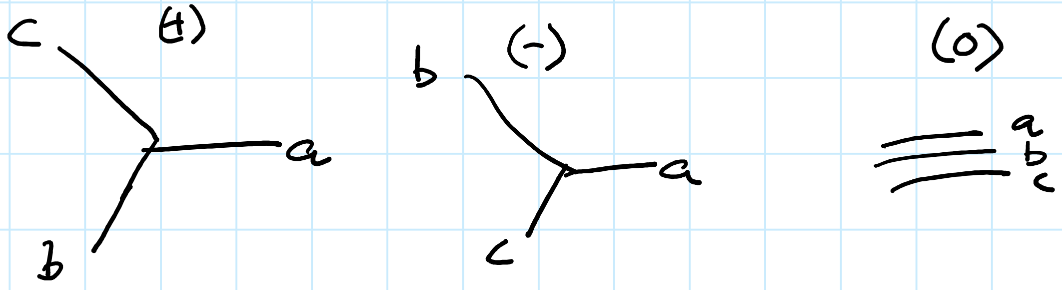




$Z_1 = Z_2$

SERIES FAULT (ONE-PHASE OPEN)





BOUNDARY CONDITIONS

$I_A = 0 \quad \underline{V_{Bxy} = 0} \quad \underline{V_{Cxy} = 0}$

① $3V_0 = V_A + V_B + V_C$

② $3V_1 = V_A + aV_B + a^2V_C$

③ $3V_2 = V_A + a^2V_B + aV_C$

} Phase A as Ref

$3V_0 = V_A + \cancel{V_B} + \cancel{V_C}$

$3V_1 = V_A + \cancel{aV_B} + \cancel{a^2V_C}$

$3V_2 = V_A + \cancel{a^2V_B} + \cancel{aV_C}$

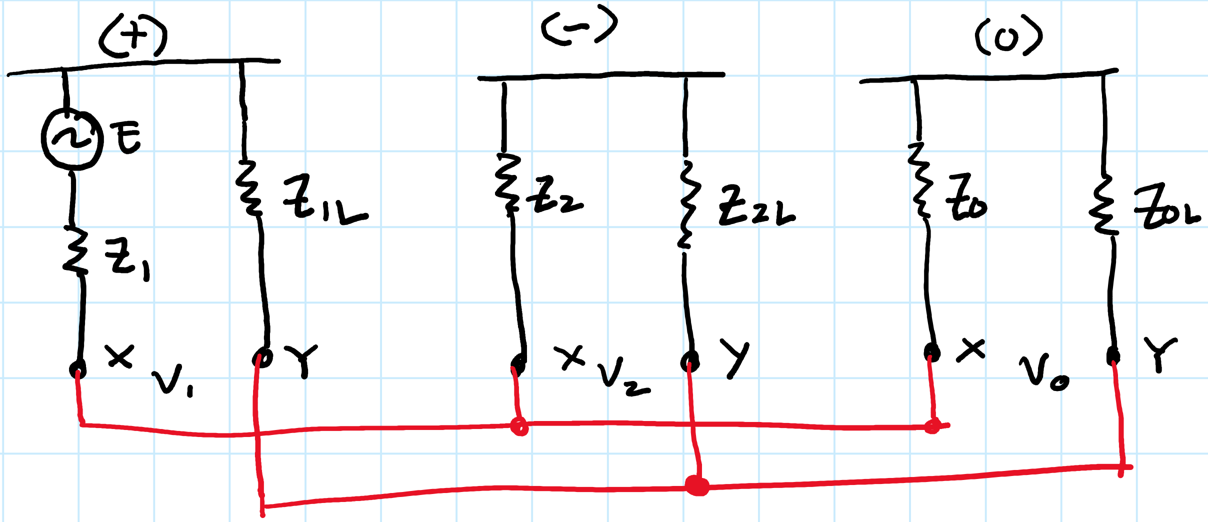
④ $3V_0 = 3V_1 = 3V_2 = V_A \rightarrow V_0 = V_1 = V_2 = 1/3\,V_A$

Phase A as Ref

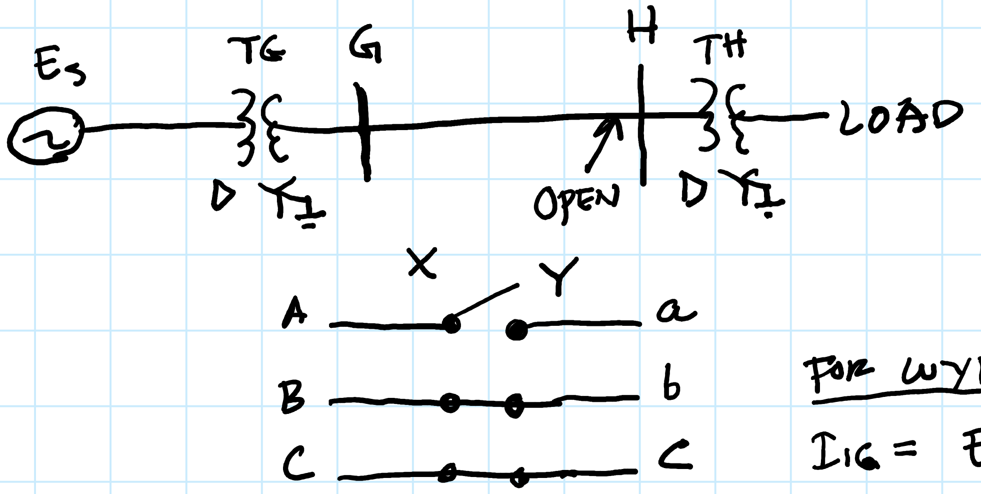
$V_A = V_{a1} + V_{a2} + V_{a0} = V_1 + V_2 + V_0$

$V_B = V_{b1} + V_{b2} + V_{b0} = a^2V_1 + aV_2 + V_0 \qquad a^2$

$V_C = V_{c1} + V_{c2} + V_{c0} = aV_1 + a^2V_2 + V_0 \qquad a$



SERIES FAULT (ONE-PHASE OPEN)



FOR WYE

$I_{1G} = E_S / [Z_1 + Z_2 // Z_0]$

$I_{2G} = \dfrac{-I_{1G} \times Z_0}{Z_2 + Z_0}$

$I_{0G} = - \dfrac{I_{1G} \times Z_2}{Z_2 + Z_0}$

ZERO SEQUENCE NETWORK IS NOT INCLUDED DUE TO OPENING @ BUS H

FOR DELTA

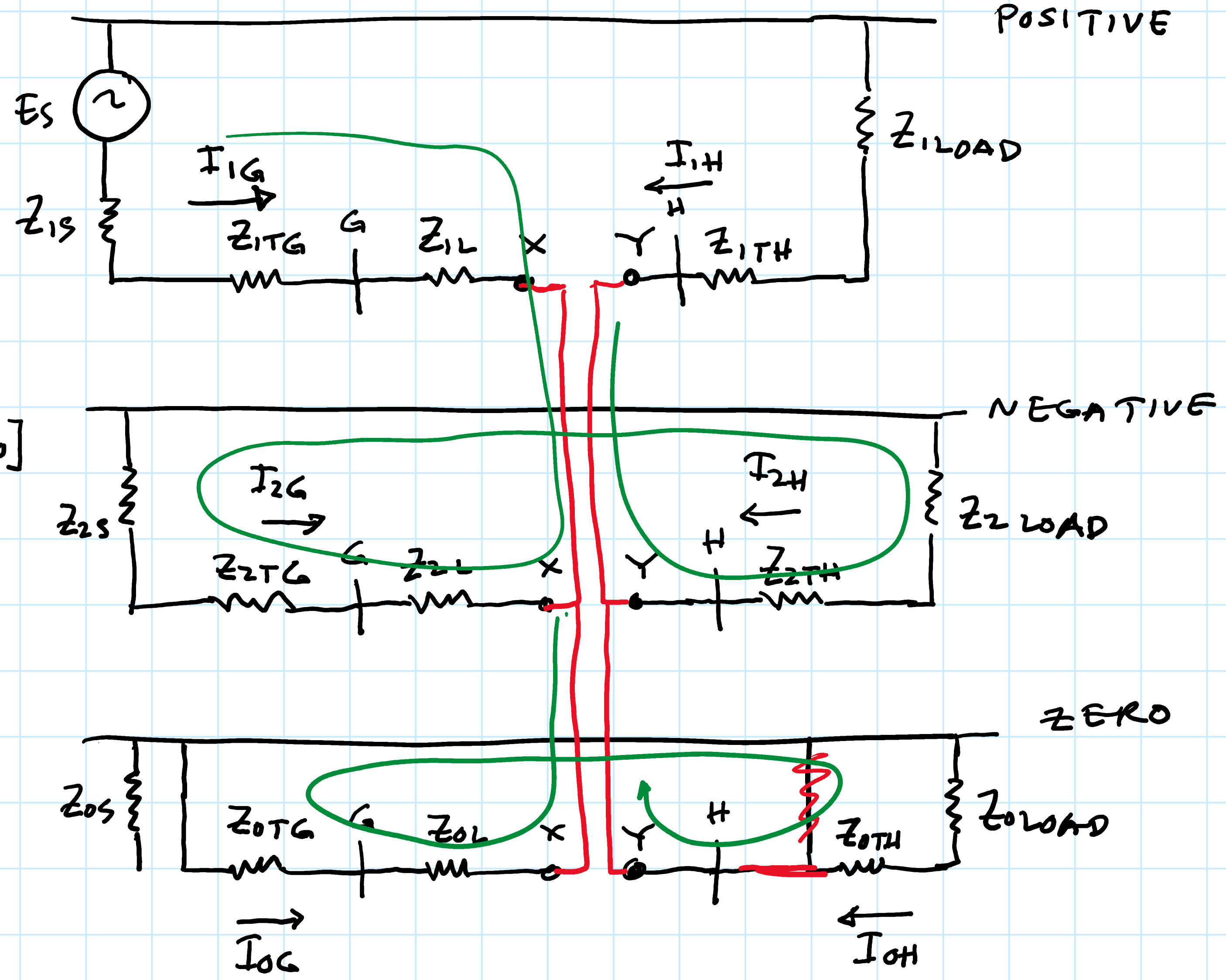
$I_{1G} = -I_{2G} = E_S / (Z_1 + Z_2)$

$Z_1 = Z_{1TG} + Z_{1L} + Z_{1TH} + Z_{1LOAD} + Z_{1S}$

$Z_2 = Z_{2S} + Z_{2TG} + Z_{2L} + Z_{2TH} + Z_{2LOAD}$

$I_{0G} = 0$

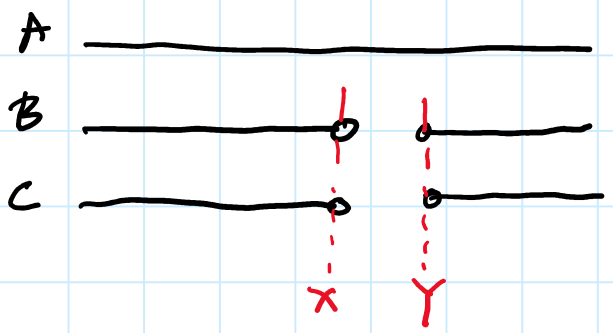
IF $Z_1 = Z_2$ THEN $I_{1G} = \dfrac{I_{PRE\text{-}FAULT}}{2}$

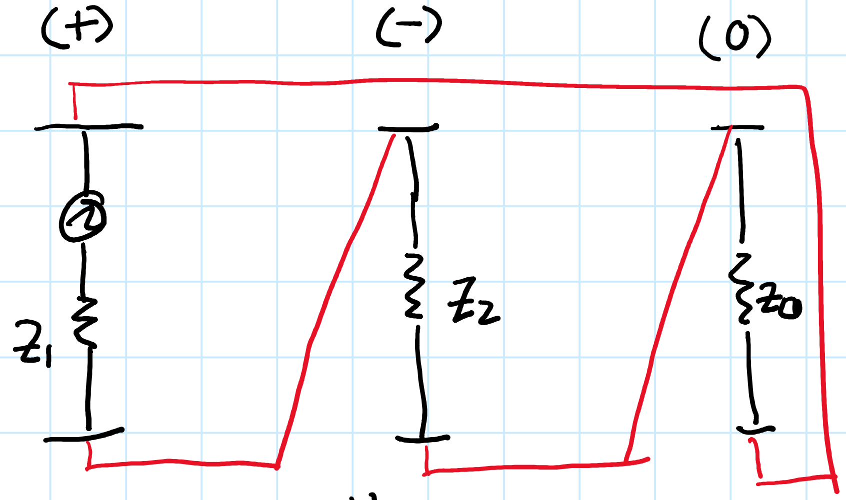


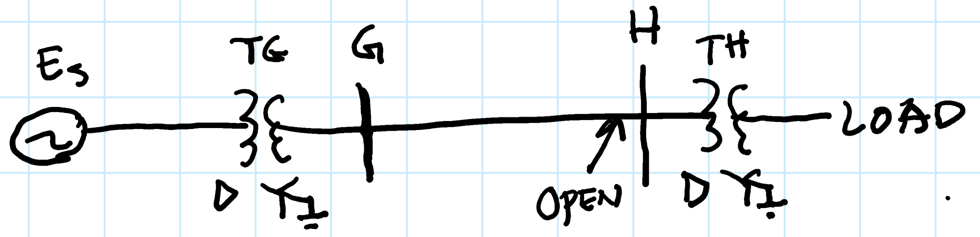
FOR DELTA: $I_2 = -I_1 \therefore \left|\dfrac{I_2}{I_1}\right| = 100\%$

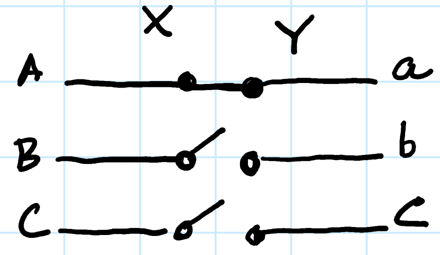
FOR WYE: $I_2 = -I_1 \left(\dfrac{Z_0}{Z_2+Z_0}\right) \therefore \left|\dfrac{I_2}{I_1}\right| \approx 50\%$ TO 100%

SERIES FAULT (TWO-PHASES OPEN)









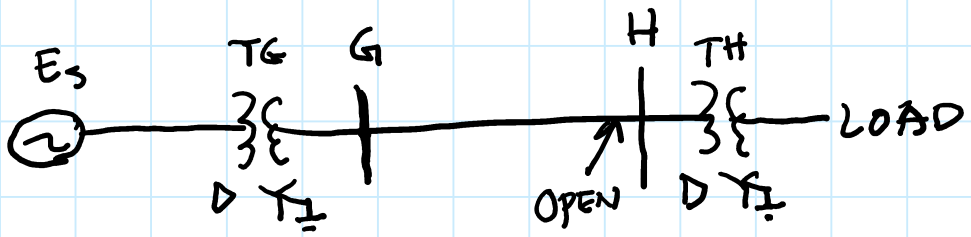
BOUNDARY CONDITIONS

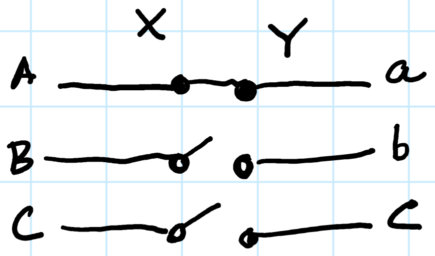
$I_B = 0 \quad I_C = 0 \quad V_{Axy} = 0$

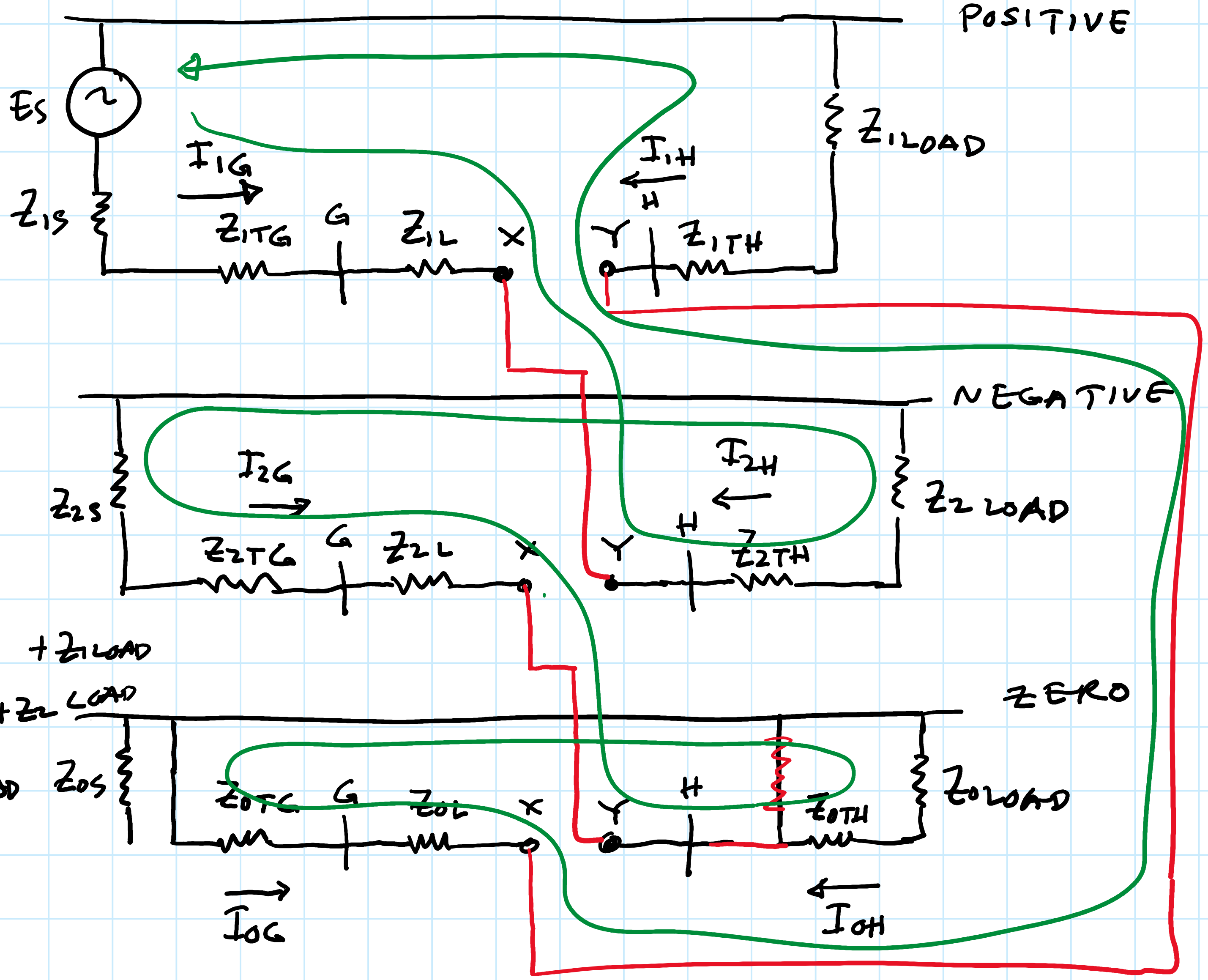
$$3I_0 = I_A + \cancel{I_B} + \cancel{I_C}$$
$$3I_1 = I_A + \cancel{aI_B} + \cancel{a^2 I_C}$$
$$3I_2 = I_A + \cancel{a^2 I_B} + \cancel{a I_C}$$

$$3I_0 = 3I_1 = 3I_2 = I_A$$
$$I_0 = I_1 = I_2 = 1/3\, I_A$$

SERIES FAULT (TWO-PHASE OPEN)







FOR DELTA

$I_{1G} = I_{2G} = I_{0G} = 0$

$Z_1 = Z_{1S} + Z_{1TG} + Z_{1L} + Z_{1TH} + Z_{1LOAD}$

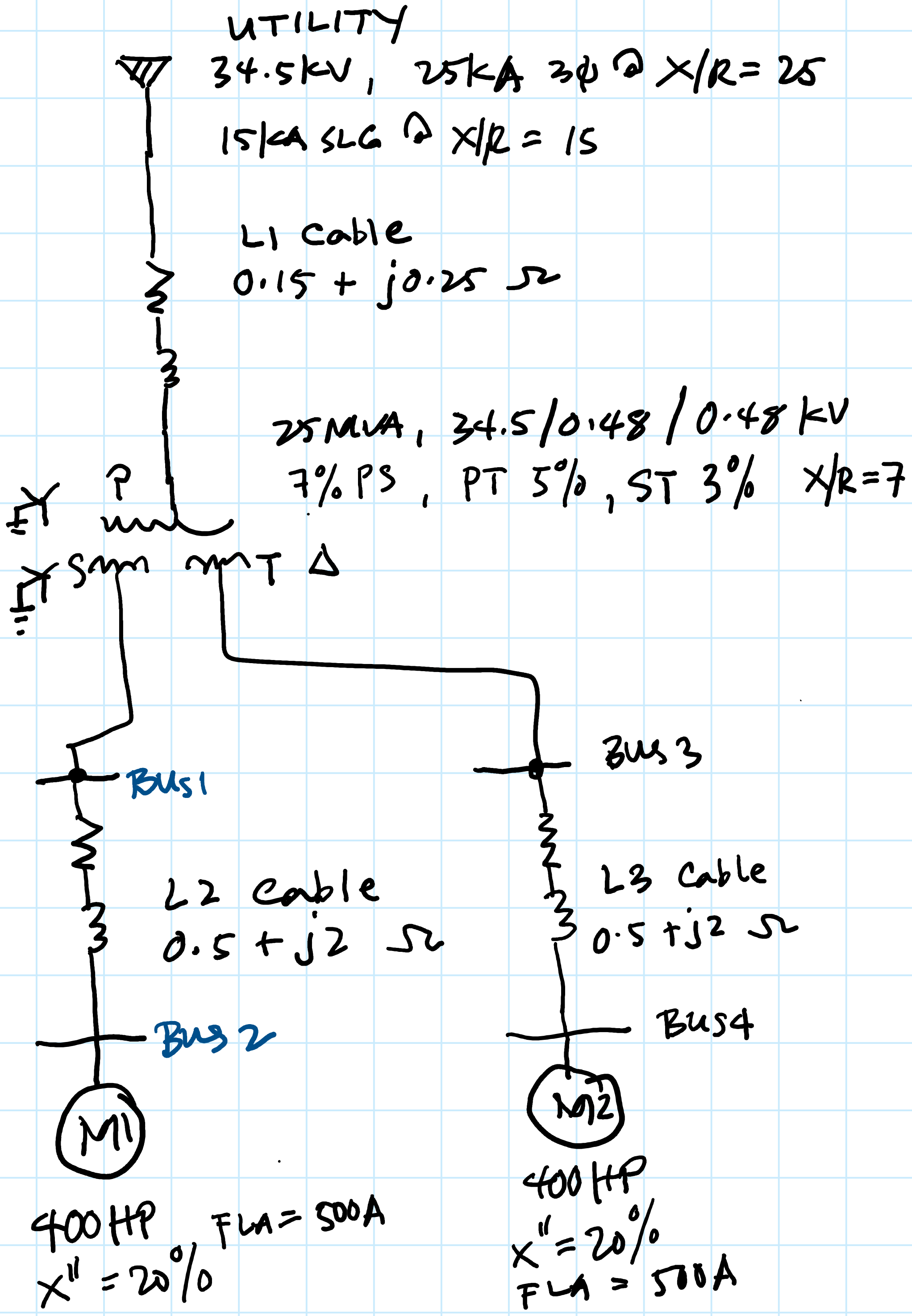
$Z_2 = Z_{2S} + Z_{2TG} + Z_{2L} + Z_{2TH} + Z_{2LOAD}$

WYE → $Z_0 = Z_{0TG} + Z_{0L} + Z_{0TH} + Z_{0LOAD}$

FOR WYE

$I_{1G} = I_{2G} = I_{0G}$

$I_{1G} = Es / (Z_1 + Z_2 + Z_0)$



CHAPTER 5 ASSIGNMENT

① Using the same system that we used as example in Chapter 5 discussion, calculate for the momentary fault current at BUS1 if the fault types are:

A) Line to line fault
B) Single-line to ground fault
C) Double line to ground fault

② Also, draw the positive, negative and zero-sequence networks to aid in your calculations and analysis.

③ Calculate for the following 3-phase fault currents @ BUS1:

A) Interrupting current (1.5 to 4 cycle) using motor M1 and M2 transient reactance of X' = 50%
B) Steady state fault current (≥ 30 cycle). Assume that all motor contributions have decayed to zero.