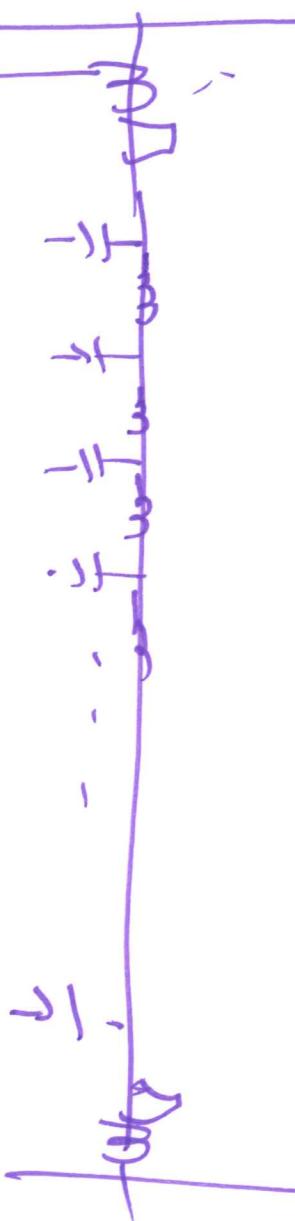
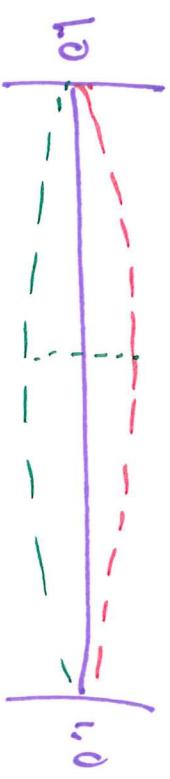


ECE 526

PROTECTION OF
POWER SYSTEMS II

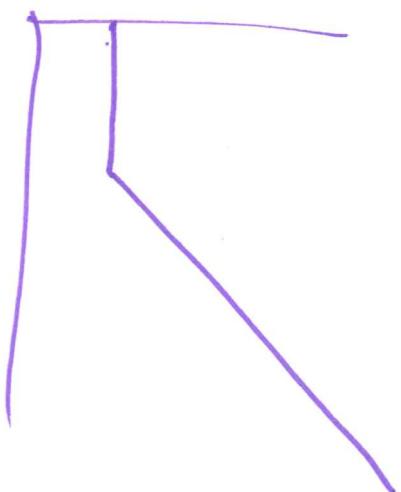
SESSION no. 13



$$|\bar{I}_{SA} + \bar{I}_{en}| = 0$$

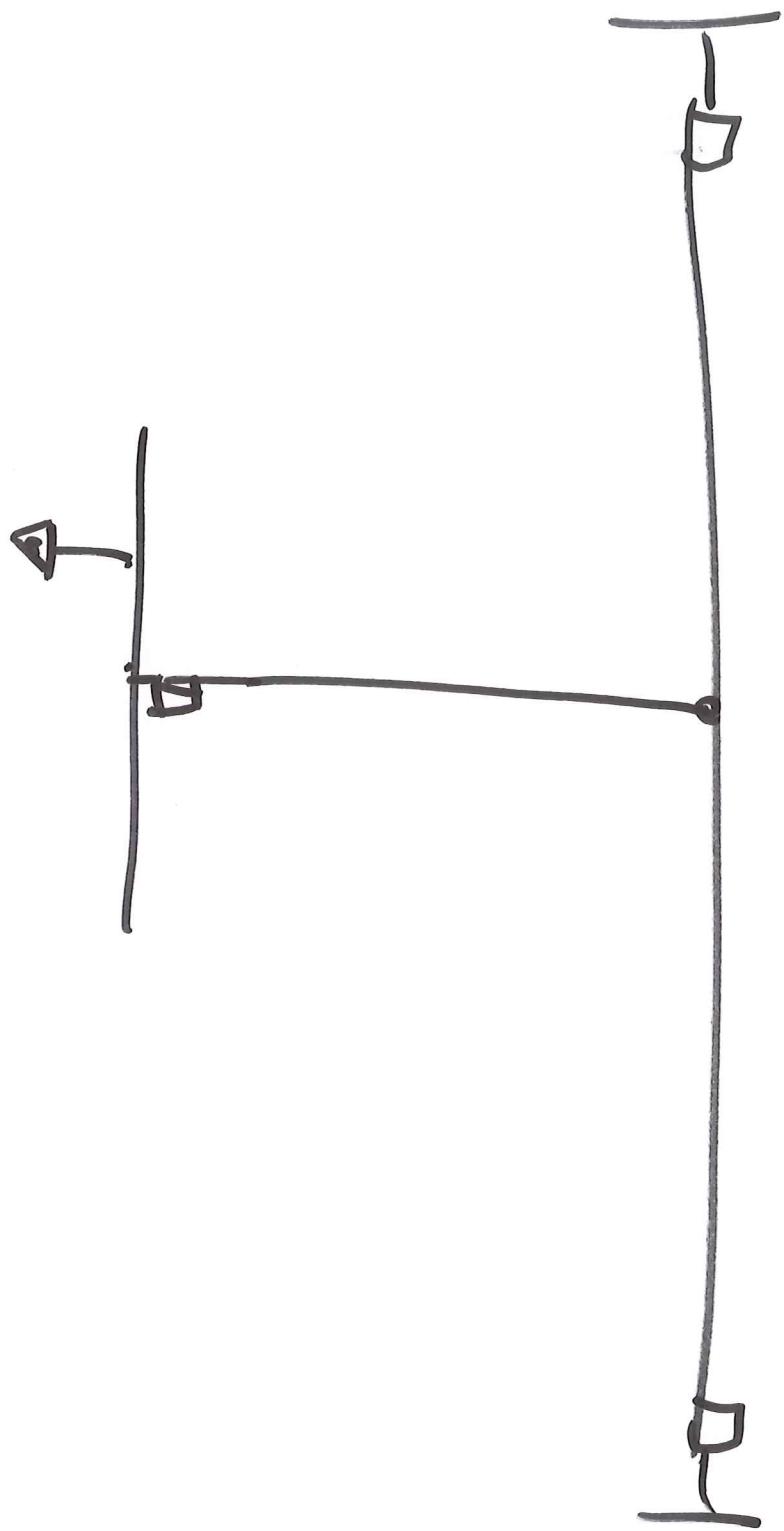
\bar{I}

$- I_{HAC}$

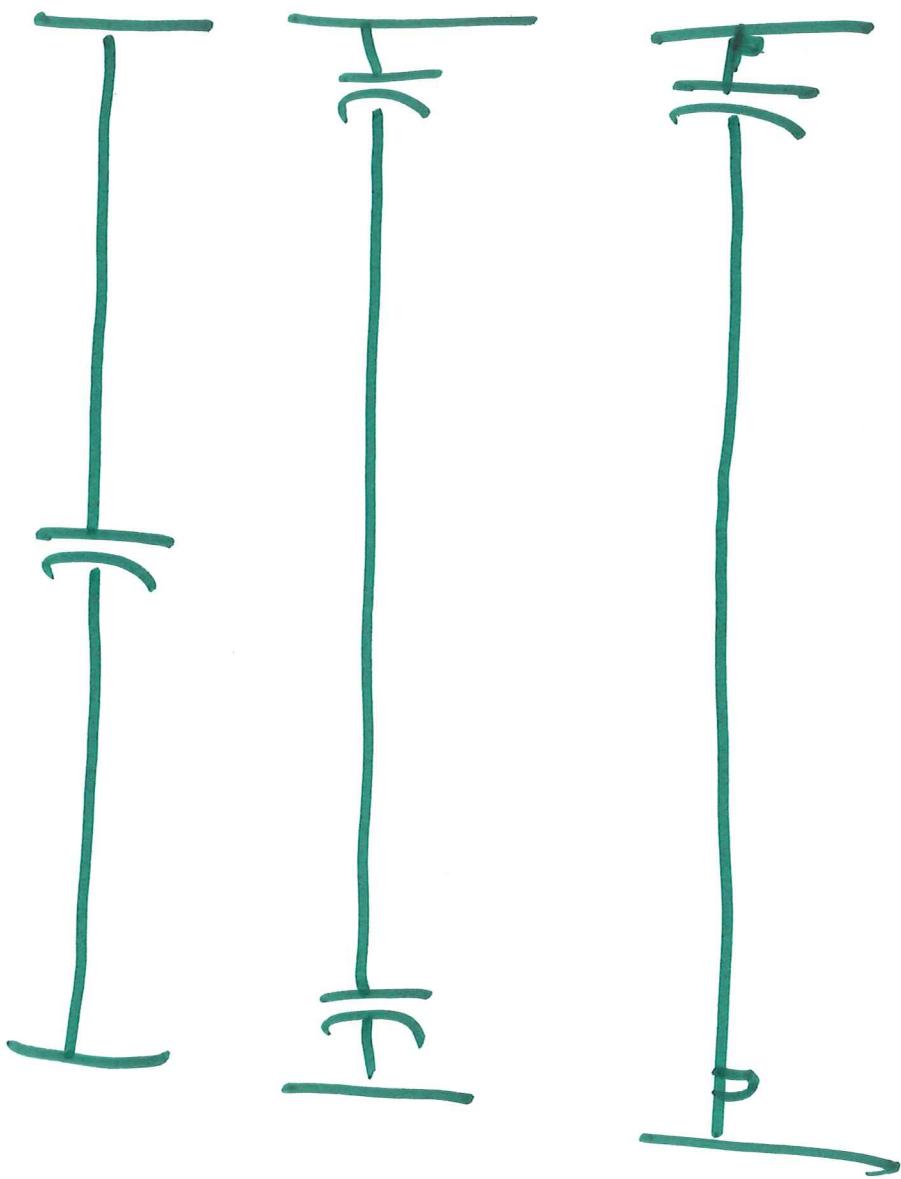


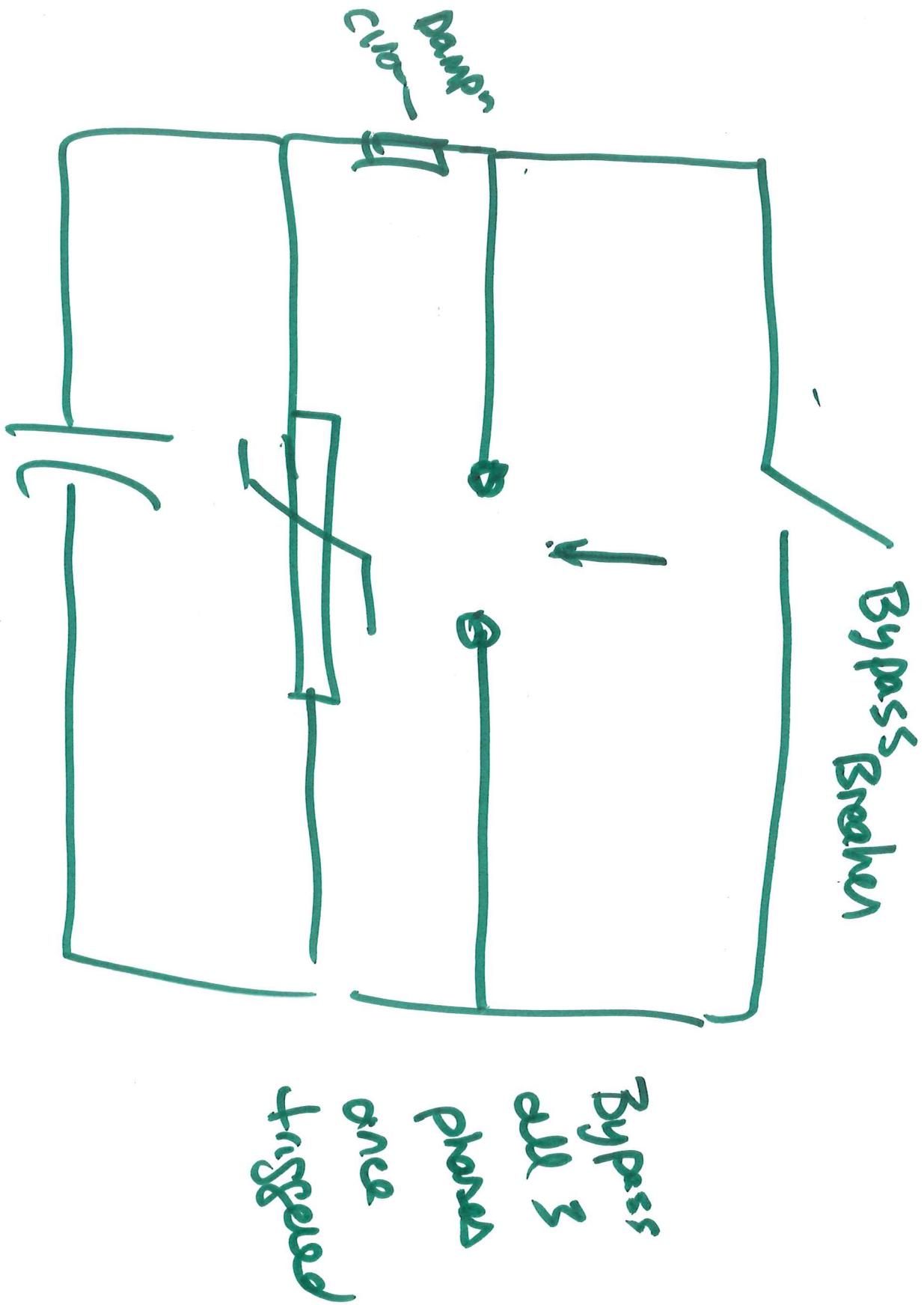
$$\frac{I_e}{I_s}$$

1. Series Capacitors
2. Single Pole Trip
3. Mutual coupling
4. Power Swings
5. Fault Location
6. Multi-terminal lines

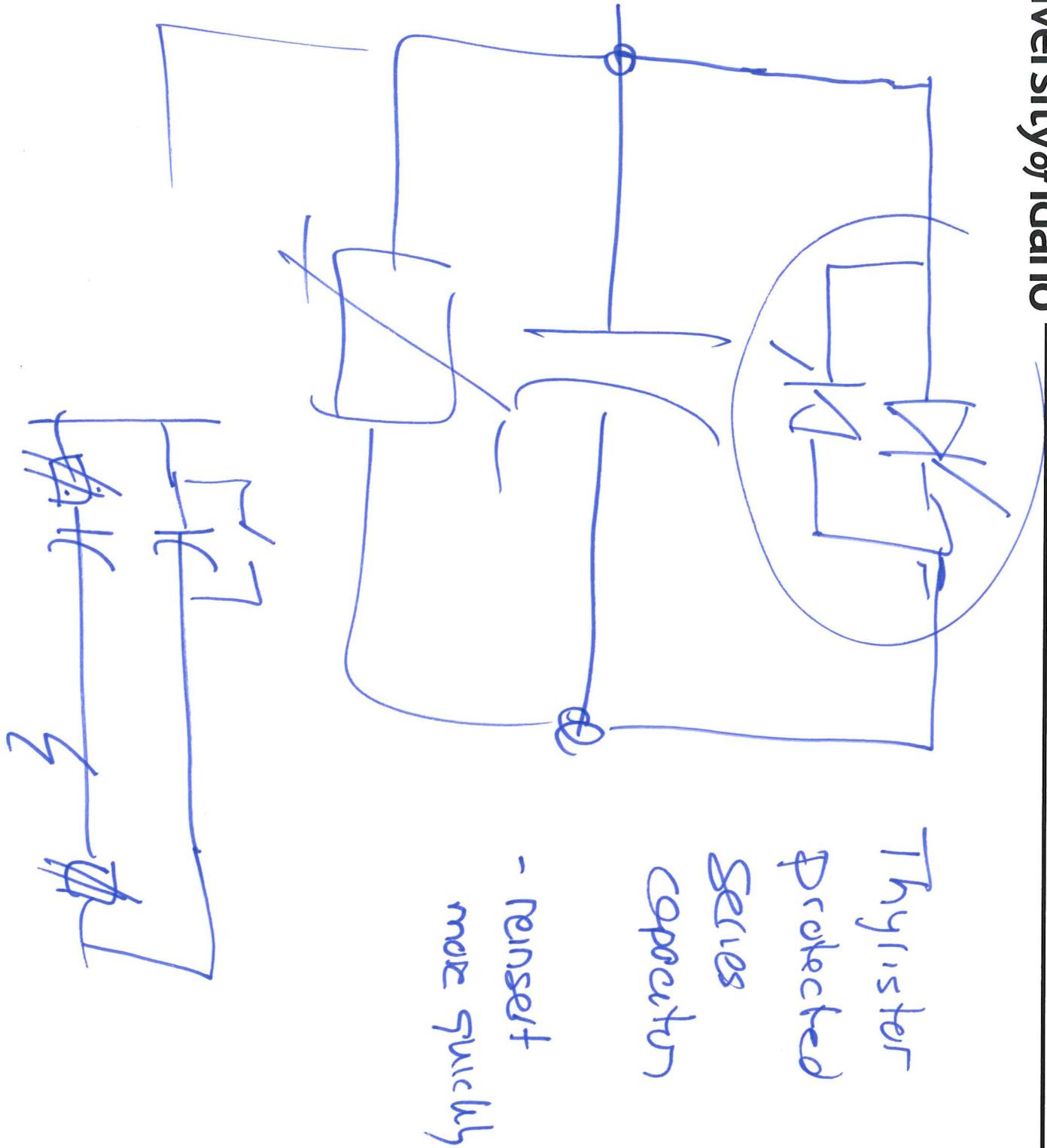


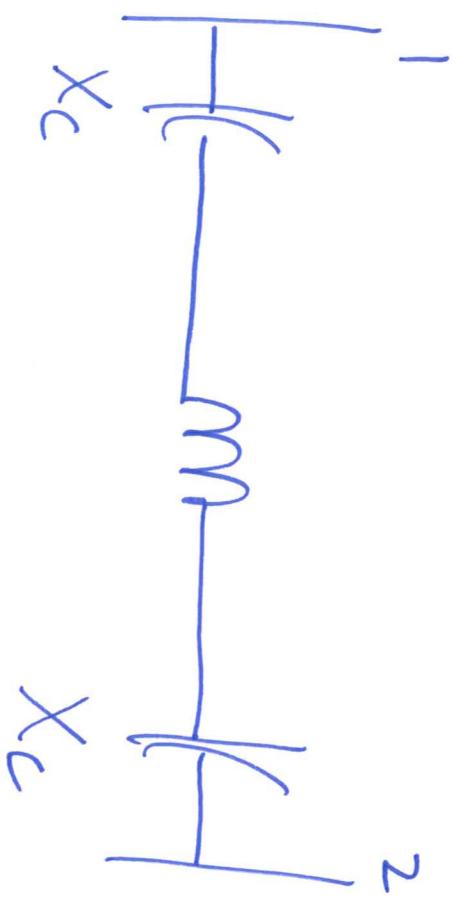
Series Capacitors





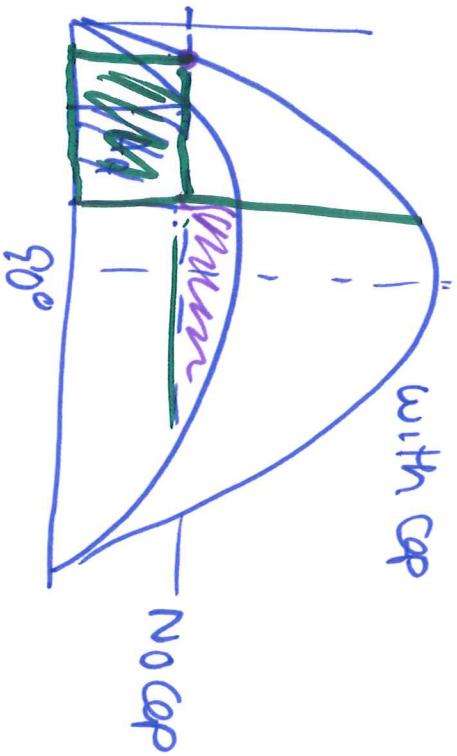






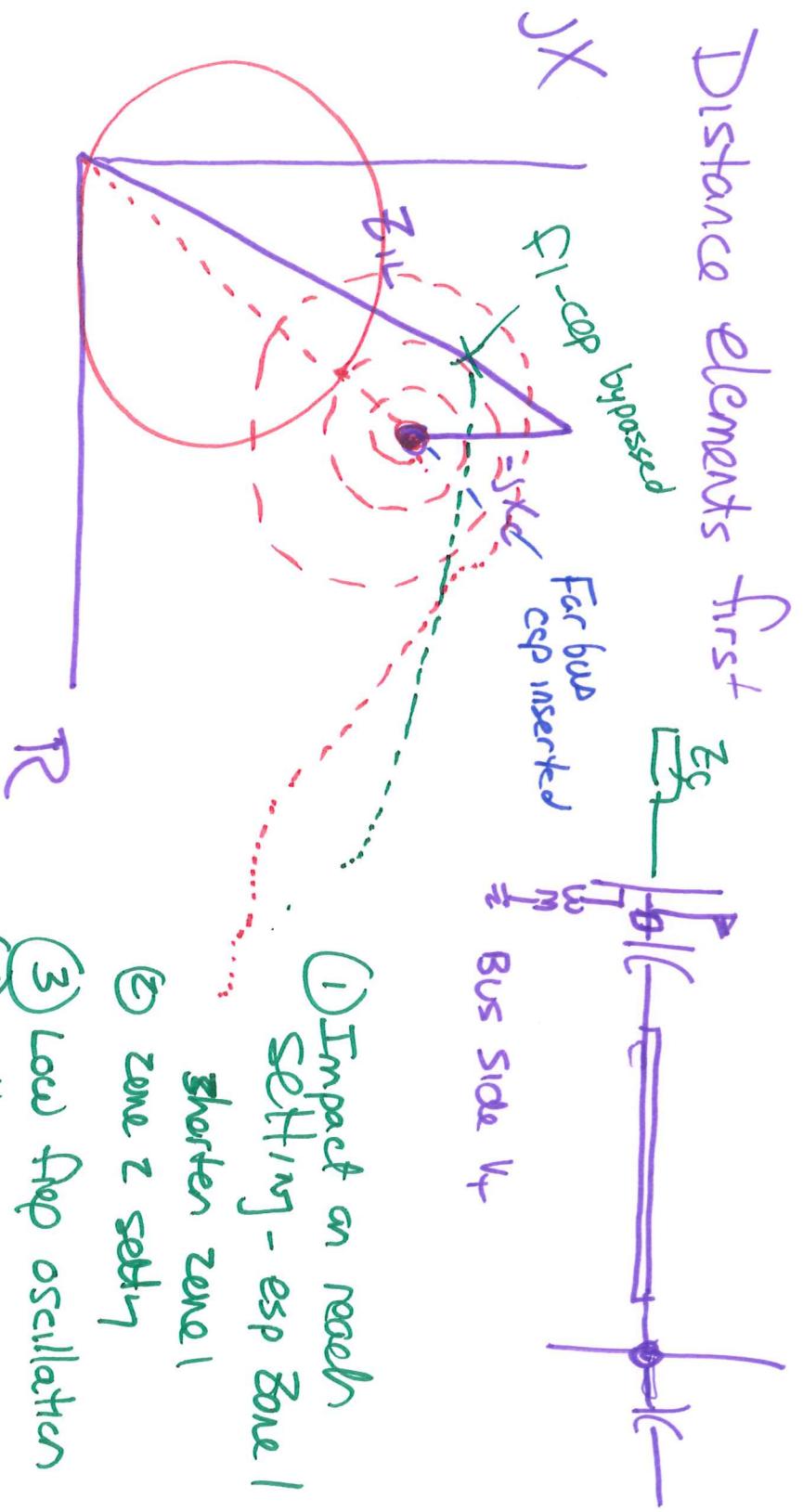
$$P_{12} \approx \frac{3(V_{B1}|V_{B2}| \sin(\theta_B) - \phi_{B2})}{X_L - 2X_C}$$

approx since
neglect R
with cap



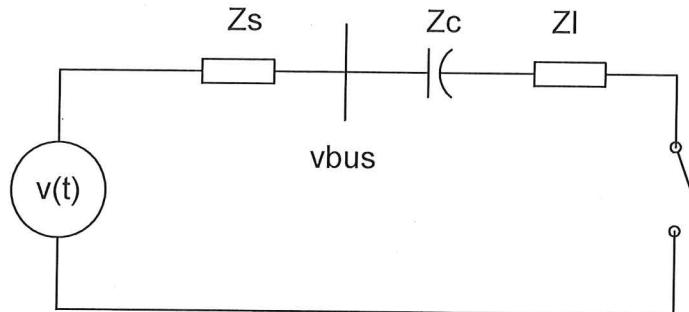
Challenges for line protection

- which elements ?
- Line current differential vs distance



Series capacitor low frequency resonance

- Fault at the far end of the line.



$$\omega_s := 2\pi \cdot 60\text{Hz}$$

$$\omega_s = 376.9911 \frac{1}{\text{s}} \text{ rad/s}$$

$$Z_{S1} := 1\text{ohm} \cdot e^{j \cdot 85^\circ \text{deg}}$$

$$Z_{S1} = (0.0872 + 0.9962i)\Omega \quad Z_{S2} := Z_{S1}$$

$$Z_{S0} := 1\text{ohm} \cdot e^{j \cdot 80^\circ \text{deg}}$$

$$Z_{S0} = (0.1736 + 0.9848i)\Omega$$

$$Z_{L1} := 4\text{ohm} \cdot e^{j \cdot 80^\circ \text{deg}}$$

$$Z_{L1} = (0.6946 + 3.9392i)\Omega \quad Z_{L2} := Z_{L1}$$

$$Z_{L0} := 12\text{ohm} \cdot e^{j \cdot 75^\circ \text{deg}}$$

$$Z_{L0} = (3.1058 + 11.5911i)\Omega$$

$$Z_C := \frac{4\text{ohm}}{3} \cdot e^{-j \cdot 90^\circ \text{deg}}$$

$$Z_C = -1.3333i\Omega \quad 33\% \text{ compensation}$$

- Equivalent impedances for SLG fault analysis (time domain equivalent response, using symmetrical components)

$$R_{\text{equiv}} := \underbrace{\text{Re}(Z_{S1})}_{\text{Pos}} + \underbrace{\text{Re}(Z_{L1})}_{\text{Neg}} + \underbrace{\text{Re}(Z_{S2})}_{\text{Zero}} + \text{Re}(Z_{L2}) + \text{Re}(Z_{S0}) + \text{Re}(Z_{L0})$$

$$R_{\text{equiv}} = 4.843\Omega$$

$$X_{\text{Lequiv}} := \text{Im}(Z_{S1}) + \text{Im}(Z_{L1}) + (\text{Im}(Z_{S2}) + \text{Im}(Z_{L2})) + \text{Im}(Z_{S0}) + \text{Im}(Z_{L0})$$

$$X_{\text{Lequiv}} = 22.4468\Omega$$

$$L_{\text{equiv}} := \frac{X_{\text{Lequiv}}}{\omega_s}$$

$$L_{\text{equiv}} = 59.5419 \cdot \text{mH}$$

$$X_{C1} := -\text{Im}(Z_C) \quad X_{C1} = 1.3333 \Omega \quad X_{C2} := X_{C1} \quad X_{C0} := X_{C1}$$

$$C_{\text{eff_slg}} := \frac{1}{\omega_s \cdot (X_{C1} + X_{C2} + X_{C0})} \quad C_{\text{eff_slg}} = 663.15 \cdot \mu\text{F}$$

$$V_{\text{src_pk}} := \frac{\sqrt{2} \cdot 120 \text{V}}{\sqrt{3}} \quad V_{\text{src_pk}} = 97.9796 \text{V} \quad \theta_{vs} := 0$$

$$t := 0, 0.0001 \text{sec..} \frac{10}{60 \text{Hz}}$$

peak L-6

$$\left(\frac{R_{\text{equiv}}}{2 \cdot L_{\text{equiv}}} \right)^2 - \frac{1}{L_{\text{equiv}} \cdot C_{\text{eff_slg}}} = -2.3672 \times 10^4 \frac{1}{\text{s}^2}$$

Negative result, so underdamped circuit.

$$\alpha := \frac{-R_{\text{equiv}}}{2 \cdot L_{\text{equiv}}} \quad \omega_d := \sqrt{\left(\frac{1}{L_{\text{equiv}} \cdot C_{\text{eff_slg}}} \right) - \left(\frac{R_{\text{equiv}}}{2 \cdot L_{\text{equiv}}} \right)^2} \quad \omega_d = 153.8576 \cdot \frac{\text{rad}}{\text{s}}$$

$$f_d := \frac{\omega_d}{2 \cdot \pi} \quad f_d = 24.4872 \cdot \text{Hz}$$

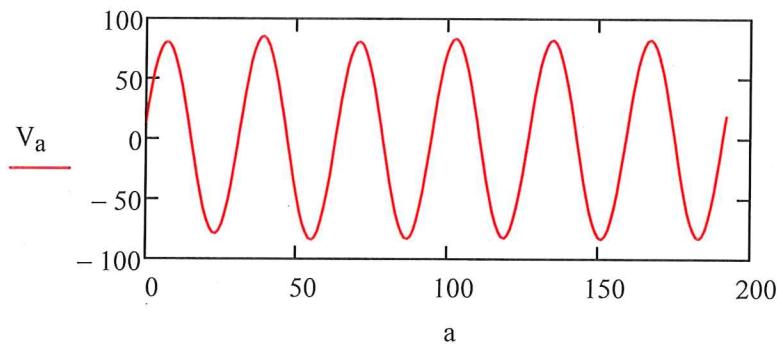
Particular solution:

$$\eta := \text{atan} \left(\frac{\frac{1}{\omega_s \cdot C_{\text{eff_slg}}} - \omega_s \cdot L_{\text{equiv}}}{R_{\text{equiv}}} \right) \quad \eta = -75.2897 \cdot \text{deg}$$

$$V_{\text{src}} := \frac{120 \text{V}}{\sqrt{3}} \quad \theta_{vs} := 0 \quad \phi := \eta + 90 \text{deg}$$

- SLG fault (we need $3 \cdot I_0$)

$$i_{L-p}(t) := \left[\frac{\sqrt{2} \cdot (3V_{\text{src}})}{\sqrt{R_{\text{equiv}}^2 + \left(\frac{1}{\omega_s \cdot C_{\text{eff_slg}}} - \omega_s \cdot L_{\text{equiv}} \right)^2}} \right] \cdot \sin(\omega_s \cdot t + \phi + \eta)$$

$$\text{V}_{\text{av}} := \begin{cases} \text{dt1} \leftarrow \frac{1}{32} \cdot \frac{1}{60} \\ \text{for } x \in 0, 1..320 \\ \quad \quad \quad t1 \leftarrow x \cdot \text{dt1} \\ \quad \quad \quad C_x \leftarrow v_{A_relay}(t1 \cdot \text{sec}) \\ \end{cases} \quad C$$


- Digital filter

$$V_{ph} := \begin{cases} \text{for } x \in 0, 1..(N) \cdot 16 \\ \quad \quad \quad M \leftarrow \text{submatrix}(V, x \cdot 2, x \cdot 2 + 31, 0, 0) \\ \quad \quad \quad \text{val}_x \leftarrow \frac{2}{K \cdot \sqrt{2}} \cdot \sum_k \left(M_k \cdot e^{-i \cdot 2 \cdot \pi \cdot \frac{k}{K}} \right) & Z_0 := Z_{L0} + Z_C \\ \end{cases} \quad Z_1 := Z_{L1} + Z_C$$

val

~~cost~~ Fourier filter

Impedance Spiral for AG fault

