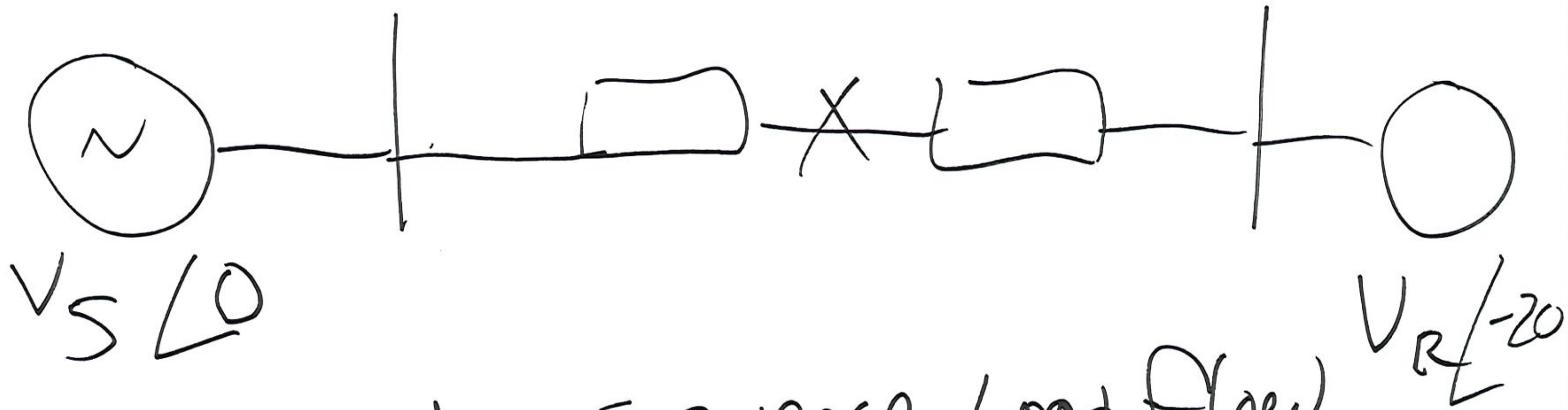
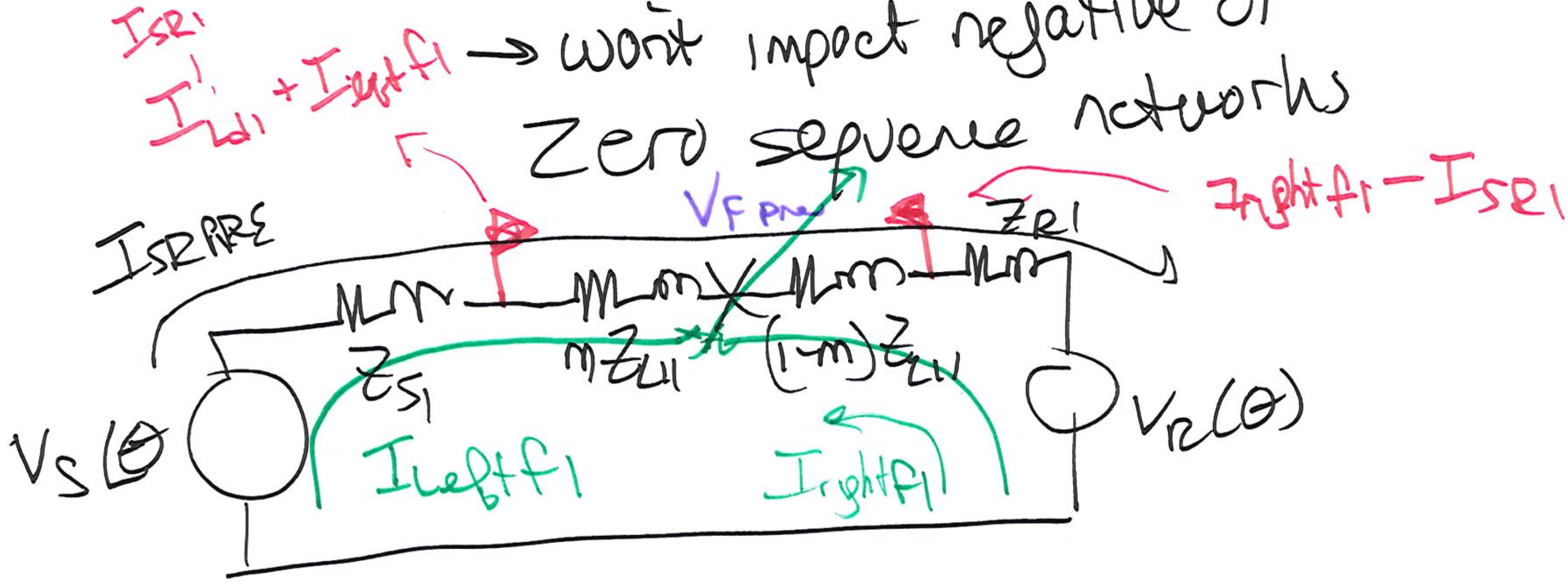
University of Idaho

ECE 523
Symmetrical Components

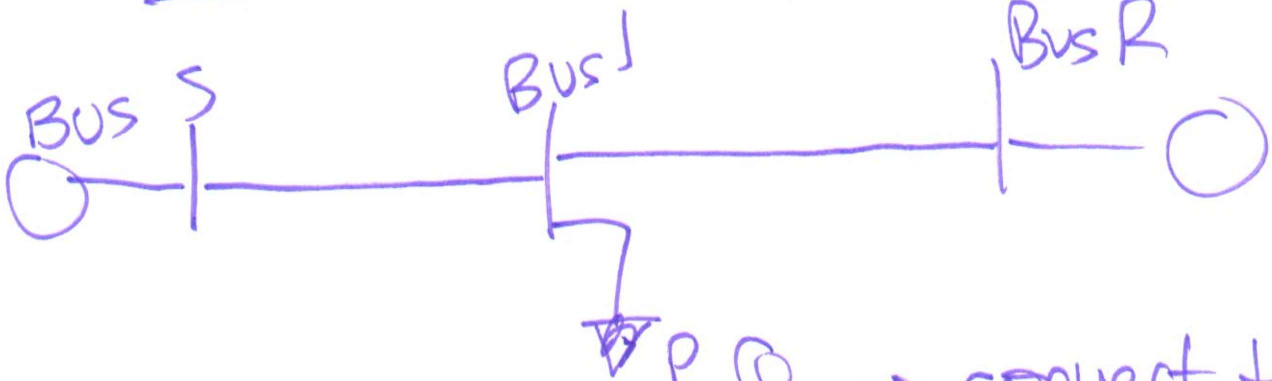
Session 16



→ Positive sequence Load flow → won't impact negative or Zero sequence networks



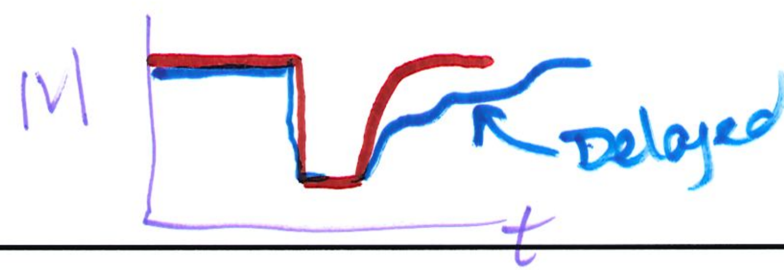
Load connected to a Bus



P, Q → convert to Impedance and put in Y_{Bus}

Load models?

Fault Induced Delayed Voltage Recovery



Delayed due stalled motors ⇒ air conditioners

ZIP - constant impedance → %

constant current → %

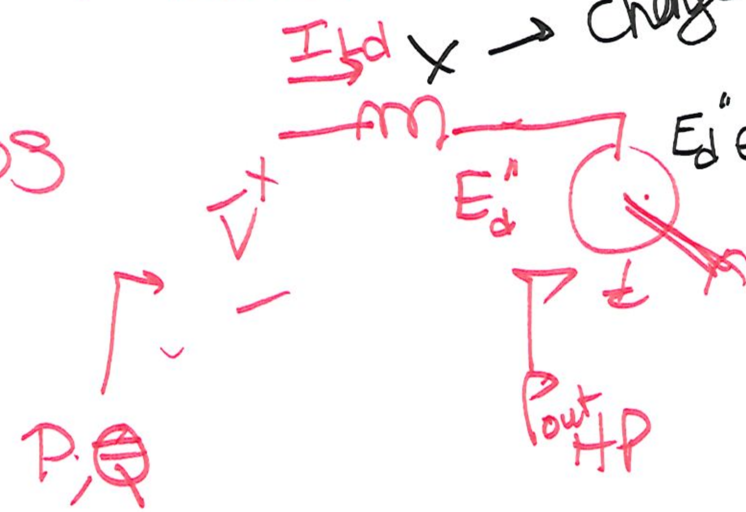
constant power → %

motor load

↳ fault model

$X'' \rightarrow$ change of base

POS



$E_d'' e^{-t/\tau}$

$$P_{in\,motor} = \frac{P_{out\,HP}(W)}{\eta}$$

$Q \Rightarrow pf$

stalled motor in fault study?

→ no longer rotating

$E_d' \to 0$

Z I P

40% 20% 40%

calculate impedance based on type

(1) const P,Q (P, pf)

$$\bar{S}_{rated\,pu} = \bar{V}\bar{I}^* = \bar{V}\left(\frac{\bar{V}}{\bar{Z}}\right)^*$$

$$= \frac{|V|^2}{\bar{Z}^*}$$

$$\bar{Z} = \frac{|V|^2}{(\bar{S}_{rated})^*}$$

$|V|^2$ ← from power flow results

$\bar{S}_{rated}$ ← from power flow setting

$|Z|$ depends on prefault voltage

② constant current load

→ find $\bar{I}$ at rated conditions

1.0 pu voltage & S_{rated}

$\bar{S} = \bar{V}\bar{I}^*$ → solve for $\bar{I}_{rated}$

($\bar{V} = 1\angle 0$)

$$\bar{Z} = \frac{|V_{prefault}|}{\bar{I}_{rated}}$$

→ $|Z|$ varies linearly with $|V_{prefault}|$

(3) constant impedance load

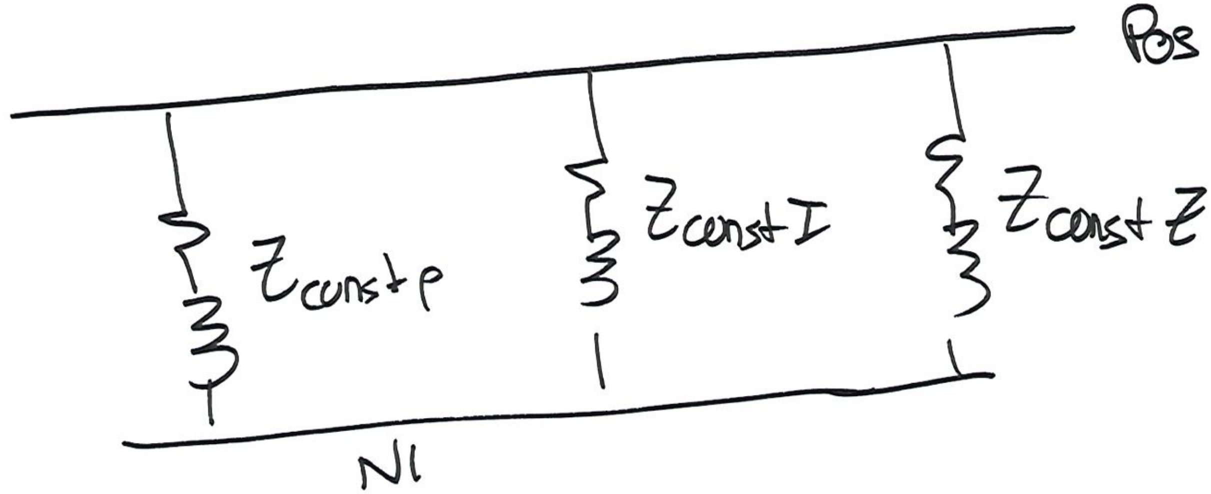
P, Q rated voltage

$$\bar{Z}_{const\,Z} = \frac{|V_{rated}|^2}{(S_{rated})^*}$$

→ doesn't change with system voltage

Bus

Pos seq & negative sequence



Zero sequence

→ programs model load as open in Zero sequence

– ungrounded either due to Δ transformer winding or ungrounded machine

L16 9/16

Now add shunt Constant Impedance Load load at Bus 1

Now add a load of 200MVA at unity power factor at Bus 1

$S_{load} := 200\text{MVA}\cdot e^{j\cdot 0\deg}$ $\qquad$ $S_{loadpu} := \dfrac{S_{load}}{100\text{MVA}}$

$Z_{load} := \dfrac{1.0\text{pu}}{S_{loadpu}}$ $\qquad$ $Z_{load} = 0.5\cdot\text{pu}$

- Treat same in positive, negative sequence
- Powerworld leaves open in zero sequence
- Not always a realistic assumption
- Add load as an admittance at bus 1

$$\frac{1}{Z_{constZ}} + \frac{1}{Z_{constI}} + \frac{1}{Z_{constP}} + \frac{1}{jX_d'}$$

- Need positive negative and zero sequence matrices $\qquad m := 0.5$

$$Y_{bus1} := \begin{array}{c} \\ \begin{bmatrix} \frac{1}{Z_{S1}} + \frac{1}{Z_{L11}} & \frac{-1}{Z_{L11}} & 0 & 0 \\ \frac{-1}{Z_{L11}} & \frac{1}{Z_{L11}} + \frac{1}{m\cdot Z_{L21}} + \frac{1}{Z_{load}} & 0 & \frac{-1}{m\cdot Z_{L21}} \\ 0 & 0 & \frac{1}{(1-m)\cdot Z_{L21}} + \frac{1}{Z_{R1}} & \frac{-1}{(1-m)\cdot Z_{L21}} \\ 0 & \frac{-1}{m\cdot Z_{L21}} & \frac{-1}{(1-m)\cdot Z_{L21}} & \frac{1}{m\cdot Z_{L21}} + \frac{1}{(1-m)\cdot Z_{L21}} \end{bmatrix} \\ \text{BUS S} \quad \text{BUS 1} \quad \text{BUS R} \quad \text{BUS F} \end{array} \begin{array}{l} \text{BUS S} \\ \text{BUS 1} \\ \text{BUS R} \\ \text{BUS F} \end{array}$$

-const Z

BUS F

jX_d'

If motor?

$$Y_{bus1} = \begin{pmatrix} 0.87 - 43.3i & -0.87 + 9.96i & 0 & 0 \\ -0.87 + 9.96i & 5.05 - 34.87i & 0 & -2.18 + 24.9i \\ 0 & 0 & 2.18 - 41.57i & -2.18 + 24.9i \\ 0 & -2.18 + 24.9i & -2.18 + 24.9i & 4.36 - 49.81i \end{pmatrix}$$

$$Z_{bus1} := Y_{bus1}^{-1}$$

$$Z_{bus1} = \begin{pmatrix} 6.67 \times 10^{-4} + 0.03i & 0 + 0.02i & 4.88 \times 10^{-4} + 0.01i & 0 + 0.01i \\ 0 + 0.02i & 0.01 + 0.07i & 0 + 0.03i & 0.01 + 0.05i \\ 4.88 \times 10^{-4} + 0.01i & 0 + 0.03i & 0 + 0.05i & 0 + 0.04i \\ 0 + 0.01i & 0.01 + 0.05i & 0 + 0.04i & 0.01 + 0.06i \end{pmatrix}$$

- Add the load at Bus 1 in the negative sequence matrix as well.

$$Y_{bus2} := \begin{bmatrix} \frac{1}{Z_{S2}} + \frac{1}{Z_{L12}} & \frac{-1}{Z_{L12}} & 0 & 0 \\ \frac{-1}{Z_{L12}} & \frac{1}{Z_{L12}} + \frac{1}{m \cdot Z_{L22}} + \frac{1}{Z_{load}} & 0 & \frac{-1}{m \cdot Z_{L22}} \\ 0 & 0 & \frac{1}{(1-m) \cdot Z_{L22}} + \frac{1}{Z_{R2}} & \frac{-1}{(1-m) \cdot Z_{L22}} \\ 0 & \frac{-1}{m \cdot Z_{L22}} & \frac{-1}{(1-m) \cdot Z_{L22}} & \frac{1}{m \cdot Z_{L22}} + \frac{1}{(1-m) \cdot Z_{L22}} \end{bmatrix}$$

L16 11/16

$Z_{bus2} := Y_{bus2}^{-1}$

- But the load is not in the zero sequence matrix

load open in zero sequence

$$Y_{bus0} := \begin{bmatrix} \frac{1}{Z_{S0}} + \frac{1}{Z_{L10}} & \frac{-1}{Z_{L10}} & 0 & 0 \\ \frac{-1}{Z_{L10}} & \frac{1}{Z_{L10}} + \frac{1}{m \cdot Z_{L20}} & 0 & \frac{-1}{m \cdot Z_{L20}} \\ 0 & 0 & \frac{1}{(1-m) \cdot Z_{L20}} + \frac{1}{Z_{R0}} & \frac{-1}{(1-m) \cdot Z_{L20}} \\ 0 & \frac{-1}{m \cdot Z_{L20}} & \frac{-1}{(1-m) \cdot Z_{L20}} & \frac{1}{m \cdot Z_{L20}} + \frac{1}{(1-m) \cdot Z_{L20}} \end{bmatrix}$$

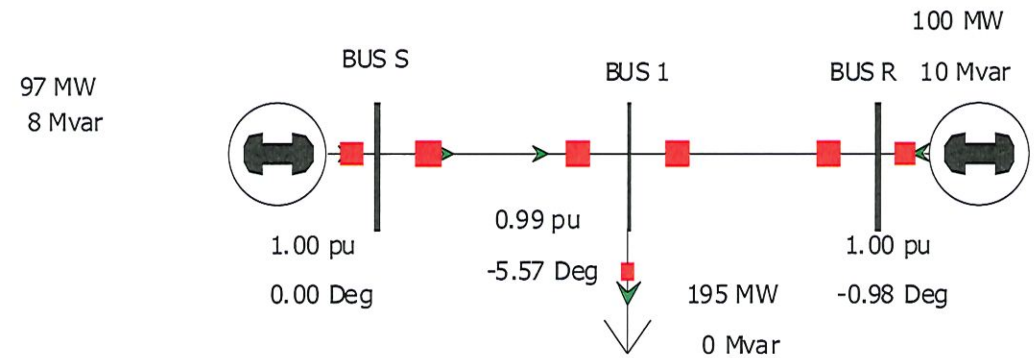
$$Y_{bus0} = \begin{pmatrix} 0.29 - 14.43i & -0.29 + 3.32i & 0 & 0 \\ -0.29 + 3.32i & 1.02 - 11.62i & 0 & -0.73 + 8.3i \\ 0 & 0 & 0.73 - 13.86i & -0.73 + 8.3i \\ 0 & -0.73 + 8.3i & -0.73 + 8.3i & 1.45 - 16.6i \end{pmatrix}$$

$Z_{bus0} := Y_{bus0}^{-1}$

L16 12/16

$$Z_{bus0} = \begin{pmatrix} 5.82\times10^{-4}+0.08i & -3.88\times10^{-4}+0.05i & -0+0.02i & -7.76\times10^{-4}+0.03i \\ -3.88\times10^{-4}+0.05i & 0.01+0.2i & 7.76\times10^{-4}+0.09i & 0.01+0.14i \\ -0+0.02i & 7.76\times10^{-4}+0.09i & 0+0.14i & 0+0.11i \\ -7.76\times10^{-4}+0.03i & 0.01+0.14i & 0+0.11i & 0.01+0.19i \end{pmatrix}$$

- Powerflow simulation needed to find the bus voltages
  - Set generator 2 at 100MW



From Power Flow

- Bus Voltages from powerflow results (add the fault point so the powerflow results include it):

$\angle(\text{mag}, \text{ang}) := \text{mag}\cdot\cos(\text{ang}\cdot\text{deg}) + j\cdot\text{mag}\cdot\sin(\text{ang}\cdot\text{deg})$

BUS S: $V_S := (1.0\text{pu}) \angle 0.0$

BUS 1: $V_1 := (0.9885) \angle -5.57$

L16 13/16

$$\Delta V2 := Z_{bus2} \cdot \begin{pmatrix} 0 \\ 0 \\ 0 \\ -I_{2\_SLG} \end{pmatrix} \qquad V2 := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \Delta V2$$

$$\Delta V0 := Z_{bus0} \cdot \begin{pmatrix} 0 \\ 0 \\ 0 \\ -I_{0\_SLG} \end{pmatrix} \qquad V0 := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \Delta V0$$

If distribution system with significant standing imbalance could use unbalanced power flow result.

- Relay 1 voltage:

$$V_{ABC\_B1} := A_{012} \cdot \begin{pmatrix} V0_1 \\ V1_1 \\ V2_1 \end{pmatrix} \qquad \overrightarrow{\left|V_{ABC\_B1}\right|} = \begin{pmatrix} 0.2328 \\ 1.2038 \\ 1.1417 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(V_{ABC\_B1}\right)} = \begin{pmatrix} -9.52 \\ -137.28 \\ 128.99 \end{pmatrix} \cdot deg$$

- Relay 1 current:

$$I_{B1\_F\_1} := \frac{V1_1 - V1_3}{m \cdot Z_{L21}} \qquad \left|I_{B1\_F\_1}\right| = 1.35 \qquad \arg\left(I_{B1\_F\_1}\right) = -126.61 \cdot deg$$

L16 14/16

BUS R: $V_R := (1.0) \angle -0.98$

BUS F: $V_{faultpt} := (0.9934) \angle -3.26$

$$I_{0\_SLG} := \frac{V_{faultpt}}{Z_{bus1_{3,3}} + Z_{bus2_{3,3}} + Z_{bus0_{3,3}}} \qquad I_{1\_SLG} := I_{0\_SLG}$$

$$I_{2\_SLG} := I_{0\_SLG} \qquad \left|I_{0\_SLG}\right| = 3.17 \qquad \arg\left(I_{0\_SLG}\right) = -88.83 \cdot deg$$

$$I_{ABC\_SLG} := A_{012} \cdot \begin{pmatrix} I_{0\_SLG} \\ I_{1\_SLG} \\ I_{2\_SLG} \end{pmatrix} \qquad \overrightarrow{\left|I_{ABC\_SLG}\right|} = \begin{pmatrix} 9.516 \\ 0 \\ 0 \end{pmatrix} \cdot pu \qquad \overrightarrow{\arg\left(I_{ABC\_SLG}\right)} = \begin{pmatrix} -88.83 \\ 27.81 \\ 27.81 \end{pmatrix} \cdot deg$$

- Now find the voltages:

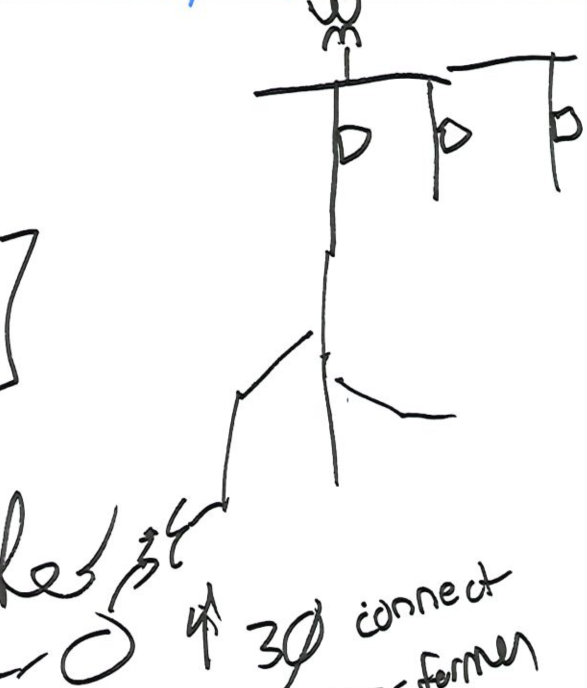
$$\Delta V1 := Z_{bus1} \cdot \begin{pmatrix} 0 \\ 0 \\ 0 \\ -I_{1\_SLG} \end{pmatrix} \qquad V1 := \begin{pmatrix} V_S \\ V_1 \\ V_R \\ V_{faultpt} \end{pmatrix} + \Delta V1$$

prefault voltage from power flow

Distributed generation

→ either on distribution system]

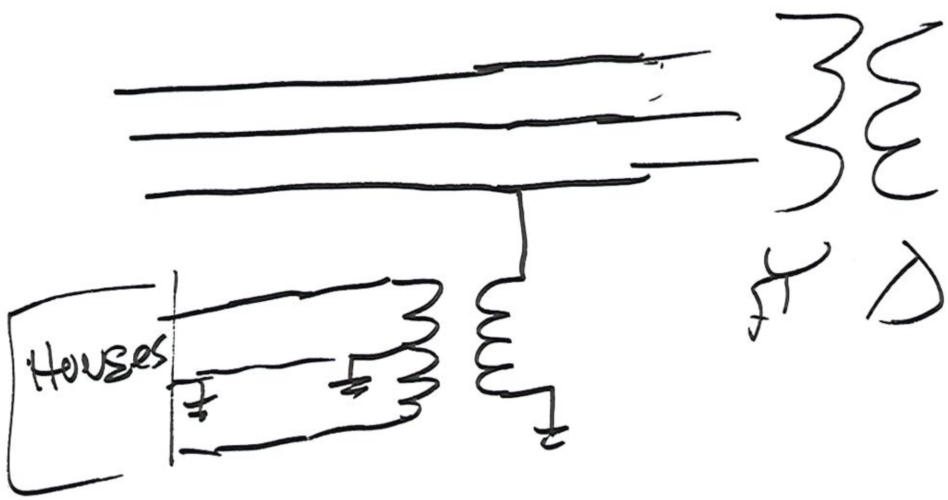
— on transmission connected



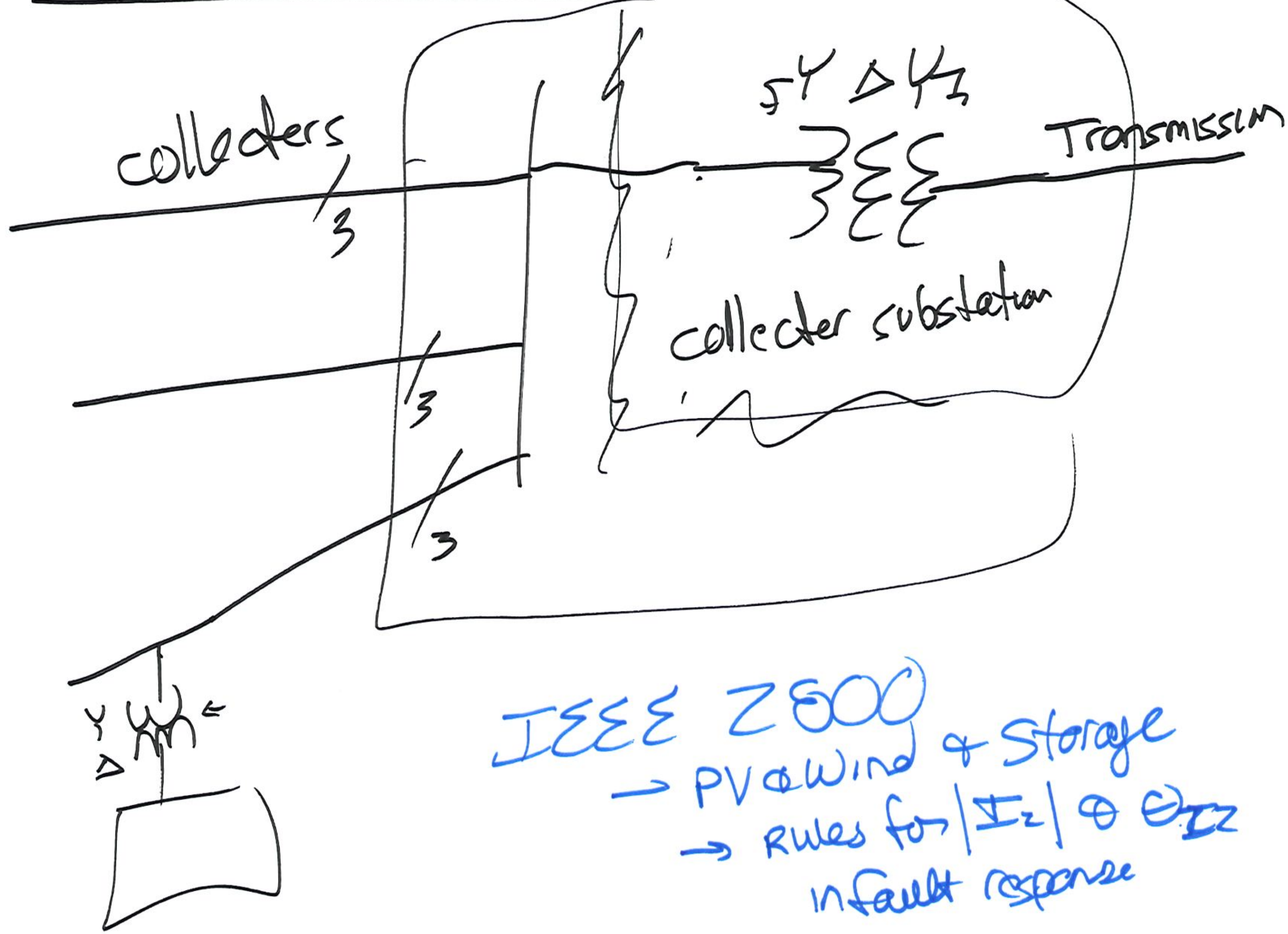
↑ 3∅ connect

→ transformer connections vary

single phase



Transmission connected → PV & wind



IEEE 2800
→ PV & Wind & Storage
→ Rules for $|I_2|$ & Θ_{I_2} in fault response