

ECE 526

PROTECTION OF
POWER SYSTEMS II

SESSION no. 5

Comparing Primary and Secondary Ohms and Converting to Per Unit on Secondary When CTR and VTR Don't Cancel

- First look at a regular transformer

We know the following:

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} \quad \text{which can be rearranged as:} \quad \frac{V_1}{V_2} = \frac{N_1}{N_2} = \text{VTR}$$

Similarly (using power transformer polarity)

$$I_1 \cdot N_1 - I_2 \cdot N_2 = 0 \quad \text{which can be rearranged as:} \quad \frac{I_1}{I_2} = \frac{N_2}{N_1} = \text{CTR}$$

- Now if we wanted to relate an impedance across the transfromer

$$Z_2 = \frac{V_2}{I_2} = \frac{V_1 \cdot \left(\frac{N_2}{N_1} \right)}{I_1 \cdot \left(\frac{N_1}{N_2} \right)} = \frac{V_1}{I_1} \cdot \left(\frac{N_2}{N_1} \right)^2 = Z_1 \cdot \left(\frac{N_2}{N_1} \right)^2 \quad \text{This is how we usually view this...}$$

Alternate simplification

$$Z_2 = \frac{V_2}{I_2} = \left[\frac{V_1 \cdot \left(\frac{N_2}{N_1} \right)}{I_1 \cdot \left(\frac{N_1}{N_2} \right)} \right] = \frac{V_1 \cdot \text{CTR}}{I_1 \cdot \text{VTR}} = Z_1 \cdot \frac{\text{CTR}}{\text{VTR}}$$

- In the case of the measurements seen at the protective relay, the voltages are stepped down through a set of voltage transformers with little current (which is not measured)
- And the currents are stepped down through a separate set of current transformers with the voltage not measured
- The measured voltage and current go into different inputs to the relay
- The relay "sees" and effective secondary impedance based on the voltages and currents stepped down by these separate VTs and CTs
- This will be more important when we look at distance relays, but it also matters for fault location calculations

L5
2/18

Example

$$Z_{\text{line_primary}} := (5 + j \cdot 50) \Omega$$

$$\text{VTR} := \frac{345 \text{kV}}{120 \text{V}}$$

$$\text{CTR} := \frac{800 \text{A}}{5 \text{A}}$$

- Now find the effective secondary line impedance.

$$Z_1 := Z_{\text{line_primary}}$$

$$Z_2 := Z_1 \cdot \frac{\text{CTR}}{\text{VTR}} \quad Z_2 = (0.28 + 2.78j) \Omega \quad Z_{\text{line_secondary}} := Z_2$$

If we had a three phase fault at the far end of the transmission line, then taking V/I

What does this do to per unit analysis?

- Note that our conventional idea of per unit analysis is no longer accurate

$$Z_{\text{BLV}} := \frac{120 \text{V}}{\sqrt{3} \cdot 5 \text{A}} \quad Z_{\text{BLV}} = 13.86 \Omega$$

$$Z_{\text{BHV}} := \frac{345 \text{kV}}{\sqrt{3} \cdot 800 \text{A}} \quad Z_{\text{BHV}} = 248.98 \Omega$$

$$Z_{\text{pu}} := \frac{Z_{\text{line_secondary}}}{Z_{\text{BLV}}} \quad Z_{\text{pu}} = 0.02 + 0.2j$$

$$Z_{\text{pu}} \cdot Z_{\text{BHV}} = (5 + 50j) \Omega$$

Polarizing reference

V_{pol} - in distance elements
angle and magnitude have
impact. \rightarrow useful impacts

options

① self polarized

$$\begin{aligned} & - Z_{AG} \rightarrow V_{AG} = V_{\text{pol}} AG \\ & Z_{BG} \rightarrow V_{BG} \\ & Z_{AB} \rightarrow V_{AG} - V_{BG} = V_{AB} \end{aligned}$$

Advantages - Simple to understand & mimic

- tracks power system frequency

disadvantages - close in faults
AG near bus (on either side)

$$V_{AG} \text{ small } \approx 0$$

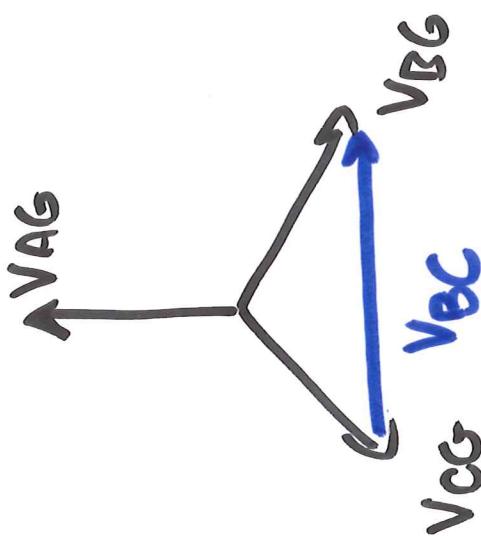
AB fault \rightarrow ~~Z_{AB}~~ element problem

② Cross polarized

for AG element:

$$\Sigma-m \text{ relays: } V_{BG} - V_{CG}$$

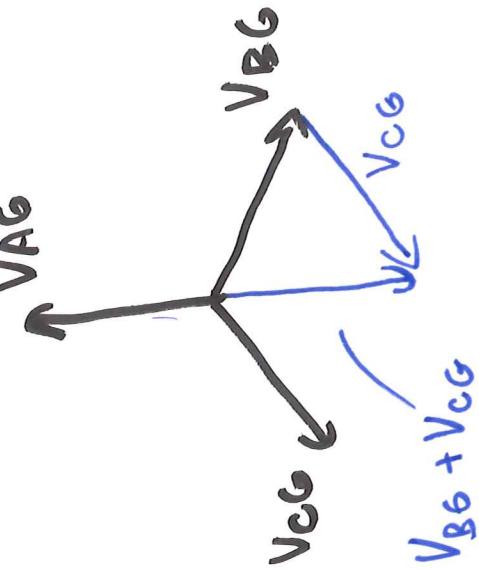
\rightarrow rotate by 90°
scale by $\sqrt{\frac{1}{2}}$



In normal SS

$$V_{AG} = -(V_{BG} + V_{CG})$$

no scaling



Cross polar.

$$AG \rightarrow V_{BG} + V_{CG}$$

$$BG \rightarrow V_{AG} + V_{CG}$$

$$CG \rightarrow V_{AG} + V_{BG}$$

$$AB \rightarrow V_{GG}$$

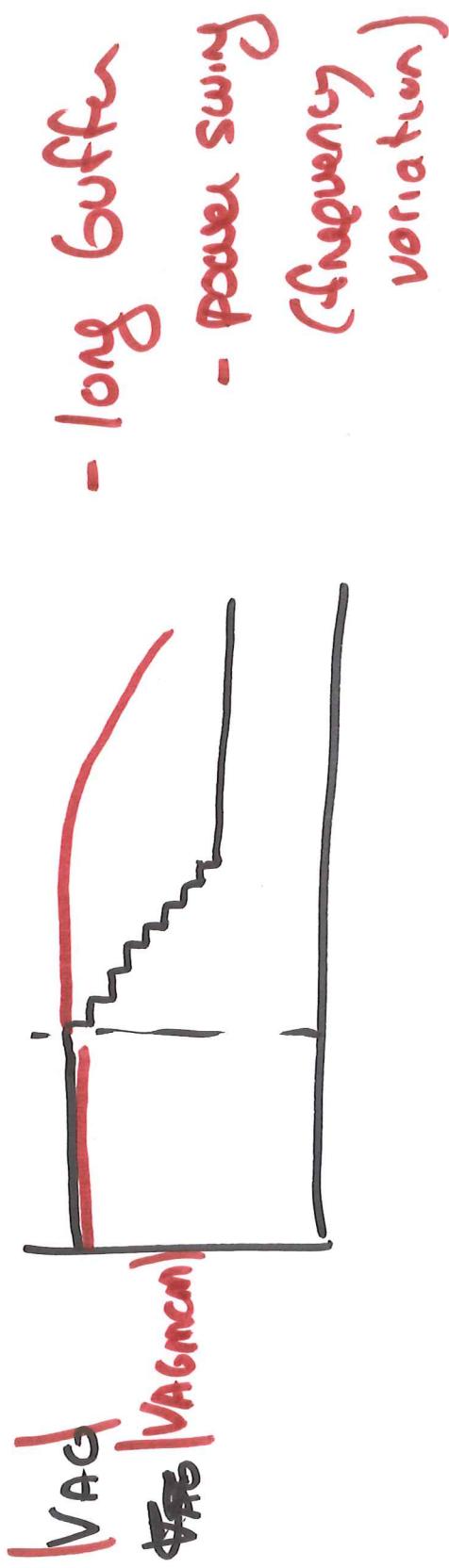
$$BC \rightarrow V_{AG}$$

$$CA \rightarrow V_{BG}$$

③ memory polarized

A) Phase voltage ($A_6, B_6, \dots = A\beta, B\beta, \dots$)

- save in a buffer



(B) Positive sequence moment polarize

- more stable angle

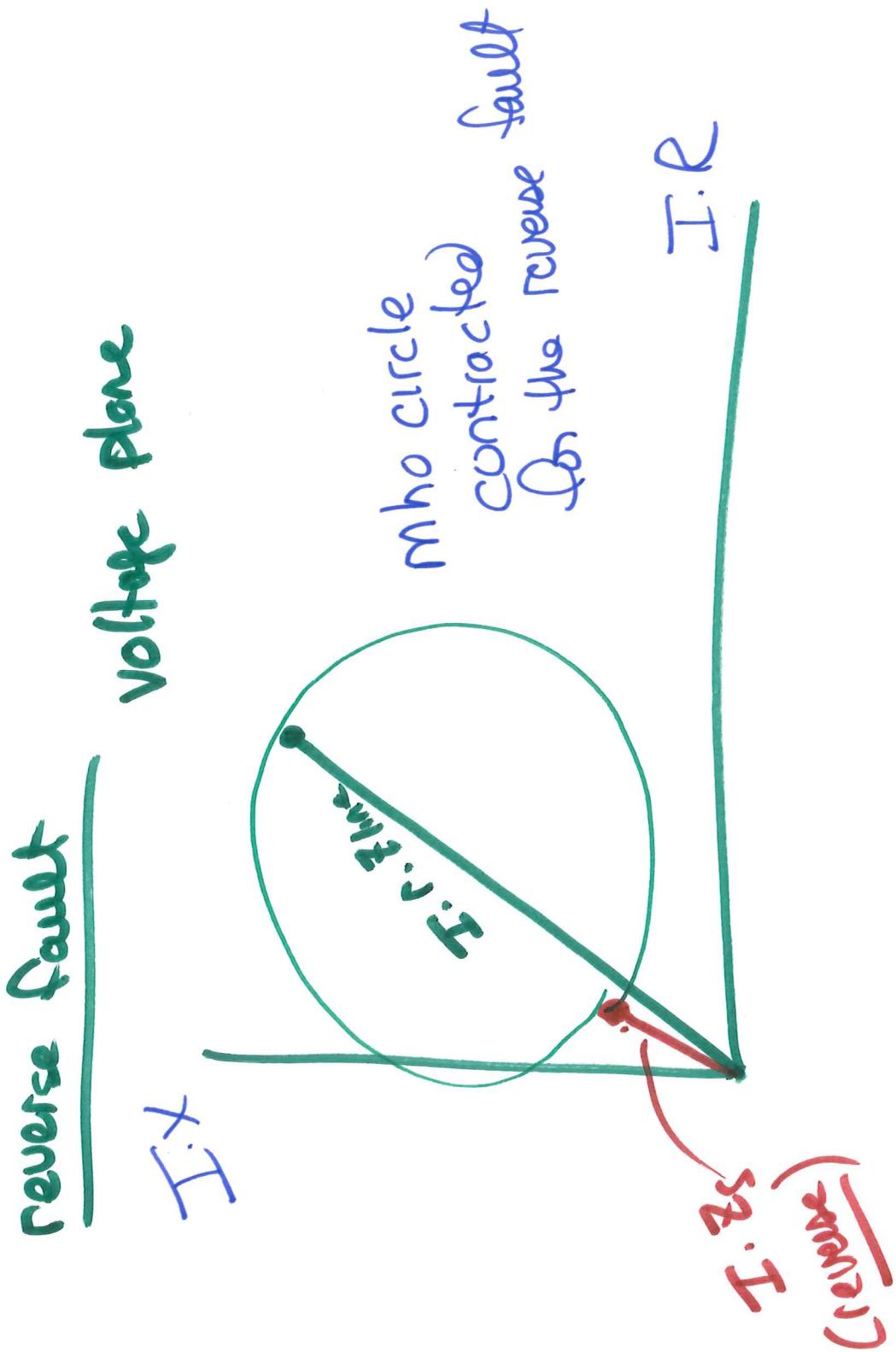
Some special cases

Zero sequence elements : use V_0 or $3V_0$

How does this effect relay response

$$\rightarrow Z_{AG} = \frac{V_{AG}}{I_A + I_0 3T_0}$$

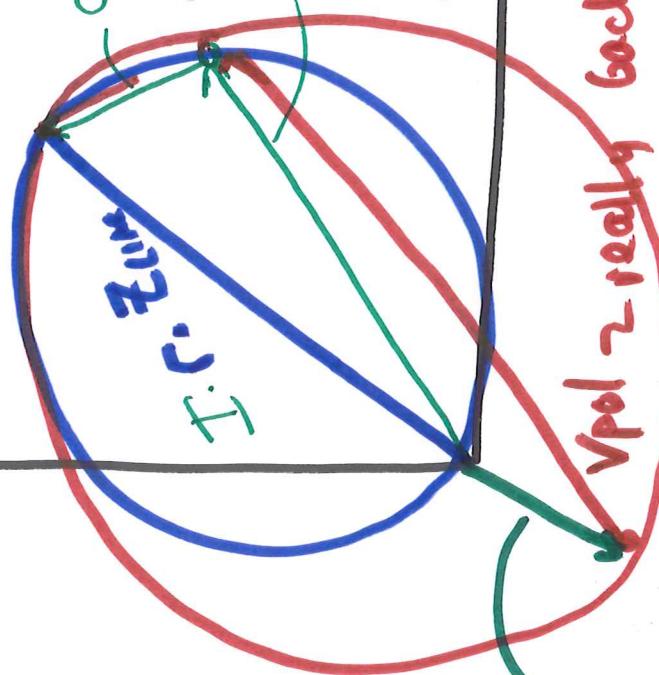
→ Mho circle is impacted
by V_{pol}, not Z_{AG}



Voltage plane

$I_r \cdot X$

δV still add up to "V_{line}"
and still add up to "V_{line}"



$V_{pol} \rightarrow$ Self polarized case.

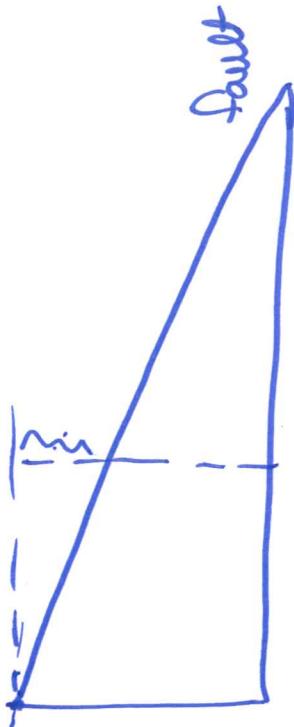
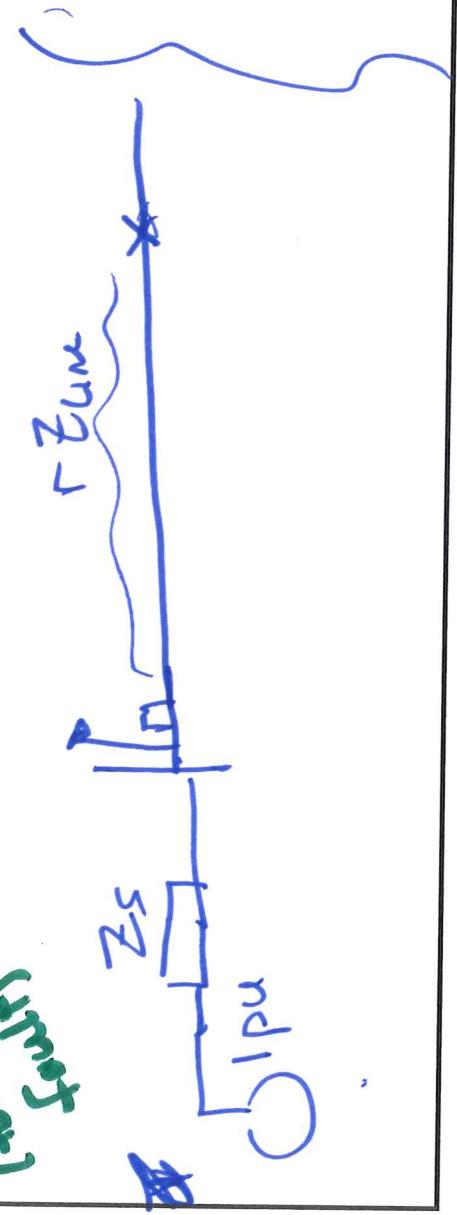
- expanded Mho circle → dynamic response

$I_r \cdot R$

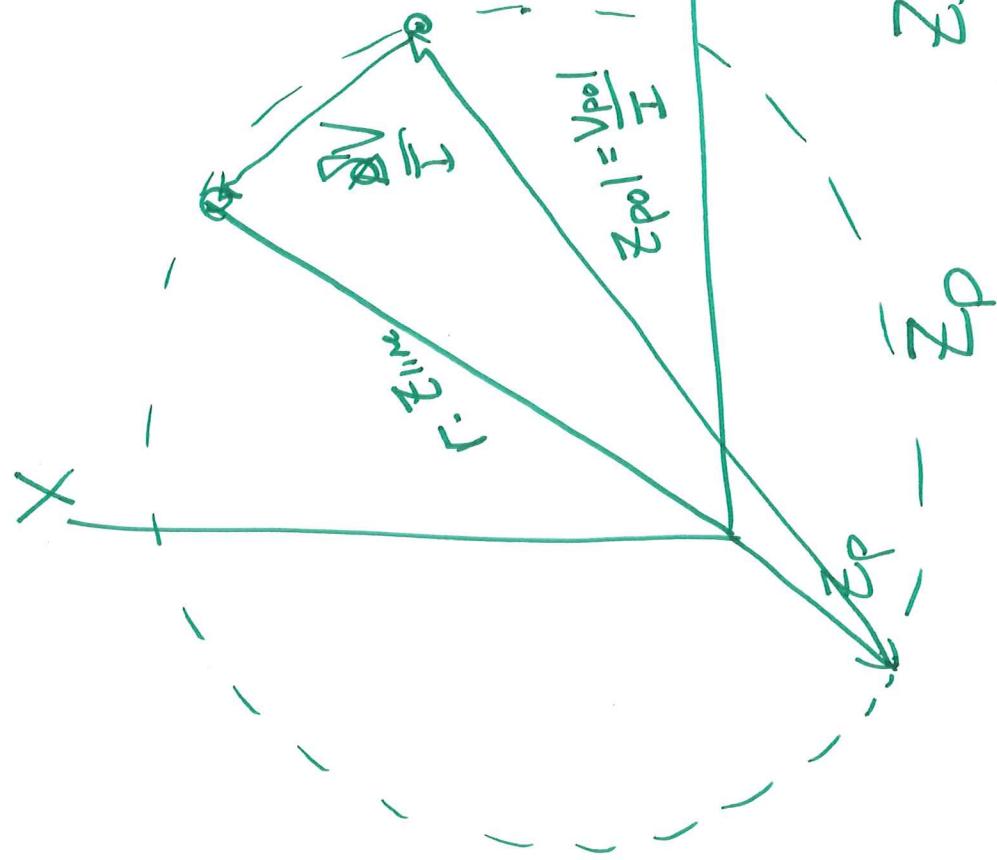
$V_{pol} = 100\% \text{ back to "Vsource"}$

(forward)

(backward)



Impedance plane



k depends on polarization: memory: $k = 1$
 cross $V_B + V_C$
 $k = -1$
 self: $k = 1$
 cross $V_B - V_C$: $\frac{j}{\sqrt{3}}$

$$\begin{cases} \text{cross } V_B + V_C \\ \text{self: } k = 1 \\ \text{cross } V_B - V_C : \frac{j}{\sqrt{3}} \end{cases}$$

$$\begin{aligned} Z_{PAG} &= \frac{V_{AG}}{I_A + k_0 3I_0} - \frac{k V_{pol}}{I_A + k_0 3I_0} \\ &= \frac{V_{AG} - k V_{pol}}{I_A + k_0 3I_0} \end{aligned}$$

- for self polarized: $Z_P = 0$
- under normal SS operation: $Z_P = 0$

Mho Circle

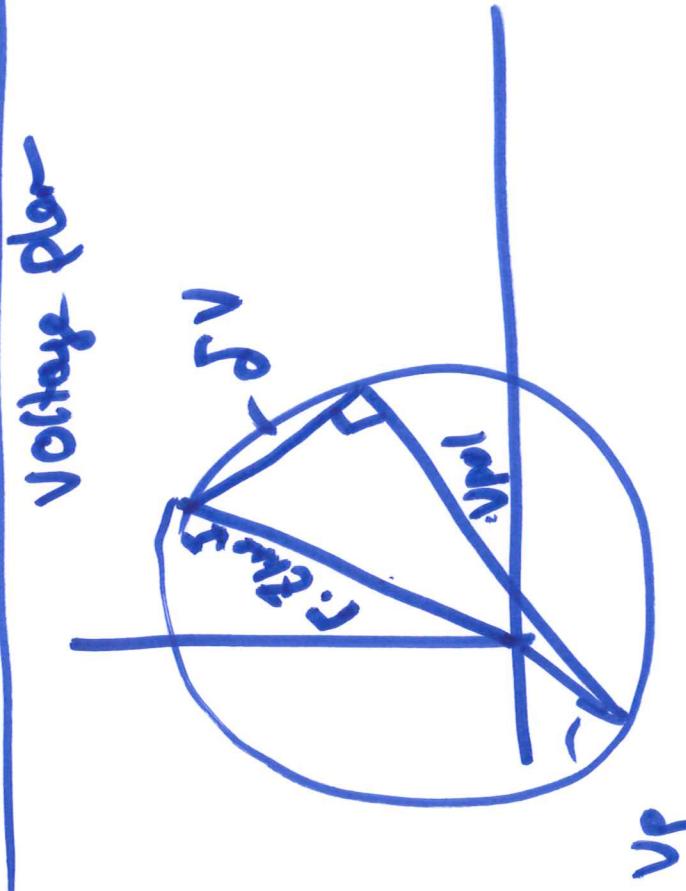
pos. esp. line imped.

Offset: $\bar{z} = [r \cdot \bar{z}_{IL} + z_p]$

magnitude & angle

Radius: $\frac{1}{2} [\bar{r} \cdot \bar{z}_{IL} - \bar{z}_p]$

A ~~microprocessor~~ friendy approach



"Torque" equation
 $\Re_e(V_{op} \cdot V_{pol}^*) = 0$ ↓
 on the circle
 $V_{op} = \sigma V = r Z_{line} \cdot I - V' - \text{voltage at load}$

$$\operatorname{Re} \left[(r Z_{\text{line}} \cdot I) \cdot V_{\text{pol}}^* \right] = 0$$

$$\operatorname{Re} \left[(r Z_{\text{line}} \cdot I) V_{\text{pol}}^* - V \cdot V_{\text{pol}}^* \right] = 0$$

$$\operatorname{Re} \left[(r Z_{\text{line}} \cdot I) \cdot V_{\text{pol}}^* \right] - \operatorname{Re} \left[V \cdot V_{\text{pol}}^* \right] = 0$$

$$\operatorname{Re} \left[V \cdot V_{\text{pol}}^* \right] = r \cdot \operatorname{Re} \left[(Z_{\text{line}} \cdot I) \cdot V_{\text{pol}}^* \right]$$

$$r = \frac{\operatorname{Re} \left[V \cdot V_{\text{pol}}^* \right]}{\operatorname{Re} \left[Z_{\text{line}} \cdot I \cdot (V_{\text{pol}})^* \right]}$$

$$I = \begin{cases} I_A + k_0 3I_0 & V = V_{A6} \\ \text{or} \\ I_B + k_0 3I_0 & V_{B6} \\ \text{or} \\ V_{C6} & V_{A6} - V_{B6} - \\ \text{or} \\ I_A - I_B & \end{cases}$$

~~Set~~ V_{pol} changes
as appropriate

Alternate Form

$$r | Z_L | = \frac{\operatorname{Re}(\bar{V} \cdot \bar{V}_{pol}^*)}{\operatorname{Re}[(1/\rho_{min}) \cdot \bar{Z} \cdot (\bar{V}_{pol})^*]}$$

