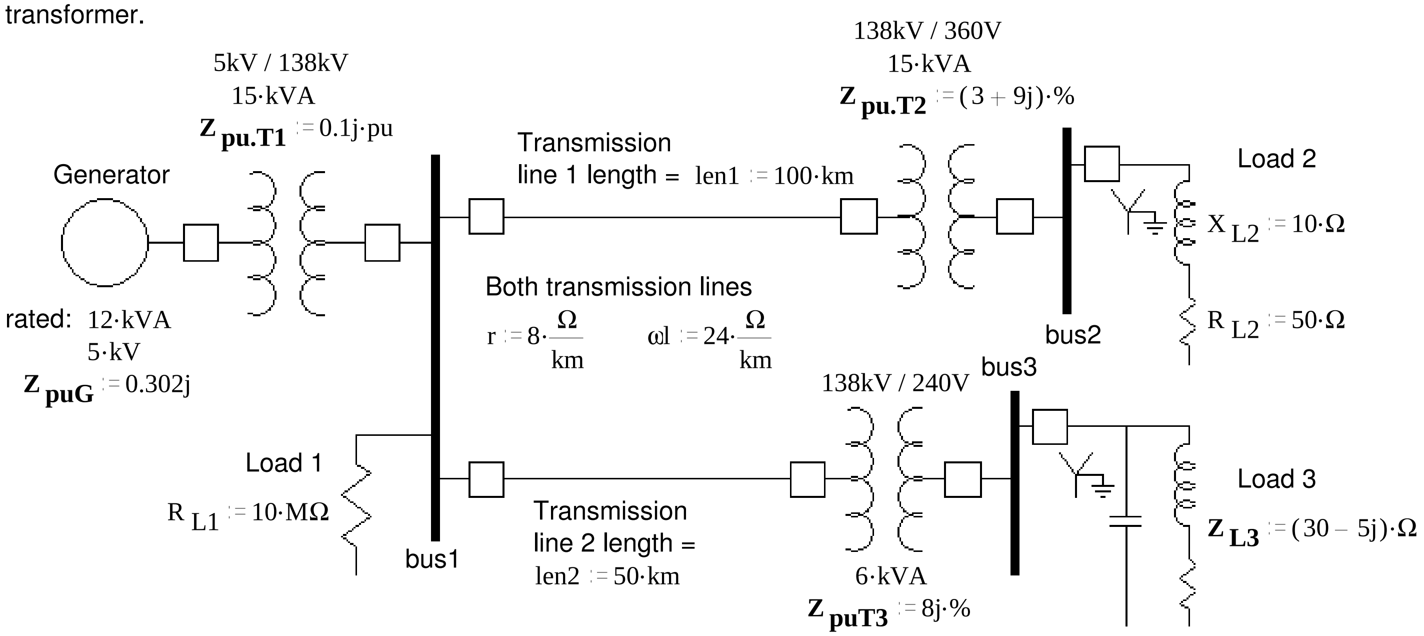
ECE 3600 Per-Unit Example   Like problem 4 on homework

A one-line diagram of a 3ϕ system is shown below. Manufacturer's information is shown for the generator and each transformer.



a) Choose an S_{base} to minimize the per-unit base conversions. Then choose regions and a V_{base} for each region.

$S_{base} := 15\cdot kVA$

Region 1	The generator	$V_{base1} := 5\cdot kV$
Region 2	Bus1, Load 1 and the transmission lines	$V_{base2} := 138\cdot kV$
Region 3	Bus2 and Load 2	$V_{base3} := 360\cdot V$
Region 4	Bus2 and Load 3	$V_{base4} := 240\cdot V$

b) Find I_{base} and Z_{base} in each of the regions.

Region 1 $\quad I_{base1} := \frac{S_{base}}{\sqrt{3}\cdot V_{base1}} \quad I_{base1} = 1.732\cdot A \quad Z_{base1} := \frac{V_{base1}^2}{S_{base}} \quad Z_{base1} = 1.667\cdot k\Omega$

Region 2 $\quad I_{base2} := \frac{S_{base}}{\sqrt{3}\cdot V_{base2}} \quad I_{base2} = 0.063\cdot A \quad Z_{base2} := \frac{V_{base2}^2}{S_{base}} \quad Z_{base2} = 1.27\cdot 10^3\cdot k\Omega$

Region 3 $\quad I_{base3} := \frac{S_{base}}{\sqrt{3}\cdot V_{base3}} \quad I_{base3} = 24.056\cdot A \quad Z_{base3} := \frac{V_{base3}^2}{S_{base}} \quad Z_{base3} = 8.64\cdot\Omega$

Region 4 $\quad I_{base4} := \frac{S_{base}}{\sqrt{3}\cdot V_{base4}} \quad I_{base4} = 36.084\cdot A \quad Z_{base4} := \frac{V_{base4}^2}{S_{base}} \quad Z_{base4} = 3.84\cdot\Omega$

c) Make the necessary per-unit S_{base} conversions.

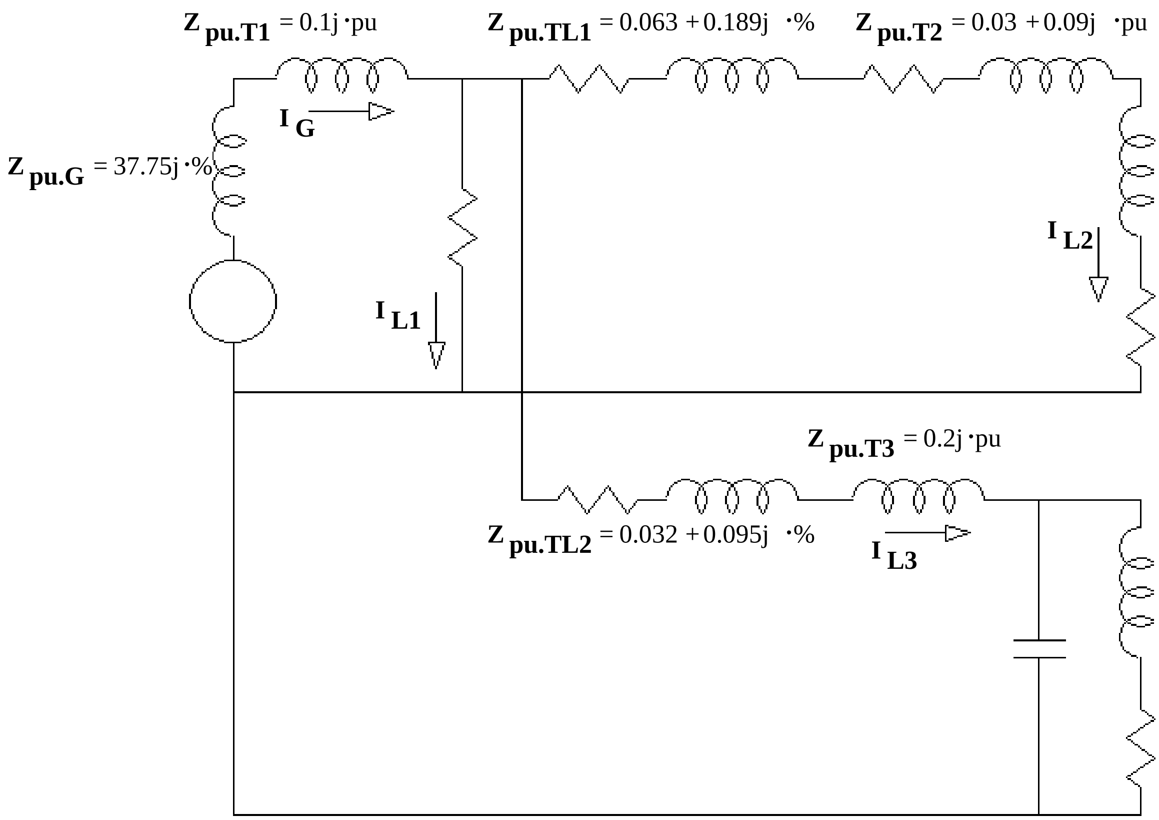
$\mathbf{Z}_{\mathbf{pu.G}} := \mathbf{Z}_{\mathbf{puG}}\cdot\frac{S_{base}}{12\cdot kVA} \quad \mathbf{Z}_{\mathbf{pu.G}} = 0.378j\cdot pu \quad \mathbf{Z}_{\mathbf{pu.T3}} := \mathbf{Z}_{\mathbf{puT3}}\cdot\frac{S_{base}}{6\cdot kVA} \quad \mathbf{Z}_{\mathbf{pu.T3}} = 0.2j\cdot pu$

d) Find the impedances of the two transmission lines and convert to pu.

$\mathbf{Z}_{\mathbf{TL1}} := (8 + 24j) \cdot \frac{\Omega}{\text{km}} \cdot \text{len1}$ $\mathbf{Z}_{\mathbf{TL1}} = 0.8 + 2.4j \ \cdot \text{k}\Omega$ $\mathbf{Z}_{\mathbf{pu.TL1}} := \frac{\mathbf{Z}_{\mathbf{TL1}}}{Z_{\text{base2}}}$ $\mathbf{Z}_{\mathbf{pu.TL1}} = 0.063 + 0.189j \ \cdot \%$

$\mathbf{Z}_{\mathbf{TL2}} := (8 + 24j) \cdot \frac{\Omega}{\text{km}} \cdot \text{len2}$ $\mathbf{Z}_{\mathbf{TL2}} = 0.4 + 1.2j \ \cdot \text{k}\Omega$ $\mathbf{Z}_{\mathbf{pu.TL2}} := \frac{\mathbf{Z}_{\mathbf{TL2}}}{Z_{\text{base2}}}$ $\mathbf{Z}_{\mathbf{pu.TL2}} = 0.032 + 0.095j \ \cdot \%$

e) Draw the per-phase diagram showing all the per-unit numbers found or given so far.



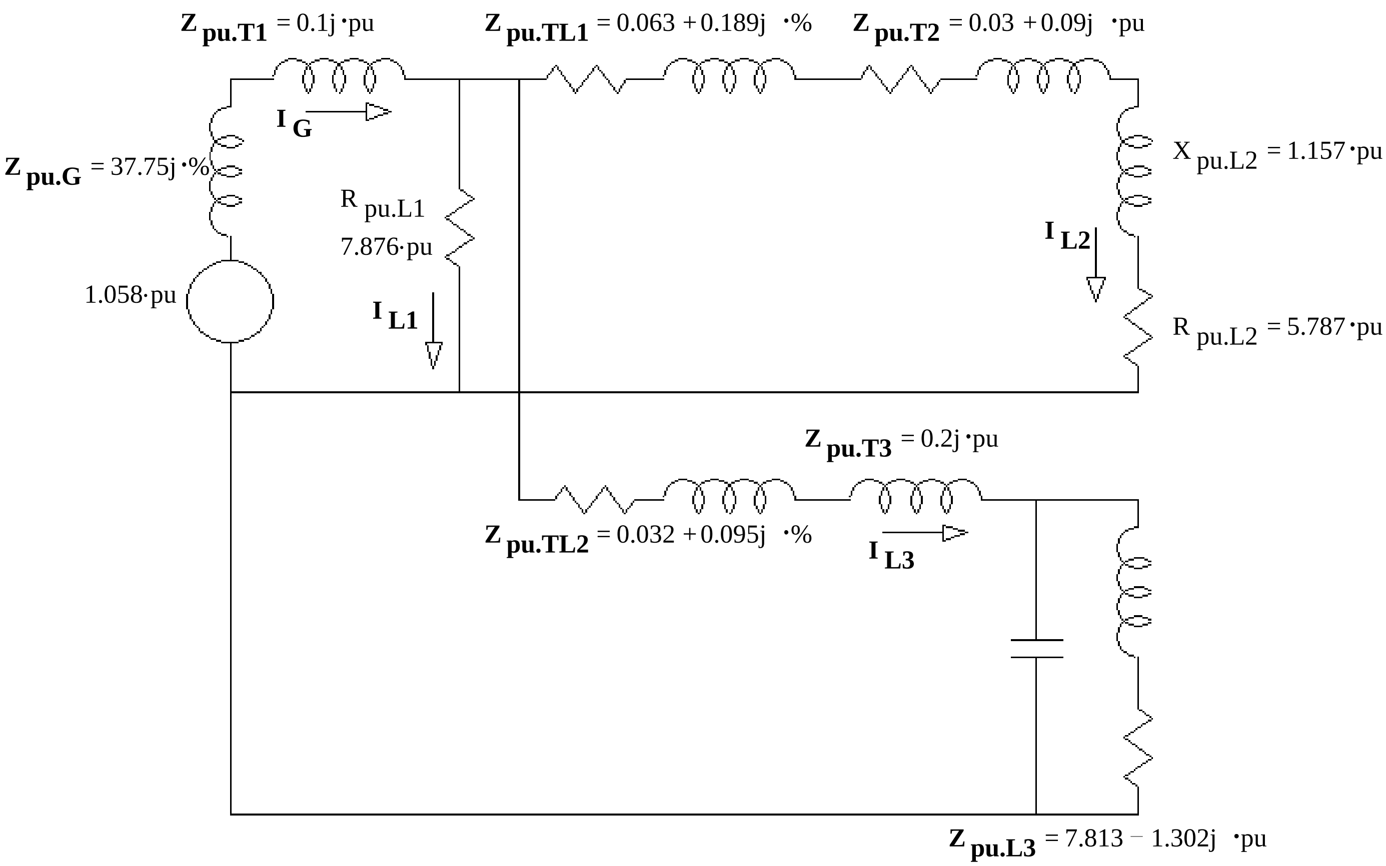
ALL calculations made to this point **ONLY need to be made ONCE** for this system and S_{base} **!!**

f) Find the pu values of the 3 loads and add that information to the per-phase diagram.

$$R_{pu.L1} := \frac{R_{L1}}{Z_{base2}} \qquad R_{pu.L1} = 7.876 \cdot pu$$

$$R_{pu.L2} := \frac{R_{L2}}{Z_{base3}} \qquad R_{pu.L2} = 5.787 \cdot pu \qquad X_{pu.L2} := \frac{X_{L2}}{Z_{base3}} \qquad X_{pu.L2} = 1.157 \cdot pu$$

$$\mathbf{Z}_{\mathbf{pu.L3}} := \frac{\mathbf{Z}_{\mathbf{L3}}}{Z_{base4}} \qquad \mathbf{Z}_{\mathbf{pu.L3}} = (7.813 - 1.302j) \cdot pu$$



g) The line voltage at bus1 is measured and found to be $V_{bus1} := 146 \cdot kV$ Assume a phase angle of 0º for the pu value.

Find all 3 load line-current magnitudes and the magnitude of the generator line-current. Please remember that you can't add magnitudes, so may need some complex values.

$$V_{pu.bus1} := \frac{146 \cdot kV}{V_{base2}} \qquad V_{pu.bus1} = 1.058 \cdot pu$$

$$\mathbf{I}_{\mathbf{pu.L1}} := \frac{V_{pu.bus1}}{R_{pu.L1}} \qquad \mathbf{I}_{\mathbf{pu.L1}} = 0.134 \cdot pu \qquad \left|\mathbf{I}_{\mathbf{pu.L1}}\right| \cdot I_{base2} = 8.429 \cdot mA$$

$$\mathbf{I}_{\mathbf{pu.L2}} := \frac{V_{pu.bus1}}{\mathbf{Z}_{\mathbf{pu.TL1}} + \mathbf{Z}_{\mathbf{pu.T2}} + \left(R_{pu.L2} + X_{pu.L2} \cdot j\right)} \qquad \mathbf{I}_{\mathbf{pu.L2}} = (0.174 - 0.037j) \cdot pu \qquad \left|\mathbf{I}_{\mathbf{pu.L2}}\right| \cdot I_{base3} = 4.277 \cdot A$$

$$\mathbf{I}_{\mathbf{pu.L3}} := \frac{V_{pu.bus1}}{\mathbf{Z}_{\mathbf{pu.TL2}} + \mathbf{Z}_{\mathbf{pu.T3}} + \mathbf{Z}_{\mathbf{pu.L3}}} \qquad \mathbf{I}_{\mathbf{pu.L3}} = (0.133 + 0.019j) \cdot pu \qquad \left|\mathbf{I}_{\mathbf{pu.L3}}\right| \cdot I_{base4} = 4.839 \cdot A$$

$$\mathbf{I}_{\mathbf{pu.G}} := \mathbf{I}_{\mathbf{pu.L1}} + \mathbf{I}_{\mathbf{pu.L2}} + \mathbf{I}_{\mathbf{pu.L3}} \qquad \mathbf{I}_{\mathbf{pu.G}} = (44.094 - 1.862j) \cdot \% \qquad \left|\mathbf{I}_{\mathbf{pu.G}}\right| \cdot I_{base1} = 0.764 \cdot A$$

h) Find the power delivered to Load 2, both in pu and in kW.

$P_{pu.L2} := \left(\left|\mathbf{I}_{\mathbf{pu.L2}}\right|\right)^2 \cdot R_{pu.L2}$ $\quad P_{pu.L2} = 0.183 \cdot pu$ $\quad P_{L2} := P_{pu.L2} \cdot S_{base}$ $\quad P_{L2} = 2.744 \cdot kW$

i) Find the line voltage at Load 2 (magnitude).

$$V_{Load2} := \left|\mathbf{I}_{\mathbf{pu.L2}}\right| \cdot \sqrt{R_{pu.L2}^{\ 2} + X_{pu.L2}^{\ 2}} \cdot V_{base3} \qquad V_{Load2} = 377.8 \cdot V$$

j) Find the line voltage at the generator (magnitude).

$\mathbf{V}_{\mathbf{pu.G}} := V_{pu.bus1} + \mathbf{I}_{\mathbf{pu.G}} \cdot \left(\mathbf{Z}_{\mathbf{pu.G}} + \mathbf{Z}_{\mathbf{pu.T1}}\right)$ $\quad \mathbf{V}_{\mathbf{pu.G}} = 106.686 + 21.055j \ \ \cdot \%$ $\quad \left|\mathbf{V}_{\mathbf{pu.G}}\right| \cdot V_{base1} = 5.437 \cdot kV$

k) The line voltage at bus1 drops by 8% to: $\quad 146 \cdot kV \cdot 0.92 = 134.32 \cdot kV$

Find the magnitude of Load-3 line current and repeat parts h) and i) for this new generator voltage.

Note: It may be helpful to realize that if one voltage in the system drops by 8%, so do all the rest, and so do all the currents. Drop by 8% means multiply by 0.92. All powers drop too, but use $(0.92)^2$ as the factor.

new $\quad I_{Load3} \quad = \quad \left|\mathbf{I}_{\mathbf{pu.L3}}\right| \cdot I_{base4} \cdot 0.92 = 4.5 \cdot A$

new $\quad P_{L2} \quad = \quad P_{L2} \cdot 0.92^2 = 2.323 \cdot kW$

new $\quad V_{Load2} \quad = \quad V_{Load2} \cdot 0.92 = 347.5 \cdot V$