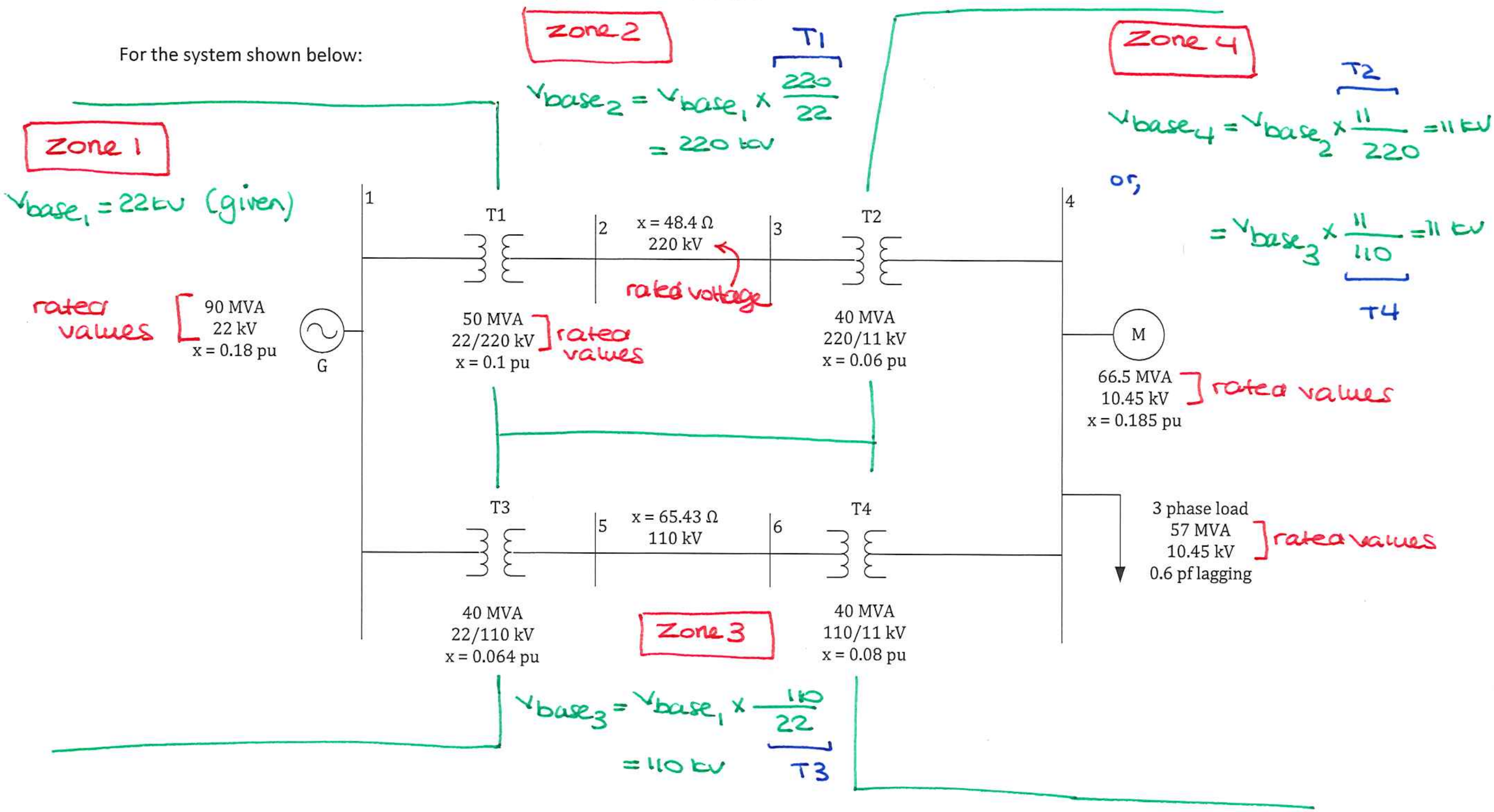
Tutorial 5

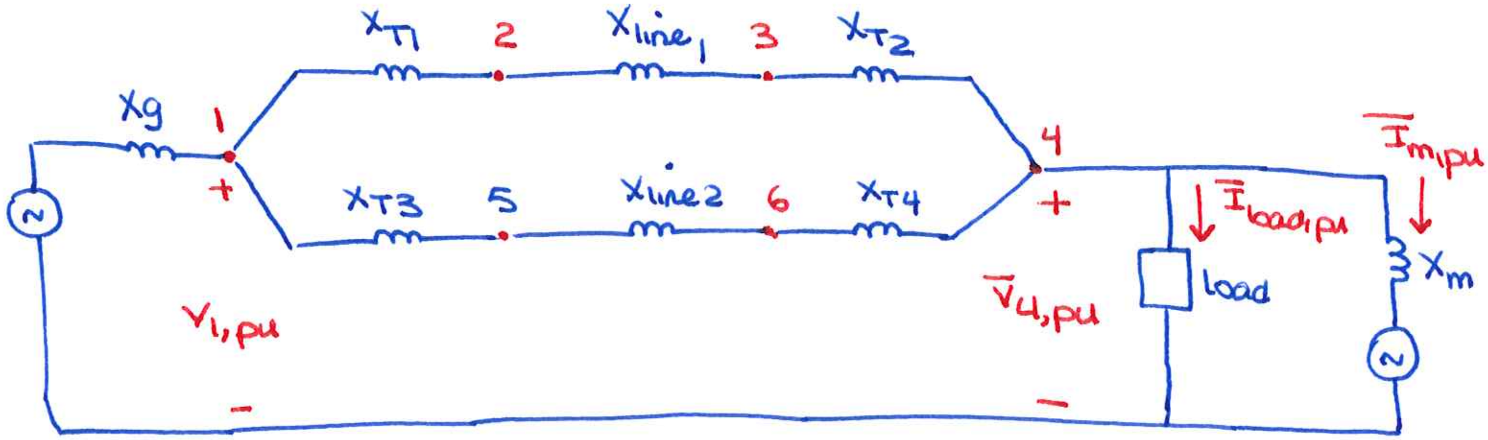
For the system shown below:



a) Draw the impedance diagram in per unit. Use 100 MVA as the base power and 22 kV as the base voltage on the generator side.

b) The motor is operating at full load, 0.8 power factor leading, and a terminal voltage of 10.45kV. The three phase load is also drawing rated power. Calculate the voltage at bus 1 (generator bus) in per unit and kV change of base equation:

$$\boxed{Z_{pu,new} = Z_{pu,old} \times \frac{V_{base,old}^{\,2}}{V_{base,new}^{\,2}} \times \frac{S_{base,new}}{S_{base,old}}}$$



$$X_g = 0.18 \times \left(\frac{\overset{22\,kV}{V_{rated}}}{\underset{22\,kV}{V_{base,1}}}\right)^2 \times \frac{\overset{100\,MVA}{S_{base}}}{\underset{90\,MVA}{S_{rated}}} = 0.2 \text{ pu}$$

$$X_{T1} = 0.1 \times \left(\frac{\overset{22\,kV}{V_{rated,LV}}}{\underset{22\,kV}{V_{base,1}}}\right)^2 \times \frac{S_{base}}{\underset{50\,MVA}{S_{rated}}} = 0.2 \text{ pu}$$

or

$$= 0.1 \times \left(\frac{\overset{220\,kV}{V_{rated,HV}}}{\underset{220\,kV}{V_{base_2}}}\right)^2 \times \frac{100}{50} = 0.2 \text{ pu}$$

Similarly, $X_{T3} = 0.064 \times \left(\frac{22\text{ kV}}{V_{base_1}}\right)^2 \times \frac{100}{40} = 0.16$ pu

$X_{T2} = 0.15$ pu & $X_{T4} = 0.2$ pu ← all calculated using change of base eq

$$X_m = 0.185 \times \left(\frac{\overset{10.45\,kV}{V_{rated}}}{V_{base\,4}}\right)^2 \times \frac{S_{base}}{\underset{66.5\,MVA}{S_{rated}}} = 0.25 \text{ pu}$$

- To find X_{line_1}: $Z_{base_2} = \frac{(V_{base_2})^2}{S_{base}} = 484\ \Omega$

$$X_{line_1} = \frac{48.4\ \Omega}{Z_{base_2}} = 0.1 \text{ pu}$$

To find X_{line2}: $Z_{base_3} = 121\ \Omega$ $\therefore$ $X_{line_2} = 0.54$ pu

Important: At this point, we cannot calculate any pu voltage, current, power quantities unless:

- we make an assumption about the operating conditions. e.g. the generator is operating at rated voltage.
- we are given info about operating conditions, e.g. part b

b) Motor terminal voltage = 10.45 kV (line-to-line)

this is bus 4 operating voltage since motor terminal is directly connected to bus 4

• Note: We can analyze pu circuits similar to 1ϕ circuits but keep in mind that quantities are pu, not 1ϕ.

$$\overline{V}_{4,pu} = \frac{10.45 \angle 0^\circ}{V_{base\,4}} = 0.95 \angle 0^\circ \text{ pu}$$

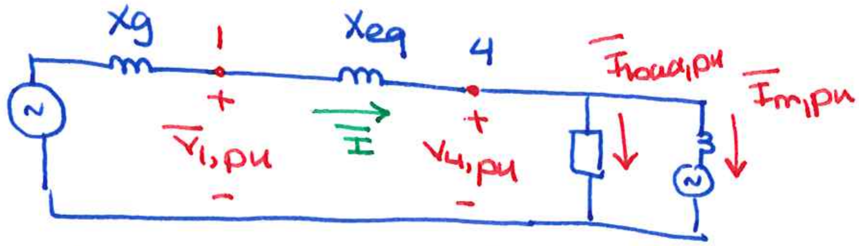
0° ← arbitrary

$$\overline{S}_{m,pu} = \frac{66.5 \angle -36.87^\circ}{S_{base}} = 0.665 \angle -36.87^\circ \text{ pu}$$

$$\overline{I}_{m,pu} = \frac{\overline{S}_{m,pu}^*}{\overline{V}_{4,pu}^*} = \frac{0.665 \angle +36.87^\circ}{0.95 \angle 0} = 0.56 + j0.42 \text{ pu}$$

$$\overline{S}_{load,pu} = \frac{57 \angle 53.13^\circ}{S_{base}} = 0.57 \angle 53.13^\circ \text{ pu}$$

$$\overline{I}_{load,pu} = \frac{\overline{S}_{load,pu}^*}{\overline{V}_{4,pu}^*} = 0.36 - j0.48 \text{ pu}$$



$$X_{eq} = (X_{T1} + X_{line,1} + X_{T2}) \,//\, (X_{T3} + X_{line2} + X_{T4}) = 0.3 \text{ pu}$$

$$\overline{I} = \overline{I}_{load,pu} + \overline{I}_{m,pu} = 0.92 - j0.06$$

$$\overline{V}_{1,pu} = \overline{V}_{4,pu} + \overline{I} \cdot (j X_{eq}) = 1.0 \angle 15.91^\circ \quad pu$$

$$V_1 = V_{1,pu} \times V_{base_1} = 22 \text{ kV}$$

← this is line-line voltage at bus 1.