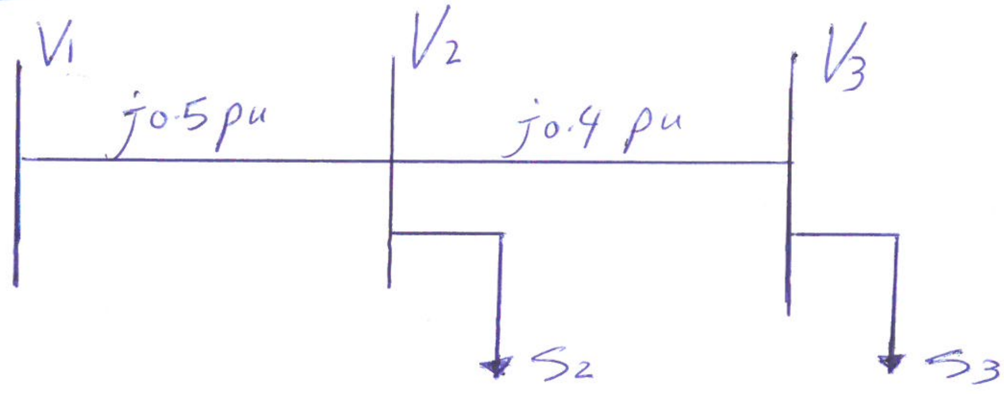
ex9) The one-line diagram of a 3-ϕ system in the fig. below

(1-24)



Impedance are marked in per unit on 100 MVA, 400 kV base. The Load at bus 2 is $S_2 = \underset{MW}{15.93} - j\,33.4$ Mvar and at bus 3 $S_3 = \underset{MW}{77} + \underset{MVar}{j14}$. It is required to hold the voltage at bus 3 at $400\angle 0$ kV

working in per unit, determin the voltage at bus 2 and 1

Sol) $V_B = 400$ (in all point because there is no Transformer)

$S_B = 100$ MVA

$$S_2 = \frac{15.9 - j\,33.4}{100} = 0.159 - j0.334 \text{ pu}$$

$$S_3 = \frac{77 + j14}{100} = 0.77 + j0.14 \text{ pu}$$

$$S_{3_{pu}} = V_{pu_3} I^*_{pu_3}$$

$$I_3 = \frac{S_3^*}{V_3^*}$$

$$V_{3_{pu}} = \frac{\text{actual}}{\text{Base}} = \frac{400}{400}$$

$$V_{3_{pu}} = 1\angle 0 \text{ pu}$$

$$\underset{pu}{I_3} = \frac{S_3^*}{V_3^*} = \frac{0.77 - j0.14}{1\angle 0} = 0.77 - j0.14 \text{ pu}$$

$$V_2 = V_3 + I_3 (j0.4)$$

$$= 1\angle 0 + (0.77 - j0.14) * (j0.4)$$

$$= 1 + j0.308 + 0.056 = 1.056 + j0.308 \text{ pu}$$

$$= 1.1 \angle 16.26°$$

$$\underset{actual}{V_2} = 1.1 \text{ pu} * \underset{Base}{400 k} = \underline{\underline{440 kV}} \text{ Line to Line}$$

$$\underset{pu}{I_2} = \frac{S_2^*}{V_2^*} = \frac{0.1593 + j0.334}{1.1 \angle -16.26°} = 0.054 + j0.332 \text{ pu}$$

$$I_1 = I_2 + I_3$$

$$= (0.054 + j0.332) + (0.77 - j0.14)$$

$$I_1 = 0.824 + j0.192 \text{ pu}$$

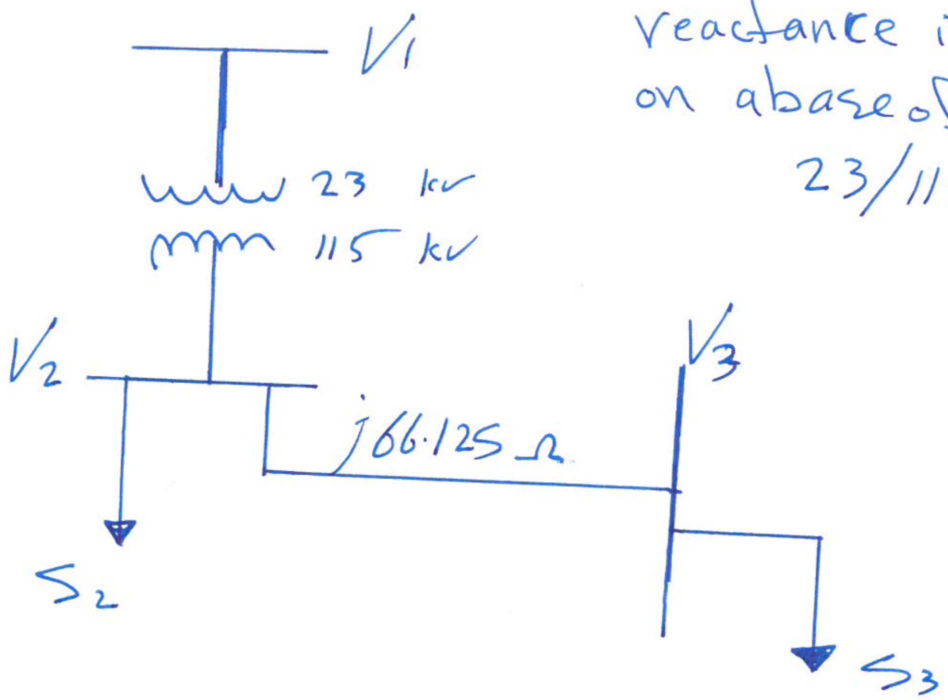
$$V_1 = V_2 + I_1 (j0.5)$$

$$= 1.1 \angle 16.26° + (0.824 + j0.192)(j0.5)$$

$$= 1.2 \angle 36.87°$$

$$V_1 = 400 * 1.2 = \underline{\underline{480 kV}} \text{ Line to Line}$$

ex 10) The one-Line diagram of a 3-φ power system is shown in the fig. below. The Transformer reactance is 20 percent on a base of 100 MVA, 23/115 kV.



The line impedance $Z = j66.125\ \Omega$.

The load $S_2 = 184.8\ MW + j6.6\ MVar$

$S_3 = 0\ MW + j20\ MVar$

It is required to hold the voltage at bus 3 at $115\angle 0$ kV. Working in per unit, find the voltage V_2, V_1

Sol)

$S_B = 100$ MVA

$V_{B1} = 23$ kV

$V_{B2} = 115$ kV

$$S_2 = \frac{184.8 + j6.6}{100} = 1.848 + j0.066 \text{ pu}$$

$$S_3 = \frac{0 + j20}{100} = 0 + j0.2 \text{ pu}$$

$$V_3 = \frac{\text{actual}}{\text{Base}} = \frac{115\angle 0}{115} = 1\angle 0 \text{ pu}$$

$$V_2 = V_3 + I_3 * Z$$

$$I_{3\,pu} = \frac{S_3^*}{V_3^*} = \frac{-j0.2}{1\angle 0} = -j0.2 \text{ pu}$$

$$Z_{pu} = \frac{\text{actual}}{\text{Base}} \quad \Bigg| \quad Z_B = \frac{V_B^2}{S_B} = \frac{115^2}{100}$$

$$Z_B = 132.25\ \Omega$$

$$Z = \frac{66.125}{132.25} = j0.5 \text{ pu}$$

$$V_2 = 1\angle 0 + (-j0.2)(j0.5)$$

$$= 1 + 0.1 = 1.1\angle 0 \text{ pu}$$

$$V_2 = 1.1 * 115 = 126.5 \text{ kV} \quad \text{line to line}$$

$$I_2 = \frac{S_2^*}{V_2^*} = \frac{1.848 - j0.066}{1.1\angle 0} = 1.68 - j0.26$$

$I_1 = I_3 + I_2$

$I_1 = (-j0.2) + (1.68 - j0.06) = 1.68 - j0.26$ pu

$V_1 = I_1 X_{Trans} + V_2$

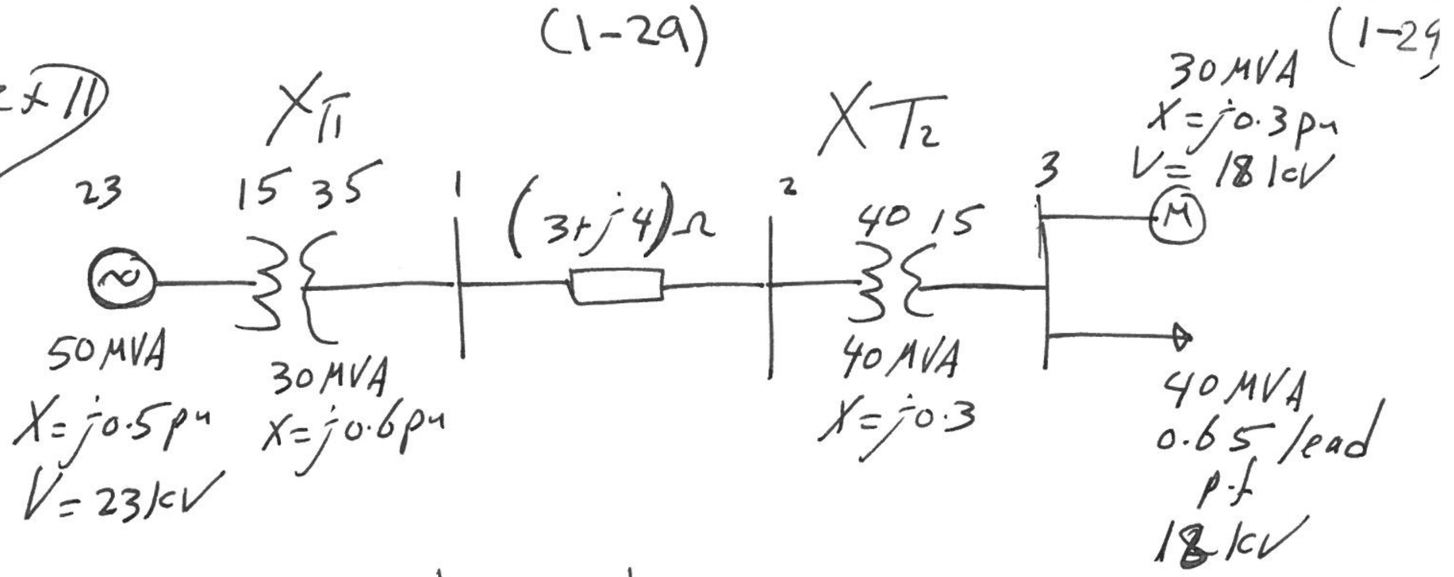
$= (1.68 - j0.26) * (j0.2) + 1.1\angle 0$

$= 1.2\angle 16.26^\circ$

$V_1 = 1.2 * 23 = \underline{27.6 \text{ kV}}$

Line to Line

ex 11)



(1) find perunit impedance

(2) find Em of the motor

Take $V_B = 22$ kV at bus bar 1

$S_B = 100$ MVA

Sol)

$$V_{G_B} = 22 * \frac{15}{35} = 9.4 \text{ kV} \quad (\text{base})$$

$$V_{m_B} = 22 * \frac{15}{40} = 8.25 \text{ kV} \ (\text{base})$$

VLoad

$$X_{G1} = 0.5\left(\frac{100}{50}\right)\left(\frac{23}{9.4}\right)^2 = j5.98 \text{ pu}$$

$$X_{T1} = 0.6\left(\frac{100}{30}\right)\left(\frac{35}{22}\right)^2 = j5.0619 \text{ pu}$$

secondary

$$X_{T2} = 0.3\left(\frac{100}{40}\right)\left(\frac{40}{22}\right)^2 = j2.47 \text{ pu}$$

primary

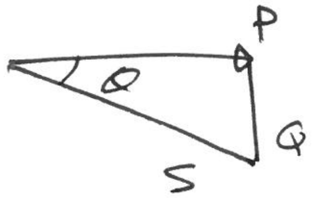
$$X_m = 0.3\left(\frac{100}{30}\right)\left(\frac{18}{8.25}\right)^2 = j4.76 \text{ pu}$$

$$Z_{B\,Line} = \frac{V_B^2}{S_B} = \frac{22^2}{100} = 4.84\ \Omega$$

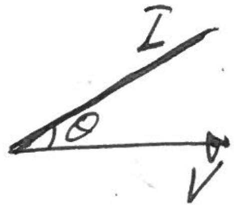
$$Z_{Line}\ pu = \frac{actual}{Base} = \frac{3+j4}{4.84} = 0.62 + j0.826\ pu$$

$$Z_{Load} = \frac{V_{LL}^2}{S^*_L} \Longrightarrow S_L = 40\angle{-\cos^{-1} 0.65} = 40\angle{-49.45}$$

$$Z_{Load} = \frac{18^2}{40\angle 49.45} = 8.1\angle{-49.45}$$



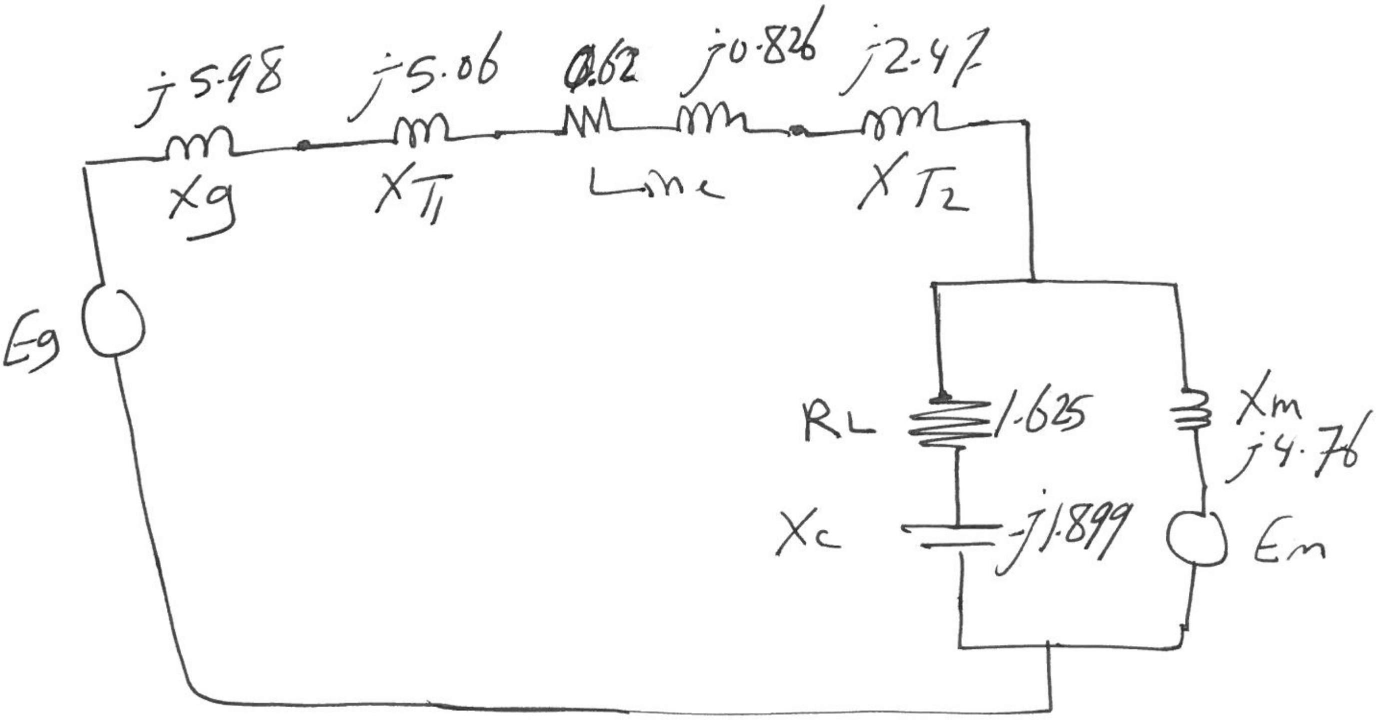
$$Z_{Load} = (5.265 - j6.154)\ \Omega$$



$$Z_{B\,Load} = \frac{V_B^2}{S_B} = \frac{18^2}{100} = 3.24\ \Omega$$

leading p.f

$$Z_{Load\,pu} = \frac{actual}{Base} = \frac{5.265 - j6.154}{3.24} = 1.625 - j1.899\ pu$$



$$E_m = V_m - \hat{I}_m X_m$$

$$V_m = \frac{\text{actual}}{\text{Base}} = \frac{18}{8.25} = 2.18 \text{ pu} = V_3$$

$$S_m = V_m \hat{I}_m^* \Longrightarrow \hat{I}_m = \frac{S_m^*}{V_m^*}$$

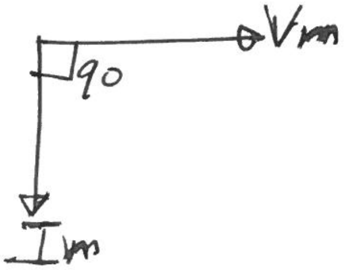
$$\hat{I}_m = \frac{S_m^*}{V_m^*}$$

$S_m = 30 \angle -90$

because it has only reactance $X_m = j0.476$ (leading p.f)

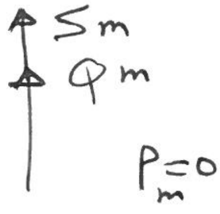
$$S_m = \frac{30\angle 90}{100} = 0.3\angle 90 = j0.3 \text{ pu}$$

$$\hat{I}_m = \frac{S_m^*}{V_m^*} = \frac{-j0.3}{2.18} = -j0.1376 \text{ pu}$$



$$E_m = V_m - \hat{I}_m X_m$$

$$= 2.18\angle 0 - (-j0.1376)^* (j4.76)$$



$$= 2.18 - 0.654$$

$$= 1.526 \text{ pu}$$

OR $E_m = V_2 - (\hat{I}_m + \hat{I}_L) X_{T_2} - \hat{I}_m X_m$

$$V_2 = V_m + (\hat{I}_m + \hat{I}_L) X_{T_2}$$

$$E_m = V_2 - (\hat{I}_m + \hat{I}_L)X_T - \hat{I}_m X_m$$

$$V_2 = (\hat{I}_m + \hat{I}_L)X_T + V_m$$

$$E_m = \cancel{(\hat{I}_m + \hat{I}_L)X_T} + V_m - \cancel{(\hat{I}_m + \hat{I}_L)X_T} - \hat{I}_m X_m$$

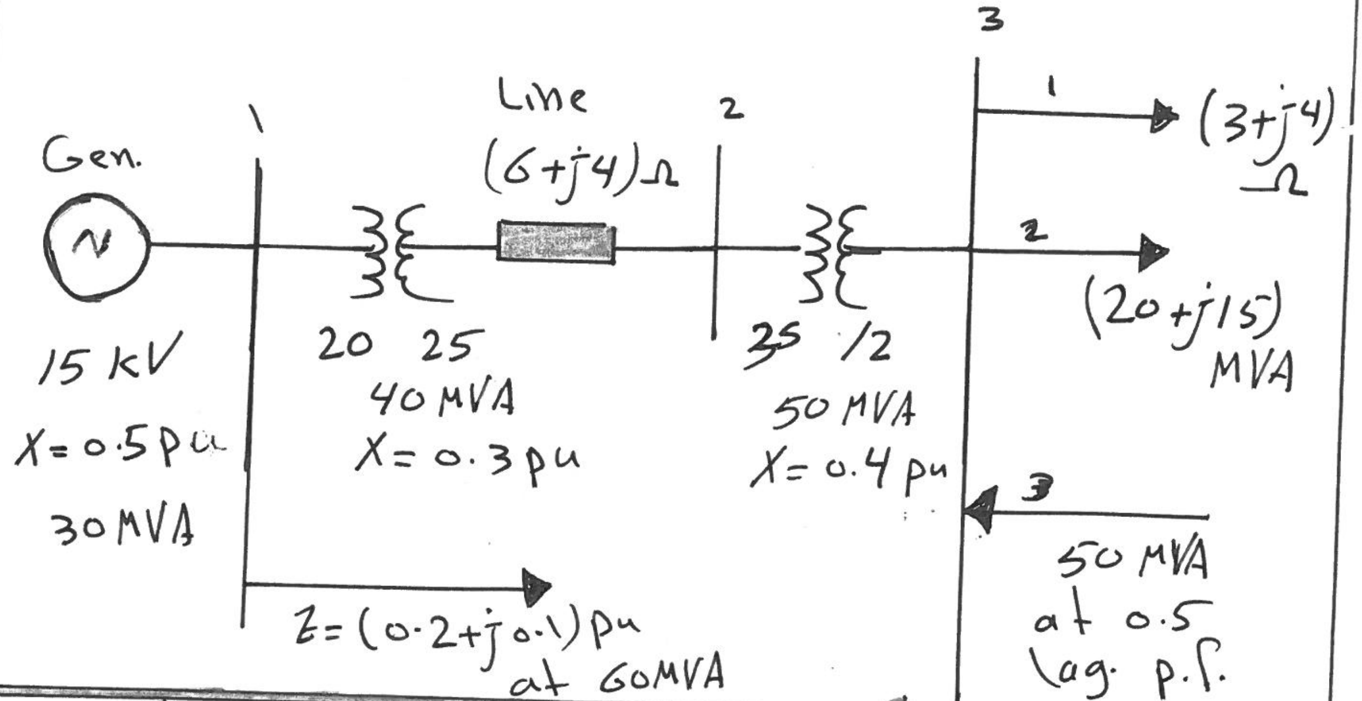
$$\boxed{E_m = V_m - \hat{I}_m X_m}$$

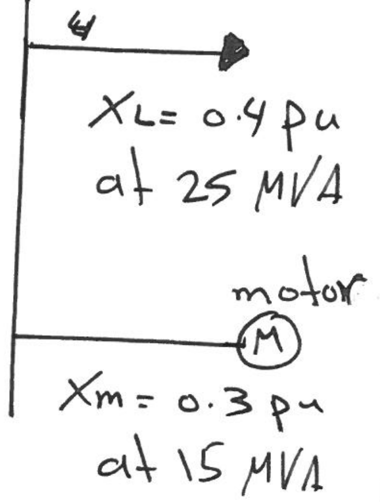
$$E_G = V_m + (\hat{I}_m + \hat{I}_L)(Z + X_G)$$

$$Z = X_{T2} + X_{Line} + X_{T1}$$

Q)

In the fig. below





The base MVA is 100 MVA and the base voltage is at the Line circuit is 40 kV

The terminal voltage at bus bar 3 is 15 kV

Find

1- The per unit impedance
2- The line current (per unit and actual)
3- The actual generator current
4- The emf of the generator and motor
5- Draw the per unit cct.

Sol)

$$V_{B1} = V_{BG} = 40 * \frac{20}{25} = 32 \text{ kV}$$

$$V_{B3} = 40 * \frac{12}{35} = 13.71 \text{ kV}$$

$$X_{G_{new}} = X_{old}\left(\frac{S_{B\,new}}{S_{B\,old}}\right)\left(\frac{V_{B\,old}}{V_{B\,new}}\right)^2$$

$$X_G = 0.5\left(\frac{100}{30}\right)\left(\frac{15}{32}\right)^2 =$$

$$= j\,0.3662 \text{ pu}$$

$$X_{T_1\,pri.} = 0.3\left(\frac{100}{40}\right)\left(\frac{20}{32}\right)^2 =$$

$$= j\,0.293 \text{ pu}$$

$$X_{T_2\,pri} = 0.4\left(\frac{100}{50}\right)\left(\frac{35}{40}\right)^2 =$$

$$= j\,0.6125 \text{ pu}$$

$$Z_{B_{Line}} = \frac{V_B^2}{S_B} = \frac{40^2}{100} = 16\ \Omega$$

$$Z_{\substack{Line\\pu}} = \frac{actual}{Base} = \frac{(6+j4)}{16} = 0.375 + j0.25 \ pu$$

$$Z_{\substack{Load\\3-1}} = (3+j4)\ \Omega$$

$$Z_B = \frac{V_B^2}{S_B} = \frac{13.71^2}{100} = 1.879\ \Omega$$

$$Z_{\substack{Load\ 3-1\\pu}} = \frac{actual}{Base} = \frac{3+j4}{1.879} = 1.596 + j2.128\ pu$$

$$Z_{\substack{Load\ 3-2\\actual}} = \frac{V_L^2}{S^*_{L\ 3-\phi}} = \frac{15^2}{(20+j15)^*} = \frac{15^2}{20-j15}$$

$$= 7.2 + j5.4 \quad \Omega$$

$$Z_{\substack{Load\ 3-2\\Base}} = \frac{V_B^2}{S_B} = \frac{13.71^2}{100} = 1.879\ \Omega$$

$$Z_{\substack{Load\ 3-2\\pu}} = \frac{actual}{Base} = \frac{7.2+j5.4}{1.879}$$

$$= 3.83 + j2.87 \ pu$$

$$Z_{Load\,3\text{-}3,\,actual} = \frac{V_L^2}{S_{L\,3\phi}^*} = \frac{15^2}{(50\angle \cos^{-1} 0.5)^*}$$

$$= \frac{15^2}{(50\angle 60^\circ)^*} = \frac{15^2}{50\angle -60^\circ}$$

$$= 4.5\angle 60^\circ \ \Omega$$

$$Z_{Load\,3\text{-}3,\,pu} = \frac{\text{actual}}{\text{Base}} = \frac{4.5\angle 60^\circ}{1.879}$$

$$= 2.395\angle 60^\circ$$

$$= 1.197 + j2.074 \ \text{pu}$$

$$Z_{Load\,3\text{-}4,\,pu} = j0.4\left(\frac{100}{25}\right)\left(\frac{15}{13.71}\right)^2$$

$$= j1.915 \ \text{pu}$$

$$X_m = 0.3\left(\frac{100}{15}\right)\left(\frac{15}{13.71}\right)^2 =$$

$$= j2.3941 \ \text{pu}$$

$$I_G = I_{Line_{pu}} = I_{L3-1} + I_{L3-2} + I_{L3-3} + I_{L3-4} + I_m$$

$$I_{L3-1_{pu}} = \frac{V_{L_{pu}}}{Z_{L_{3-1_{pu}}}}$$

$$V_{L_{pu}} = \frac{V_{L\,actual}}{V_{L\,Base}} = \frac{15}{13.71} = 1.094\angle 0$$

$$I_{L3-1_{pu}} = \frac{1.094}{1.596 + j2.128}$$

$$I_{L3-1} = 0.246 - j0.329 \quad (\text{lagging}$$

$$= 0.4113\angle -53.13^\circ \text{ pu}$$

$$I_{L3-2_{pu}} = \frac{V_L}{Z_{L_{3-2}}} = \frac{1.094\angle 0}{7.2 + j5.4} =$$

$$= 0.0972 - j0.0729 \text{ pu}$$

$$I_{L3-3_{pu}} = \frac{V_L}{Z_{L3-3}} = \frac{1.094\angle 0}{1.197 + j2.074}$$

$$= 0.2284 - j0.3957$$

pu

$$I_{L_{3-4}\,pu} = \frac{V_L}{Z_{3-4}} = \frac{1.094\angle 0}{j1.915} =$$

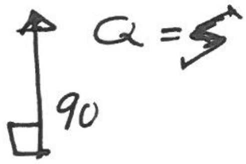
$$= -j0.5713 \ pu$$

$$I_m = \frac{S_m^*}{V_m^*} \quad \text{where} \quad S_m = V_m I_m^*$$

$$S_{m\,pu} = \frac{S_m \ \text{actual}}{S_m \ \text{Base}} = \frac{15}{100} = 0.15 \ pu$$

$$I_m = \frac{(0.15\angle +90^\circ)^*}{1.094\angle 0} = 0.1371\angle -90^\circ$$

where $X_m = j2.394$
means that this motor have
an inductive effect (lagging p.f)
pure inductive in this case.



$I_G = I_{Line} =$
$(0.246 - j0.329) + (0.0972 - j0.0729)$
$- (0.2284 - j0.3957) + (-j0.5713)$
$+ (-j0.1371) =$

$$I_G = I_{Line} = 0.1148 - j0.7146 \text{ pu}$$

$$V_1 = V_3 + I_{Line} * (\underbrace{X_{T_2} + Z_{Line} + X_{T_1}}_{Z})$$

$$V_3 = 1.094 \angle 0$$

$$I_{Line} = 0.1148 - j0.7146$$

$$Z = (j0.6125) + (0.375 + j0.25) + (j0.293)$$

$$Z = 0.375 + j1.155 \text{ pu}$$

$$V_1 = 1.094 + (0.1148 - j0.7146) * (0.375 + j1.155)$$

$$= \underline{1.9628 - j0.135} \text{ pu} = 1.967 \angle -3.93^\circ \text{ pu}$$

$$= 1.967 * \underset{kV}{32} = \underline{\underset{kV}{62.95}}$$

$$ZL_{1\text{-}1\,pu} = (0.2 + j0.1) * \left(\frac{100}{60}\right)\left(\frac{62.95}{32}\right)^2$$

$$= \underline{1.289 + j0.645} \text{ pu}$$

$$E_{g_{pu}} = V_1 + I_G X_G$$

$$= (1.9628 - j0.135) + (0.1148 - j0.7146) * j0.3662$$

$$E_g = 2.2245 - j0.093 \text{ p.u}$$

$$2.2264 \angle -2.393^\circ \text{ pu}$$

$$E_{g_{actual}} = 2.264 * 32$$

$$= 71.244 \text{ kV}$$

$$I_{G_{actual}} = (1.9628 - j0.135) * I_B$$

$$I_B = \frac{S_B}{\sqrt{3}\, V_{B_{gen.}}} = \frac{100*10^6}{\sqrt{3} * 32*10^3}$$

at the generator cct.

$$I_B = 1.80427*10^3 \text{ A}$$

$$= 1804.27 \text{ A}$$

$$I_G = (1.9628 - j0.135) * 1804.27$$

$$= 3541.4 - j243.57 \text{ A}$$

$$I_{\substack{Line \\ actual}} = (1.9628 - j0.135) * I_B$$

$$I_{actual} = I_{pu} * I_B$$

$$I_{B_{Line}} = \frac{S_B}{\sqrt{3}\, V_{B_{Line}}} = \frac{100*10^6}{\sqrt{3} * 40*10^3}$$

$$= 1443.41 \quad A$$

$$I_{\substack{Line \\ actual}} = 1443.41 * (1.9628 - j0.135)$$

$$= 2833.1 - j194.86 \quad A$$

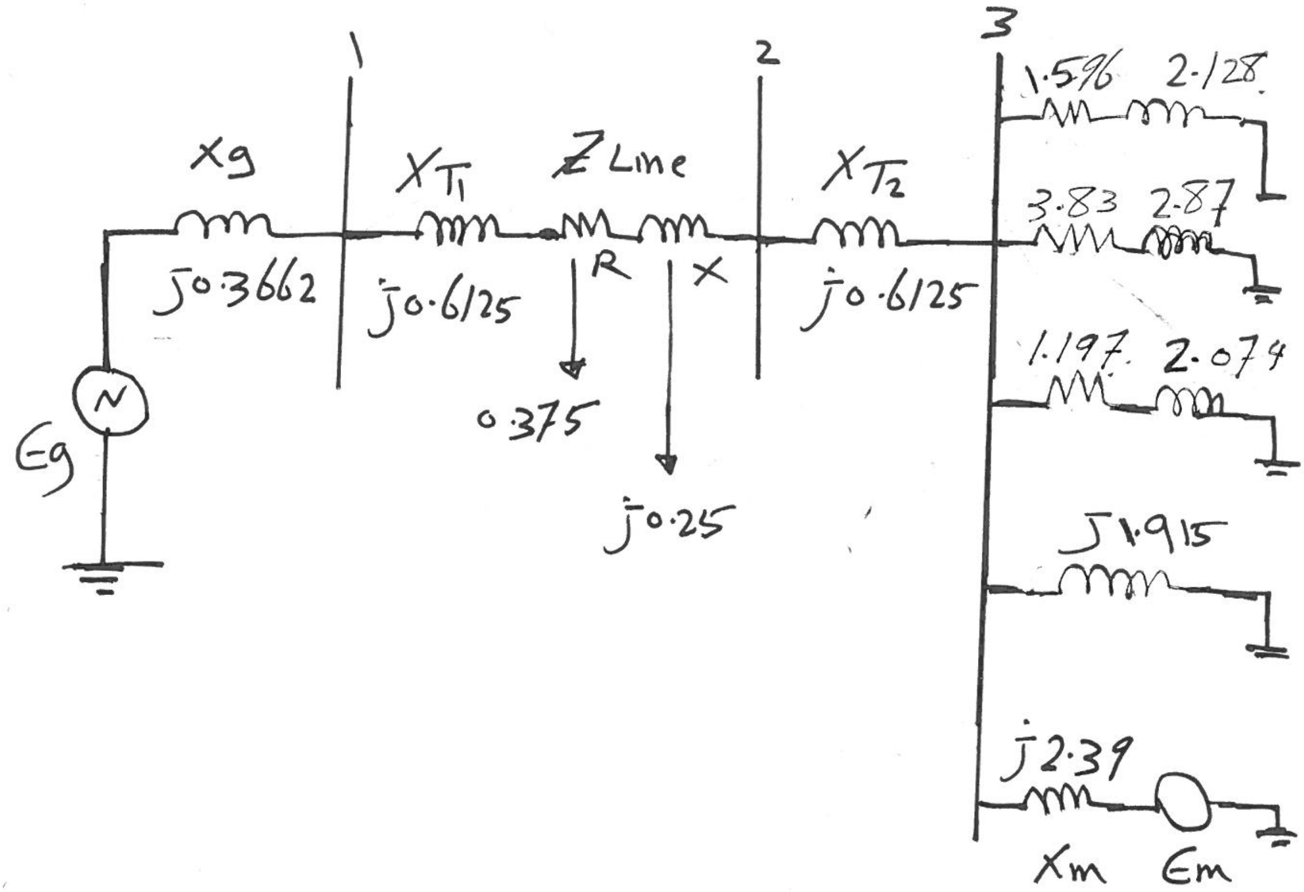
$$emf_{\substack{motor \\ pu}} = E_m = V_m - I_m X_m$$

$$= 1.094 \angle 0 - (-j0.1371) * (j2.394)$$

$$= \underline{0.7657 \ pu}$$

$$emf_{\substack{m \\ actual}} = 0.7657 * 13.71 \ kV$$

$$= \underline{\underline{10.498 \ kV}}$$


1
2
3
Xg
X_{T_1}
Z Line
X_{T_2}
j0.3662
j0.6125
R
X
j0.6125
0.375
j0.25
Eg
1.596
2.128
3.83
2.87
1.197
2.074
j1.915
j2.39
Xm
Em