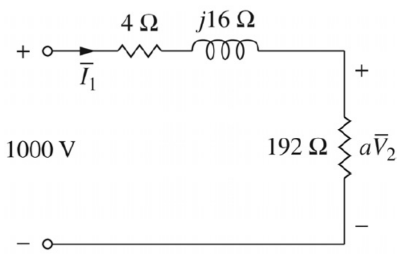
Set 2 Solution

3.9 (a) $a = N_1 / N_2 = 2000/500 = 4$

$R_{eq1} = 2 + 0.125(4)^2 = 4\ \Omega$; $X_{eq1} = 8 + (0.5)4^2 = 16\ \Omega$

$\bar{Z}_2' = 12(4)^2 = 192\ \Omega$

The equivalent circuit referred to primary is shown below:



$$\bar{I}_1 = \frac{1000\angle 0^\circ}{192 + 4 + j16} = 5.08\angle -4.67^\circ\ \text{A}$$

$$a\bar{V}_2 = 192(5.08\angle -4.67^\circ) = 975.4\angle -4.67^\circ\ \text{V}$$

$$\bar{V}_2 = \frac{975.4\angle -4.67^\circ}{4} = 243.8\angle -4.67^\circ\ \text{V} \quad \leftarrow$$

(b) $V_{2,NL} = V_1 / a = 1000/4 = 250\ \text{V}$

$$\text{Voltage Regulation} = \frac{250 - 243.8}{243.8} \times 100 = 2.54\% \quad \leftarrow$$

3.10 Rated current magnitude on the 66-kV side is given by

$$I_1 = \frac{13{,}000}{66} = 197.0\ \text{A}$$

$$I_1^2 R_{eq1} = (197.0)^2 R_{eq1} = 100 \times 10^3$$

$$\therefore R_{eq1} = 2.58\ \Omega \quad \leftarrow$$

$$\bar{Z}_{eq1} = \frac{5.5 \times 10^3}{197.0} = 27.9\ \Omega$$

Then $X_{eq1} = \sqrt{\bar{Z}_{eq1}^2 - R_{eq1}^2} = \sqrt{(27.9)^2 - (2.58)^2} = 27.8\ \Omega \quad \leftarrow$

3.11 Turns Ratio $= a = N_1/N_2 = 66/11.5 = 5.74$

Just a long-winded way of saying: $G_c = P_{oc} / (V_{rated,\ HV})^2$

With high-voltage side designated as 1, and L-V side as 2,

$$(11.5\times10^3)^2 a^2 G_{C1} = 65\times10^3 \text{, based on O.C test.}$$

Note: To transfer shunt admittance from H-V side to L-V side, we need to multiply by a^2.

$$\therefore G_{C1} = \frac{65\times10^3}{(11.5\times10^3)^2(5.74)^2} = 14.9\times10^{-6}\text{ S} \leftarrow$$

$$Y_1 = \frac{I_2}{V_2}\times\frac{1}{a^2} = \frac{30}{11.5\times10^3}\times\frac{1}{(5.74)^2} = 79.2\times10^{-6}\text{ S} \longleftrightarrow$$

Identical to: $|Y| = I_{HV,OC} / V_{rated,\ HV}$

$$\therefore B_{m1} = \sqrt{Y_1^2 - G_{C1}^2} = 10^{-6}\sqrt{(79.2)^2-(14.9)^2}$$

$$= 77.79\times10^{-6}\text{ S} \leftarrow$$

In the given operating conditions (10 MW of load at 0.8 PF and rated voltage):

$$S_{load} = \frac{P_{load}}{pf} = \frac{10}{0.8} = 12.5\ MVA$$

$$I_{load}(referred\ to\ HV\ side) = \frac{S_{load}}{V_{load,ref\ to\ HV}} = \frac{12.5\times10^6}{66\times10^3} = 189.4\ A$$

$$Losses\ in\ winding\ resistance = I_{load}(referred\ to\ HV\ side)^2 \times R_{eq,1} = 189.4^2\ \times 2.58 = 92.5\ KW$$

(In the above calculation, we neglected the excitation branch current and assumed that all of I_{load} referred to HV side will go through R_{eq}.You can calculate the excitation branch current = 66kV/(G_c+jB_m) and subtract this from I_{load} referred to HV side to get the exact current through R_{eq}.)

$$Losses\ in\ G_c = 65kW\ (from\ the\ OC\ test. Can\ you\ see\ why?)$$

$$\eta = \frac{10\ MW}{10\ MW + 92.5\ KW + 65\ KW} = 98.4\%$$

3.23

$$G: X = 0.18\left(\frac{100}{90}\right) = 0.2; T_1 : X = 0.1\left(\frac{100}{50}\right) = 0.2$$

$$T_2 : X = 0.06\left(\frac{100}{40}\right) = 0.15; T_2 : X = 0.06\left(\frac{100}{40}\right) = 0.15$$

$$T_3 : X = 0.064\left(\frac{100}{40}\right) = 0.16; T_4 : X = 0.08\left(\frac{100}{40}\right) = 0.2$$

$$M : X = 0.185\left(\frac{100}{66.5}\right)\left(\frac{10.45}{11}\right)^2 = 0.25$$

For Line 1, $Z_{BASE} = \dfrac{(220)^2}{100} = 484\,\Omega$ and $X = \dfrac{48.4}{484} = 0.1$

For Line 2, $Z_{BASE} = \dfrac{(110)^2}{100} = 121\,\Omega$ and $X = \dfrac{65.43}{121} = 0.54$

The load complex power at 0.6 Lagging *pf* is $\overline{S}_{L(3\phi)} = 57\angle 53.13^\circ\,\text{MVA}$

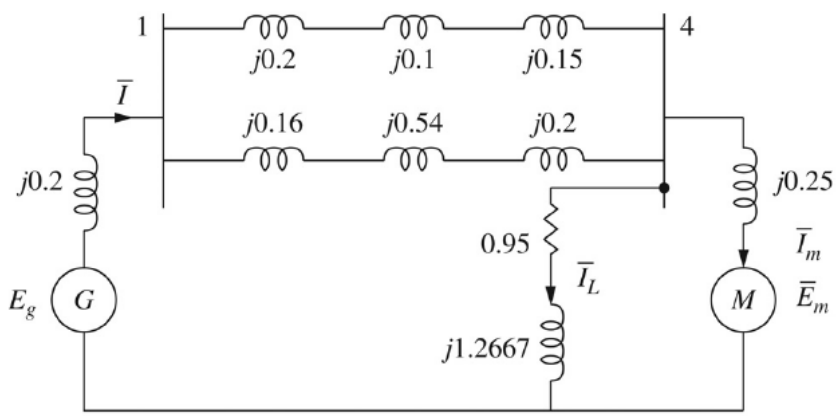
$\therefore$ The load impedance in OHMS is $\overline{Z}_L = \dfrac{(10.45)^2}{57\angle -53.13^\circ} = \dfrac{V_{LL}^2}{\overline{S}^*_{L(3\phi)}}$

$$= 1.1495 + j1.53267\,\Omega$$

The base impedance for the load is $(11)^2/100 = 1.21\,\Omega$

$\therefore$ Load Impedance in pu $= \dfrac{1.1495 + j1.53267}{1.21} = 0.95 + j1.2667$

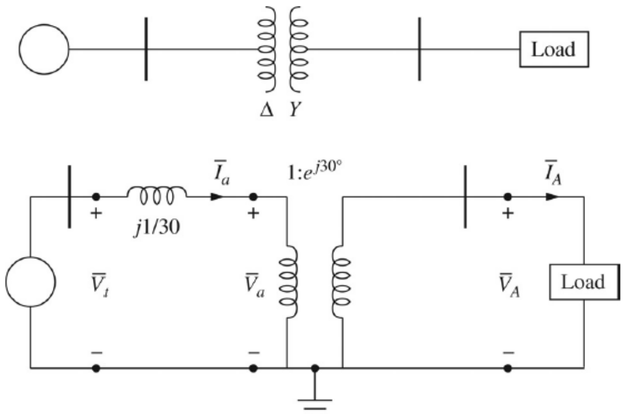
The per-unit equivalent circuit is shown below:



Per-unit impedance diagram

You are not required to know how to model motors in 487, yet! For (steady-state) circuit analysis, motors are modelled identical to generators, i.e. they are an EMF behind an impedance. The only difference is generators produce power while motors consume it.

3.38 (a) The single-line diagram and the per-phase equivalent circuit, with all parameters in per unit, are given below:



Reminder: Pf = cos (θ_v-θ_I)
Since we're choosing θ_v=0,
θ_I=-cos^{-1}(Pf)

Current supplied to the load is $\dfrac{240\times10^3}{\sqrt{3}\times230}=602.45\,\text{A}$

Base current at the load is $100{,}000\big/\left(\sqrt{3}\times230\right)=251.02\,\text{A}$

The power-factor angle of the load current is $\theta=\cos^{-1}0.9=25.84°$ Lag . With $\bar{V}_A=1.0\angle0°$ as reference, the line currents drawn by the load are

$$I_A=\frac{602.45}{251.02}\angle-25.84°=2.4\angle-25.84° \text{ per unit}$$

$$\bar{I}_B=2.4\angle-25.84°-120°=2.4\angle-145.84° \text{ per unit}$$

$$\bar{I}_C=2.4\angle-25.84°+120°=2.4\angle94.16° \text{ per unit}$$

(b) Low-voltage side currents further lag by 30° because of phase shift

$$\bar{I}_a=2.4\angle-55.84°;\bar{I}_b=2.4\angle175.84°;\bar{I}_c=2.4\angle64.16°$$

(c) The transformer reactance modified for the chosen base is

$$X=0.11\times\left(100/330\right)=\frac{1}{30}\text{pu}$$

The terminal voltage of the generator is then given by

$$\begin{aligned}\bar{V}_t&=\bar{V}_A\angle-30°+jX\bar{I}_a\\&=1.0\angle-30°+j\left(1/30\right)\left(2.4\angle-55.34°\right)\\&=0.9322-j0.4551=1.0374\angle-26.02°\,\text{pu}\end{aligned}$$

Terminal voltage of the generator is $23\times1.0374=23.86\,\text{kV}$
The real power supplied by the generator is

$$\text{Re}\left[\bar{V}_t\bar{I}_a^*\right]=1.0374\times2.4\cos\left(-26.02°+55.84°\right)=2.16\,\text{pu}$$

which corresponds to 216 MW absorbed by the load, since there are no I^2R losses.

(d) By omitting the phase shift of the transformer altogether, recalculating $\overline{V}_t$ with the reactance $j\left(\frac{1}{30}\right)$ on the high-voltage side, the student will find the same value for V_t i.e. $\left|\overline{V}_t\right|$.

3.49 Base kV in transmission-line circuit = 132 kV

Base kV in the generator G_1 circuit = $132 \times \frac{13.2}{165} = 10.56\,\text{kV}$

Base kV in the generator G_2 circuit = $132 \times \frac{13.8}{165} = 11.04\,\text{kV}$

On the common base of 100 MVA for the entire system,

$$G_1 : \bar{Z} = j0.15 \times \frac{100}{50} \times \left(\frac{13.2}{10.56}\right)^2 = j0.4688\,\text{pu}$$

$$G_2 : \bar{Z} = j0.15 \times \frac{100}{20} \times \left(\frac{13.8}{11.04}\right)^2 = j1.1719\,\text{pu}$$

$$T_1 : \bar{Z} = j0.1 \times \frac{100}{80} \times \left(\frac{13.2}{10.56}\right)^2 = j0.1953\,\text{pu}$$

$$T_2 : \bar{Z} = j0.1 \times \frac{100}{40} \times \left(\frac{13.8}{11.04}\right)^2 = j0.3906\,\text{pu}$$

Base impedance in transmission-line circuit is

$$\frac{(132)^2}{100} = 174.24\,\Omega$$

$$\bar{Z}_{TR.LINE\,1} = \frac{50 \times j200}{174.24} = 0.287 + j1.1478\,\text{pu}$$

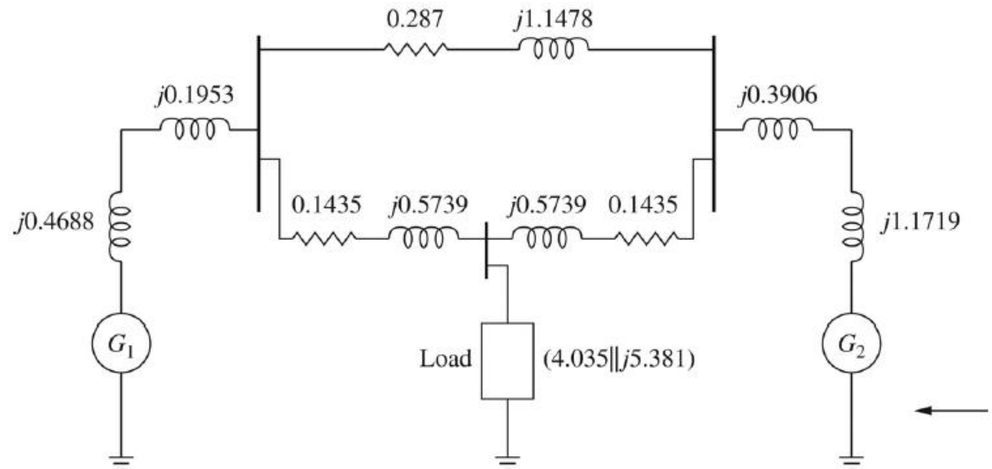
$$\bar{Z}_{TR.LINE\,2} = \frac{25 \times j100}{174.24} = 0.1435 + j0.5739\,\text{pu}$$

$$LOAD : 40(0.8 + j0.6) = (32 + j24)\,\text{MVA}$$

$$R_{LOAD} = \frac{(150)^2}{32} = 703.1\,\Omega = \frac{703.1}{174.24}\,\text{pu} = 4.035\,\text{pu}$$

$$X_{LOAD} = \frac{(150)^2}{24} = 937.5\,\Omega = \frac{937.5}{174.24}\,\text{pu} = 5.381\,\text{pu}$$

$$\bar{Z}_{LOAD} = \left(R_{LOAD} \parallel jX_{LOAD}\right)$$



Impedance diagram of the system with pu values