Transformers Suggested Problems

Dr. Muhammad Abu-Khaizaran

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2-1. A 100-kVA 8000/277-V distribution transformer has the following resistances and reactances:

$$R_P = 5\ \Omega \qquad R_S = 0.005\ \Omega$$

$$X_P = 6\ \Omega \qquad X_S = 0.006\ \Omega$$

$$R_C = 50\ \text{k}\Omega \qquad X_M = 10\ \text{k}\Omega$$

The excitation branch impedances are given referred to the high-voltage side of the transformer.

(a) Find the equivalent circuit of this transformer referred to the low-voltage side.

(b) Find the per-unit equivalent circuit of this transformer.

(c) Assume that this transformer is supplying rated load at 277 V and 0.85 PF lagging. What is this transformer's input voltage? What is its voltage regulation?

(d) What are the copper losses and core losses in this transformer under the conditions of part *(c)*?

(e) What is the transformer's efficiency under the conditions of part *(c)*?

SOLUTION

(a) The turns ratio of this transformer is a = 8000/277 = 28.88. Therefore, the primary impedances referred to the low voltage (secondary) side are

$$R_P' = \frac{R_P}{a^2} = \frac{5\ \Omega}{(28.88)^2} = 0.006\ \Omega$$

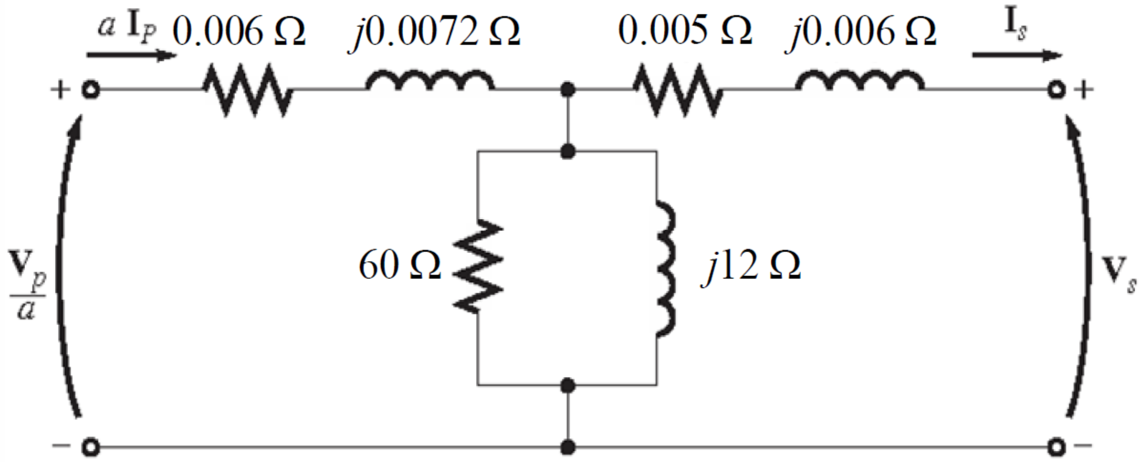
$$X_P' = \frac{R_P}{a^2} = \frac{6\ \Omega}{(28.88)^2} = 0.0072\ \Omega$$

and the excitation branch elements referred to the secondary side are

$$R_C' = \frac{R_C}{a^2} = \frac{50\ \text{k}\Omega}{(28.88)^2} = 60\ \Omega$$

$$X_M' = \frac{X_M}{a^2} = \frac{10\ \text{k}\Omega}{(28.88)^2} = 12\ \Omega$$

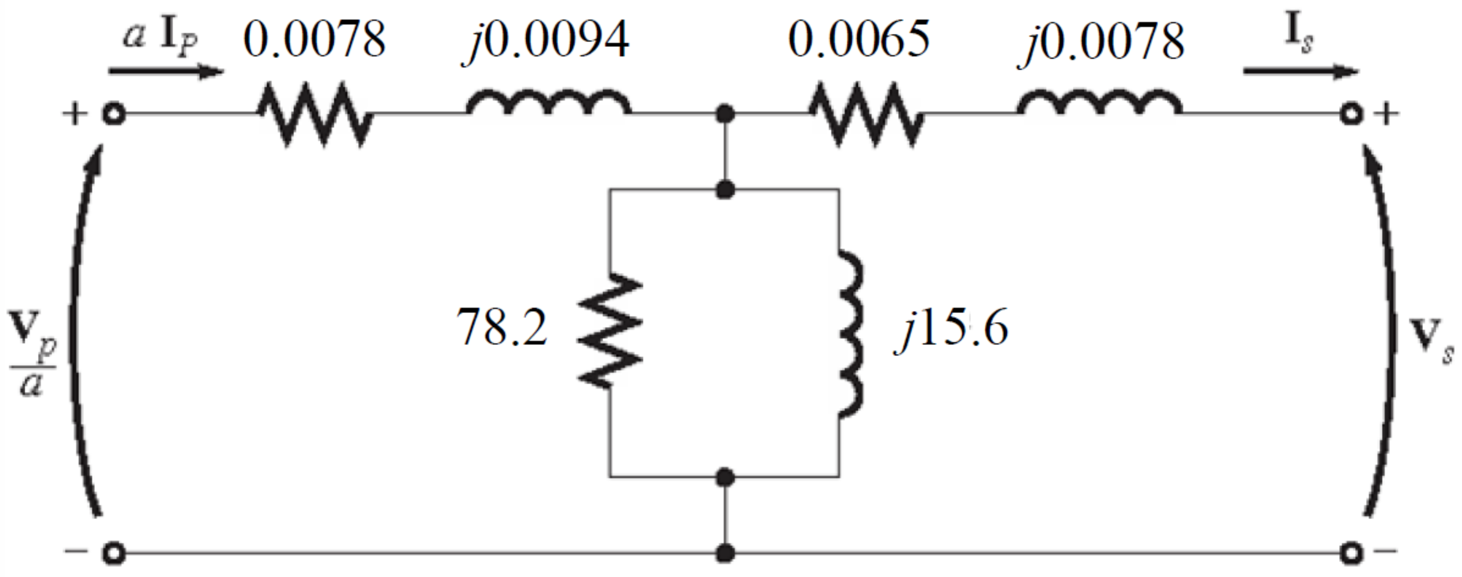
The resulting equivalent circuit is



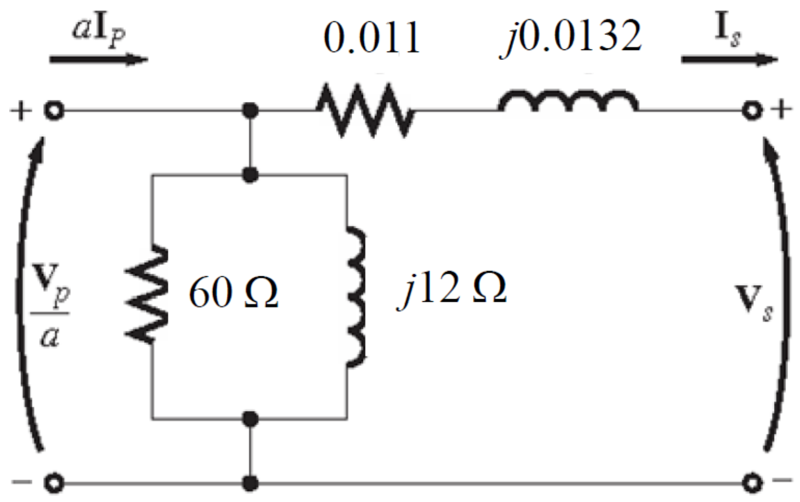
(b) The rated kVA of the transformer is 100 kVA, and the rated voltage on the secondary side is 277 V, so the rated current in the secondary side is 100 kVA/277 V = 361 A. Therefore, the base impedance on the primary side is

$$Z_{base} = \frac{V_{base}}{I_{base}} = \frac{277 \text{ V}}{361 \text{ A}} = 0.767 \ \Omega$$

Since $Z_{pu} = Z_{actual} / Z_{base}$, the resulting per-unit equivalent circuit is as shown below:



(c) To simplify the calculations, use the simplified equivalent circuit referred to the secondary side of the transformer:



The secondary current in this transformer is

$$\mathbf{I}_S = \frac{100 \text{ kVA}}{277 \text{ V}} \angle -31.8° \text{ A} = 361\angle -31.8° \text{ A}$$

Therefore, the primary voltage on this transformer (referred to the secondary side) is

$$\mathbf{V}_P' = \mathbf{V}_S + \left(R_{EQ} + jX_{EQ}\right) \mathbf{I}_S$$

$$\mathbf{V}_P' = 277\angle 0° \text{ V} + \left(0.011 + j0.0132\right)\left(361\angle -31.8° \text{ A}\right) = 283\angle 0.4° \text{ V}$$

The voltage regulation of the transformer under these conditions is

$$\text{VR} = \frac{283 - 277}{277} \times 100\% = 2.2\%$$

(d) Under the conditions of part *(c)*, the transformer's output power copper losses and core losses are:

$$P_{OUT} = S \cos\theta = (100\text{ kVA})(0.85) = 85\text{ kW}$$

$$P_{CU} = (I_S)^2 R_{EQ} = (361)^2 (0.011) = 1434\text{ W}$$

$$P_{core} = \frac{V_P'^2}{R_C} = \frac{283^2}{60} = 1335\text{ W}$$

(e) The efficiency of this transformer is

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{CU} + P_{core}} \times 100\% = \frac{85{,}000}{85{,}000 + 1434 + 1335} \times 100\% = \mathbf{96.8\%}$$

2-7. A 30-kVA 8000/230-V distribution transformer has an impedance referred to the primary of $20 + j100\ \Omega$. The components of the excitation branch referred to the primary side are $R_C = 100\ \text{k}\Omega$ and $X_M = 20\ \text{k}\Omega$.

(a) If the primary voltage is 7967 V and the load impedance is $Z_L = 2.0 + j0.7\ \Omega$, what is the secondary voltage of the transformer? What is the voltage regulation of the transformer?

(b) If the load is disconnected and a capacitor of $-j3.0\ \Omega$ is connected in its place, what is the secondary voltage of the transformer? What is its voltage regulation under these conditions?

SOLUTION

(a) The easiest way to solve this problem is to refer all components to the *primary* side of the transformer. The turns ratio is $a = 8000/230 = 34.78$. Thus the load impedance referred to the primary side is

$$Z_L' = (34.78)^2 (2.0 + j0.7\ \Omega) = 2419 + j847\ \Omega$$

The referred secondary current is

$$\mathbf{I}_S' = \frac{7967\angle 0°\ \text{V}}{(20 + j100\ \Omega) + (2419 + j847\ \Omega)} = \frac{7967\angle 0°\ \text{V}}{2616\angle 21.2°\ \Omega} = 3.045\angle -21.2°\ \text{A}$$

and the referred secondary voltage is

$$\mathbf{V}_S' = \mathbf{I}_S' Z_L' = (3.045\angle -21.2^\circ \text{ A})(2419 + j847\ \Omega) = 7804\angle -1.9^\circ \text{ V}$$

The actual secondary voltage is thus

$$\mathbf{V}_S = \frac{\mathbf{V}_S'}{a} = \frac{7804\angle -1.9^\circ \text{ V}}{34.78} = 224.4\angle -1.9^\circ \text{ V}$$

The voltage regulation is

$$\text{VR} = \frac{7967\text{-}7804}{7804} \times 100\% = 2.09\%$$

(b) The easiest way to solve this problem is to refer all components to the *primary* side of the transformer. The turns ratio is again $a = 34.78$. Thus the load impedance referred to the primary side is

$$Z_L' = (34.78)^2(-j3.0\ \Omega) = -j3629\ \Omega$$

The referred secondary current is

$$\mathbf{I}_S' = \frac{7967\angle 0°\ \text{V}}{(20 + j100\ \Omega) + (-j3629\ \Omega)} = \frac{7967\angle 0°\ \text{V}}{3529\angle -89.7°\ \Omega} = 2.258\angle 89.7°\ \text{A}$$

and the referred secondary voltage is

$$\mathbf{V}_S' = \mathbf{I}_S' Z_L' = (2.258\angle 89.7°\ \text{A})(-j3629\ \Omega) = 8194\angle -0.3°\ \text{V}$$

The actual secondary voltage is thus

$$\mathbf{V}_S = \frac{\mathbf{V}_S'}{a} = \frac{8194\angle -0.3°\ \text{V}}{34.78} = 235.6\angle -0.3°\ \text{V}$$

The voltage regulation is

$$\text{VR} = \frac{7967 - 8194}{8194} \times 100\% = -2.77\%$$

2-20. A 50-kVA 20,000/480-V 60-Hz single-phase distribution transformer is tested with the following results:

Open-circuit test (measured from secondary side)	Short-circuit test (measured from primary side)
$V_{OC} = 480$ V	$V_{SC} = 1130$ V
$I_{OC} = 4.1$ A	$I_{SC} = 1.30$ A
$P_{OC} = 620$ W	$P_{SC} = 550$ W

(a) Find the per-unit equivalent circuit for this transformer at 60 Hz.

(b) What is the efficiency of the transformer at rated conditions and unity power factor? What is the voltage regulation at those conditions?

(c) What would the ratings of this transformer be if it were operated on a 50-Hz power system?

(d) Sketch the equivalent circuit of this transformer referred to the primary side *if it is operating at 50 Hz.*

(e) What is the efficiency of the transformer at rated conditions on a 50 Hz power system, with unity power factor? What is the voltage regulation at those conditions?

(f) How does the efficiency of a transformer at rated conditions and 60 Hz compare to the same physical device running a 50 Hz?

SOLUTION

(a) The base impedance of this transformer referred to the primary side is

$$Z_{\text{base},P} = \frac{(V_P)^2}{S} = \frac{(20{,}000\text{ V})^2}{50\text{ kVA}} = 8\text{ k}\Omega$$

The base impedance of this transformer referred to the secondary side is

$$Z_{\text{base},S} = \frac{(V_S)^2}{S} = \frac{(480\text{ V})^2}{50\text{ kVA}} = 4.608\ \Omega$$

The open circuit test yields the values for the excitation branch (referred to the *secondary* side):

$$|Y_{EX}| = \frac{I_{\phi,OC}}{V_{\phi,OC}} = \frac{4.10\text{ A}}{480\text{ V}} = 0.00854\ \text{ S}$$

$$\theta = -\cos^{-1}\left(\frac{P_{OC}}{V_{OC}\ I_{OC}}\right) = -\cos^{-1}\left(\frac{620\text{ W}}{(480\text{ V})(4.1\text{ A})}\right) = -71.6°$$

$$Y_{EX} = G_C - jB_M = 0.00854\angle -71.6° = 0.00270 - j0.00810$$

$$R_C = 1/G_C = 370\ \Omega$$

$$X_M = 1/B_M = 123\ \Omega$$

The excitation branch elements can be expressed in per-unit as

$$R_C = \frac{370\ \Omega}{4.608\ \Omega} = 80.3\text{ pu} \qquad X_M = \frac{123\ \Omega}{4.608\ \Omega} = 26.7\text{ pu}$$

The short circuit test yields the values for the series impedances (referred to the *primary* side):

$$\left|Z_{EQ}\right| = \frac{V_{SC}}{I_{SC}} = \frac{1130\text{ V}}{1.30\text{ A}} = 869\ \ \Omega$$

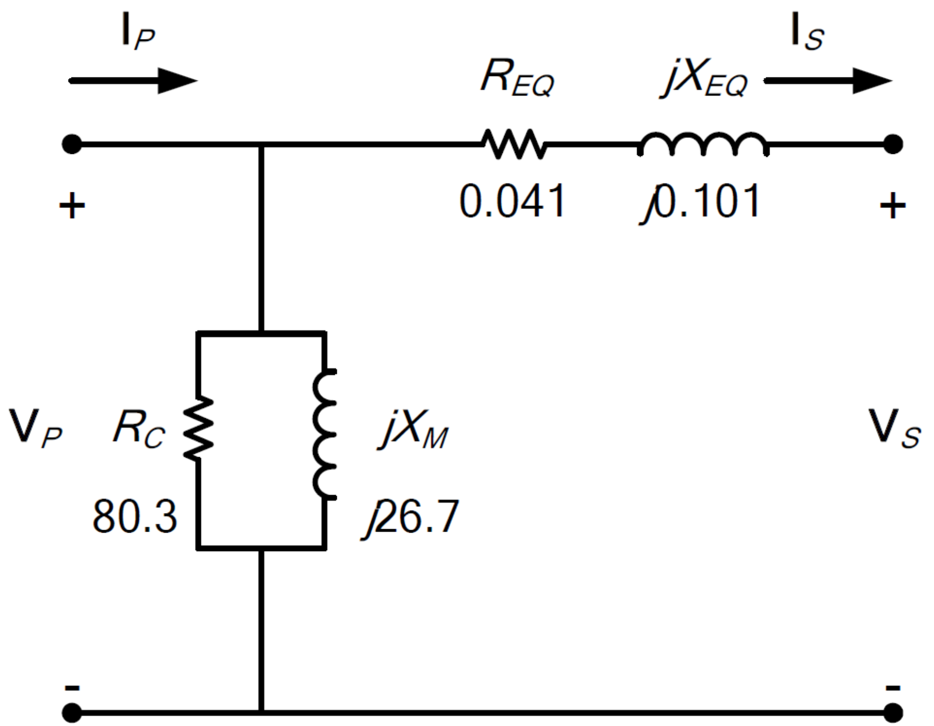
$$\theta = \cos^{-1}\left(\frac{P_{SC}}{V_{SC}\ I_{SC}}\right) = \cos^{-1}\left(\frac{550\text{ W}}{(1130\text{ V})(1.30\text{ A})}\right) = 68.0°$$

$$Z_{EQ} = R_{EQ} + jX_{EQ} = 869\angle 68° = 326 + j806\ \Omega$$

The resulting per-unit impedances are

$$R_{EQ} = \frac{326\ \Omega}{8{,}000\ \Omega} = 0.041\text{ pu} \qquad X_{EQ} = \frac{806\ \Omega}{8{,}000\ \Omega} = 0.101\text{ pu}$$

The per-unit equivalent circuit is



(b) The per-unit primary voltage at rated conditions and unity power factor is

$$\mathbf{V}_P = \mathbf{V}_S + \mathbf{I}_S Z_{EQ}$$

$$\mathbf{V}_P = 1\angle 0^\circ \text{ V} + (1\angle 0^\circ)(0.041 + j0.101\ \Omega) = 1.046\angle 5.54^\circ \text{ pu}$$

The per-unit power consumed by R_{EQ} is

$$P_{EQ} = I^2 R = (1 \text{ pu})^2 (0.041 \text{ pu}) = 0.041 \text{ pu}$$

The per-unit power consumed by R_C is

$$P_C = \frac{V_P^{\,2}}{R_C} = \frac{(1.046)^2}{80.3} = 0.0136 \text{ pu}$$

Therefore the efficiency of this transformer at rated load and unity power factor is

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_{out}}{P_{out} + P_{EQ} + P_C} \times 100\% = \frac{1.00}{1.00 + 0.041 + 0.0136} \times 100\% = 94.8\%$$

and the voltage regulation is

$$\text{VR} = \frac{1.046 - 1.00}{1.00} \times 100\% = 4.6\%$$

(c) The voltage and apparent power ratings of this transformer must be reduced in direct proportion to the decrease in frequency in order to avoid flux saturation effects in the core. At 50 Hz, the ratings are

$$S_{\text{rated}} = \frac{50\text{ Hz}}{60\text{ Hz}}\left(50\text{ kVA}\right) = 41.7\text{ kVA}$$

$$V_{P,\text{rated}} = \frac{50\text{ Hz}}{60\text{ Hz}}\left(20,000\text{ V}\right) = 16,667\text{ kV}$$

$$V_{S,\text{rated}} = \frac{50\text{ Hz}}{60\text{ Hz}}\left(480\text{ V}\right) = 400\text{ V}$$

(d) The transformer parameters referred to the primary side *at 60 Hz* are:

$$R_C = Z_{\text{base}} R_{C,\text{pu}} = (8\text{ k}\Omega)(80.3) = 642\text{ k}\Omega$$

$$X_M = Z_{\text{base}} X_{M,\text{pu}} = (8\text{ k}\Omega)(26.7) = 214\text{ k}\Omega$$

$$R_{\text{EQ}} = Z_{\text{base}} R_{EQ,\text{pu}} = (8\text{ k}\Omega)(0.041) = 328\ \Omega$$

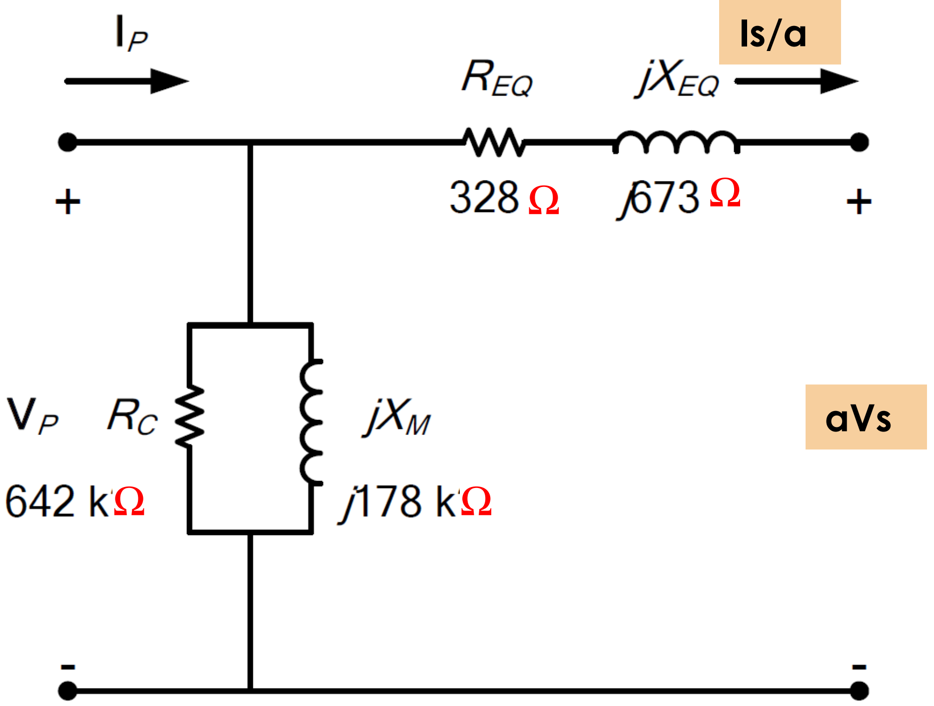
$$X_{\text{EQ}} = Z_{\text{base}} X_{EQ,\text{pu}} = (8\text{ k}\Omega)(0.101) = 808\ \Omega$$

At 50 Hz, the resistance will be unaffected but the reactances are reduced in direct proportion to the decrease in frequency. At 50 Hz, the reactances are

$$X_M = \left(\frac{50\text{ Hz}}{60\text{ Hz}}\right)(214\text{ k}\Omega) = 178\text{ k}\Omega$$

$$X_{\text{EQ}} = \left(\frac{50\text{ Hz}}{60\text{ Hz}}\right)(808\ \Omega) = 673\ \Omega$$

The resulting equivalent circuit referred to the primary at 50 Hz is shown below:



(e) The base impedance of this transformer *at 50 Hz* referred to the primary side is

$$Z_{\text{base},P} = \frac{(V_P)^2}{S} = \frac{(16{,}667\ \text{V})^2}{41.7\ \text{kVA}} = 6.66\ \text{k}\Omega$$

The base impedance of this transformer *at 50 Hz* referred to the secondary side is

$$Z_{\text{base},S} = \frac{(V_S)^2}{S} = \frac{(400\ \text{V})^2}{41.7\ \text{kVA}} = 3.837\ \Omega$$

The excitation branch elements can be expressed in per-unit as

$$R_C = \frac{642\ \text{k}\Omega}{6.66\ \text{k}\Omega} = 96.4\ \text{pu} \qquad X_M = \frac{178\ \text{k}\Omega}{6.66\ \text{k}\Omega} = 26.7\ \text{pu}$$

The series impedances can be expressed in per-unit as

$$R_{EQ} = \frac{328\ \Omega}{6.66\ \text{k}\Omega} = 0.0492\ \text{pu} \qquad X_{EQ} = \frac{673\ \Omega}{6.66\ \text{k}\Omega} = 0.101\ \text{pu}$$

The per-unit primary voltage at rated conditions and unity power factor is

$$\mathbf{V}_P = \mathbf{V}_S + \mathbf{I}_S Z_{\text{EQ}}$$

$$\mathbf{V}_P = 1\angle 0^\circ\ \text{V} + (1\angle 0^\circ)(0.0492 + j0.101\ \Omega) = 1.054\angle 5.49^\circ\ \text{pu}$$

The per-unit power consumed by R_{EQ} is

$$P_{\text{EQ}} = I^2 R = (1\ \text{pu})^2 (0.0492\ \text{pu}) = 0.0492\ \text{pu}$$

The per-unit power consumed by R_C is

$$P_{\text{C}} = \frac{V_P{}^2}{R_C} = \frac{(1.054)^2}{96.4} = 0.0115\ \text{pu}$$

Therefore the efficiency of this transformer at rated load and unity power factor is

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\% = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{EQ}} + P_C} \times 100\% = \frac{1.00}{1.00 + 0.0492 + 0.0115} \times 100\% = 94.3\%$$

and the voltage regulation is

$$\text{VR} = \frac{1.054 - 1.00}{1.00} \times 100\% = 5.4\%$$

(f) The efficiency of the transformer at 50 Hz is almost the same as the efficiency at 60 Hz (just slightly less), but the total apparent power rating of the transformer at 50 Hz must be less than the apparent power rating at 60 Hz by the ratio 50/60. In other words, the efficiencies are similar, but the power handling capability is reduced.

2-24. Figure P2-4 shows a one-line diagram of a power system consisting of a three-phase 480-V 60-Hz generator supplying two loads through a transmission line with a pair of transformers at either end (NOTE: One-line diagrams are described in Appendix A, the discussion of three-phase power circuits.)

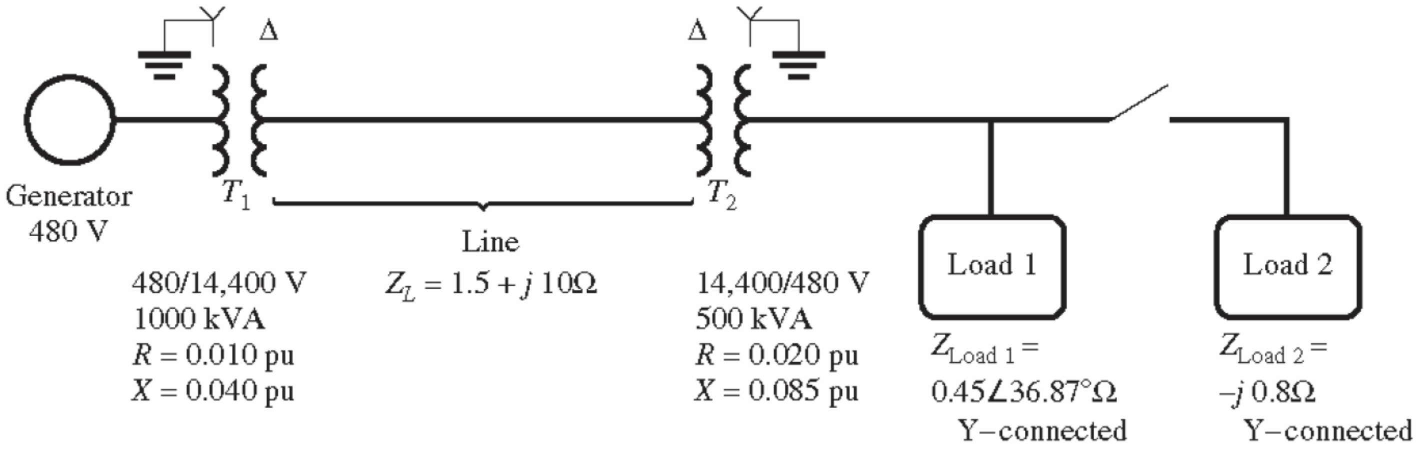


FIGURE P2–4
A one-line diagram of the power system of Problem 2–24. Note that some impedance values are given in the per-unit system, while others are given in ohms.

(a) Sketch the per-phase equivalent circuit of this power system.

(b) With the switch opened, find the real power *P*, reactive power *Q*, and apparent power *S* supplied by the generator. What is the power factor of the generator?

(c) With the switch closed, find the real power *P*, reactive power *Q*, and apparent power *S* supplied by the generator. What is the power factor of the generator?

(d) What are the transmission losses (transformer plus transmission line losses) in this system with the switch open? With the switch closed? What is the effect of adding Load 2 to the system?

SOLUTION This problem can best be solved using the per-unit system of measurements. The power system can be divided into three regions by the two transformers. If the per-unit base quantities in Region 1 (left of transformer 1) are chosen to be $S_{\text{base1}} = 1000$ kVA and $V_{L,\text{base1}} = 480$ V, then the base quantities in Regions 2 (between the transformers) and 3 (right or transformer 2) will be as shown below.

Region 1	**Region 2**	**Region 3**
$S_{\text{base1}} = 1000\text{ kVA}$	$S_{\text{base2}} = 1000\text{ kVA}$	$S_{\text{base3}} = 1000\text{ kVA}$
$V_{L,\text{base2}} = 480\text{ V}$	$V_{L,\text{base2}} = 14{,}400\text{ V}$	$V_{L,\text{base3}} = 480\text{ V}$

The base impedances of each region will be:

$$Z_{\text{base1}} = \frac{3V_{\phi 1}{}^2}{S_{\text{base1}}} = \frac{3(277\text{ V})^2}{1000\text{ kVA}} = 0.238\ \Omega$$

$$Z_{\text{base2}} = \frac{3V_{\phi 2}{}^2}{S_{\text{base2}}} = \frac{3(8314\text{ V})^2}{1000\text{ kVA}} = 207.4\ \Omega$$

$$Z_{\text{base3}} = \frac{3V_{\phi 3}{}^2}{S_{\text{base3}}} = \frac{3(277\text{ V})^2}{1000\text{ kVA}} = 0.238\ \Omega$$

(a) To get the per-unit, per-phase equivalent circuit, we must convert each impedance in the system to per-unit on the base of the region in which it is located. The impedance of transformer T_1 is already in per-unit to the proper base, so we don't have to do anything to it:

$$R_{1,\text{pu}} = 0.010$$

$$X_{1,\text{pu}} = 0.040$$

The impedance of transformer T_2 is already in per-unit, but it is per-unit to the base of transformer T_2, so it must be converted to the base of the power system.

$$(R,\ X,\ Z)_{\text{pu on base 2}} = (R,\ X,\ Z)_{\text{pu on base 1}} \frac{(V_{\text{base 1}})^2 (S_{\text{base 2}})}{(V_{\text{base 2}})^2 (S_{\text{base 1}})}$$

$$R_{2,\text{pu}} = 0.020 \frac{(8314\text{ V})^2 (1000\text{ kVA})}{(8314\text{ V})^2 (500\text{ kVA})} = 0.040$$

$$X_{2,\text{pu}} = 0.085 \frac{(8314\text{ V})^2 (1000\text{ kVA})}{(8314\text{ V})^2 (500\text{ kVA})} = 0.170$$

The per-unit impedance of the transmission line is

$$Z_{\text{line,pu}} = \frac{Z_{\text{line}}}{Z_{\text{base2}}} = \frac{1.5 + j10\ \Omega}{207.4\ \Omega} = 0.00723 + j0.0482$$

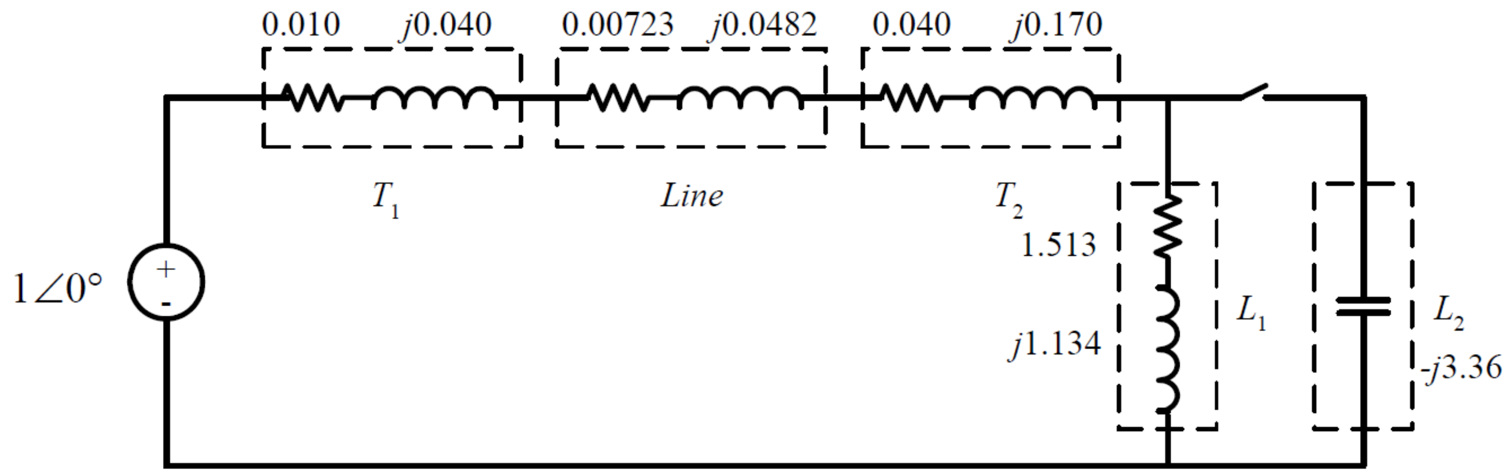
The per-unit impedance of Load 1 is

$$Z_{\text{load1,pu}} = \frac{Z_{\text{load1}}}{Z_{\text{base3}}} = \frac{0.45\angle 36.87^\circ\ \Omega}{0.238\ \Omega} = 1.513 + j1.134$$

The per-unit impedance of Load 2 is

$$Z_{\text{load2,pu}} = \frac{Z_{\text{load2}}}{Z_{\text{base3}}} = \frac{-j0.8\ \Omega}{0.238\ \Omega} = -j3.36$$

The resulting per-unit, per-phase equivalent circuit is shown below:



(b) With the switch opened, the equivalent impedance of this circuit is

$$Z_{EQ} = 0.010 + j0.040 + 0.00723 + j0.0482 + 0.040 + j0.170 + 1.513 + j1.134$$

$$Z_{EQ} = 1.5702 + j1.3922 = 2.099\angle 41.6°$$

The resulting current is

$$\mathbf{I} = \frac{1\angle 0°}{2.099\angle 41.6°} = 0.4765\angle -41.6°$$

The load voltage under these conditions would be

$$\mathbf{V}_{\text{Load,pu}} = \mathbf{I}\, Z_{\text{Load}} = (0.4765\angle -41.6°)(1.513 + j1.134) = 0.901\angle -4.7°$$

$$V_{\text{Load}} = V_{\text{Load,pu}} V_{\text{base3}} = (0.901)(480\text{ V}) = 432\text{ V}$$

The power supplied to the load is

$$P_{\text{Load,pu}} = I^2 R_{\text{Load}} = (0.4765)^2 (1.513) = 0.344$$

$$P_{\text{Load}} = P_{\text{Load,pu}} S_{\text{base}} = (0.344)(1000\text{ kVA}) = 344\text{ kW}$$

The power supplied by the generator is

$$P_{G,\text{pu}} = VI\cos\theta = (1)(0.4765)\cos 41.6° = 0.356$$

$$Q_{G,\text{pu}} = VI\sin\theta = (1)(0.4765)\sin 41.6° = 0.316$$

$$S_{G,\text{pu}} = VI = (1)(0.4765) = 0.4765$$

$$P_G = P_{G,\text{pu}} S_{\text{base}} = (0.356)(1000\text{ kVA}) = 356\text{ kW}$$

$$Q_G = Q_{G,\text{pu}} S_{\text{base}} = (0.316)(1000\text{ kVA}) = 316\text{ kVAR}$$

$$S_G = S_{G,\text{pu}} S_{\text{base}} = (0.4765)(1000\text{ kVA}) = 476.5\text{ kVA}$$

The power factor of the generator is

$$\text{PF} = \cos 41.6° = 0.748\text{ lagging}$$

(c) With the switch closed, the equivalent impedance of this circuit is

$$Z_{EQ} = 0.010 + j0.040 + 0.00723 + j0.0482 + 0.040 + j0.170 + \frac{(1.513 + j1.134)(-j3.36)}{(1.513 + j1.134) + (-j3.36)}$$

$$Z_{EQ} = 0.010 + j0.040 + 0.00788 + j0.0525 + 0.040 + j0.170 + (2.358 + j0.109)$$

$$Z_{EQ} = 2.415 + j0.367 = 2.443\angle 8.65°$$

The resulting current is

$$\mathbf{I} = \frac{1\angle 0°}{2.443\angle 8.65°} = 0.409\angle -8.65°$$

The load voltage under these conditions would be

$$\mathbf{V}_{\text{Load,pu}} = \mathbf{I}\, Z_{\text{Load}} = (0.409\angle -8.65°)(2.358 + j0.109) = 0.966\angle -6.0°$$

$$V_{\text{Load}} = V_{\text{Load,pu}} V_{\text{base3}} = (0.966)(480\text{ V}) = 464\text{ V}$$

The power supplied to the two loads is the power supplied to the resistive component of the parallel combination of the two loads: 2.358 pu.

$$P_{\text{Load,pu}} = I^2 R_{\text{Load}} = (0.409)^2 (2.358) = 0.394$$

$$P_{\text{Load}} = P_{\text{Load,pu}} S_{\text{base}} = (0.394)(1000\text{ kVA}) = 394\text{ kW}$$

The power supplied by the generator is

$$P_{G,\text{pu}} = VI\cos\theta = (1)(0.409)\cos 6.0° = 0.407$$
$$Q_{G,\text{pu}} = VI\sin\theta = (1)(0.409)\sin 6.0° = 0.0428$$
$$S_{G,\text{pu}} = VI = (1)(0.409) = 0.409$$
$$P_G = P_{G,\text{pu}} S_{\text{base}} = (0.407)(1000 \text{ kVA}) = 407 \text{ kW}$$
$$Q_G = Q_{G,\text{pu}} S_{\text{base}} = (0.0428)(1000 \text{ kVA}) = 42.8 \text{ kVAR}$$
$$S_G = S_{G,\text{pu}} S_{\text{base}} = (0.409)(1000 \text{ kVA}) = 409 \text{ kVA}$$

The power factor of the generator is

$$\text{PF} = \cos 6.0° = 0.995 \text{ lagging}$$

(d) The transmission losses with the switch *open* are:

$$P_{\text{line,pu}} = I^2 R_{\text{line}} = (0.4765)^2 (0.00723) = 0.00164$$
$$P_{\text{line}} = P_{\text{line,pu}} S_{\text{base}} = (0.00164)(1000 \text{ kVA}) = 1.64 \text{ kW}$$

The transmission losses with the switch *closed* are:

$$P_{\text{line,pu}} = I^2 R_{\text{line}} = (0.409)^2 (0.00723) = 0.00121$$
$$P_{\text{line}} = P_{\text{line,pu}} S_{\text{base}} = (0.00121)(1000 \text{ kVA}) = 1.21 \text{ kW}$$

Load 2 improved the power factor of the system, increasing the load voltage and the total power supplied to the loads, while simultaneously decreasing the current in the transmission line and the transmission line losses. This problem is a good example of the advantages of power factor correction in power systems.

Many Thanks

for

Your Attention!

Reference

- Instructor's Solutions Manual to accompany Electric Machinery Fundamentals by Stephen Chapman, 5th Ed., McGraw-Hill, Inc., 2012.