EEL 3216 Introduction to Power Systems
Homework # 3

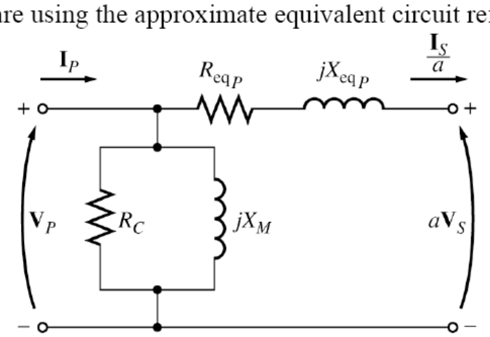
Solutions

CHAPTER 3
(Problems 3-1, 3-2, 3-3, 3-4, 3-6, 3-7, 3-8, pp 154-157 in Textbook)

1. The secondary winding of a transformer has a terminal voltage of $v_s(t) = 282.8 \sin 377t$ V. The turns ratio of the transformer is 50:200 ($a = 0.25$). If the secondary current of the transformer is $i_s(t) = 7.07 \sin(377t - 36.87°)$A , what is the primary current of this transformer? What are its voltage regulation and efficiency? The impedances of this transformer referred to the primary side are

$$R_{eq} = 0.05\ \Omega \qquad R_C = 75\ \Omega$$
$$X_{eq} = 0.225\ \Omega \qquad X_M = 20\ \Omega$$

SOLUTION The equivalent circuit of this transformer is shown below. (Since no particular equivalent circuit was specified, we are using the approximate equivalent circuit referred to the primary side.)



(a) $R_{eq\,P} = R_P + a^2 R_S$

$X_{eq\,P} = X_P + a^2 X_S$

The secondary voltage and current are

$$\mathbf{V}_S = \frac{282.8}{\sqrt{2}}\angle 0^\circ \text{ V} = 200\angle 0^\circ \text{ V}$$

$$\mathbf{I}_S = \frac{7.07}{\sqrt{2}}\angle -36.87^\circ \text{ A} = 5\angle -36.87^\circ \text{ A}$$

The secondary voltage referred to the primary side is

$$\mathbf{V}_S' = a\mathbf{V}_S = 50\angle 0^\circ \text{ V}$$

The secondary current referred to the primary side is

$$\mathbf{I}_S' = \frac{\mathbf{I}_S}{a} = 20\angle -36.87^\circ \text{ A}$$

The primary circuit voltage is given by

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

$$\mathbf{V}_P = 50\angle 0^\circ \text{ V} + \left(20\angle -36.87^\circ \text{ A}\right)\left(0.05\ \Omega + j0.225\ \Omega\right) = 53.6\angle 3.2^\circ \text{ V}$$

The excitation current of this transformer is

$$\mathbf{I}_{\text{EX}} = \mathbf{I}_C + \mathbf{I}_M = \frac{53.6\angle 3.2^\circ \text{ V}}{75\ \Omega} + \frac{53.6\angle 3.2^\circ \text{ V}}{j20\ \Omega} = 0.7145\angle 3.2^\circ + 2.679\angle -86.8^\circ$$

$$\mathbf{I}_{\text{EX}} = 2.77\angle -71.9^\circ$$

Therefore, the total primary current of this transformer is

$$\mathbf{I}_P = \mathbf{I}_S' + \mathbf{I}_{\text{EX}} = 20\angle -36.87^\circ + 2.77\angle -71.9^\circ = 22.3\angle -41.0^\circ \text{ A}$$

The voltage regulation of the transformer at this load is

$$\text{VR} = \frac{V_P - aV_S}{aV_S}\times 100\% = \frac{53.6 - 50}{50}\times 100\% = 7.2\%$$

The input power to this transformer is

$$P_{\text{IN}} = V_P I_P \cos\theta = (53.6 \text{ V})(22.3 \text{ A})\cos\left[3.2^\circ - (-41.0^\circ)\right]$$

$$P_{\text{IN}} = (53.6 \text{ V})(22.3 \text{ A})\cos 44.2^\circ = 857 \text{ W}$$

The output power from this transformer is

$$P_{\text{OUT}} = V_S I_S \cos\theta = (200 \text{ V})(5 \text{ A})\cos(36.87^\circ) = 800 \text{ W}$$

Therefore, the transformer's efficiency is

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}}\times 100\% = \frac{800 \text{ W}}{857 \text{ W}}\times 100\% = 93.4\%$$

2. A 20-kVA 8000/277-V distribution transformer has the following resistances and reactances:

$R_P = 32\ \Omega$	$R_S = 0.05\ \Omega$
$X_P = 45\ \Omega$	$X_S = 0.06\ \Omega$
$R_C = 250\ \text{k}\Omega$	$X_M = 30\ \text{k}\Omega$

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

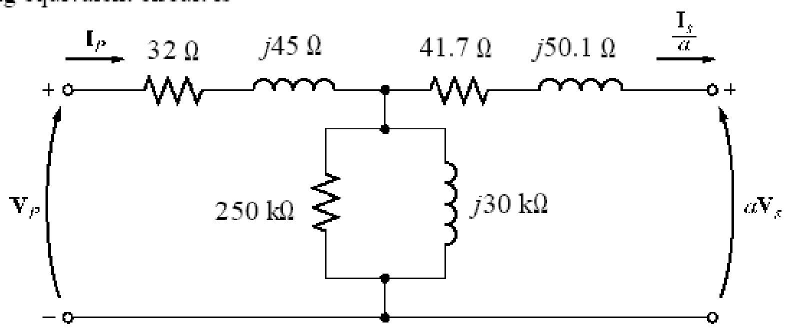
(a) Find the equivalent circuit of this transformer referred to the high-voltage side.
(b) Find the per-unit equivalent circuit of this transformer.
(c) Assume that this transformer is supplying rated load at 277 V and 0.8 PF lagging. What is this transformer's input voltage? What is its voltage regulation?
(d) What is the transformer's efficiency under the conditions of part (c)?

SOLUTION

(a) The turns ratio of this transformer is a = 8000/277 = 28.89. Therefore, the secondary impedances referred to the primary side are

$$R_S' = a^2 R_S = (28.89)^2 (0.05\ \Omega) = 41.7\ \Omega$$
$$X_S' = a^2 X_S = (28.89)^2 (0.06\ \Omega) = 50.1\ \Omega$$

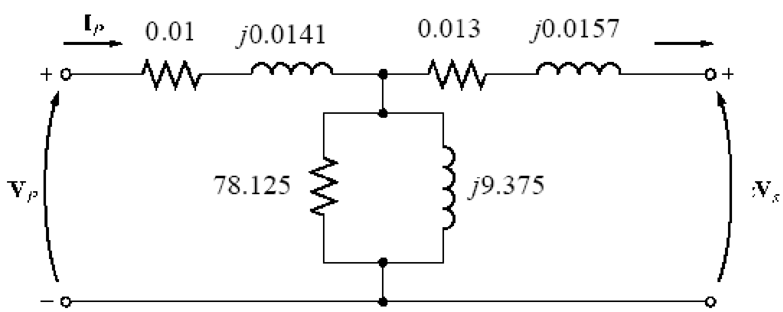
The resulting equivalent circuit is



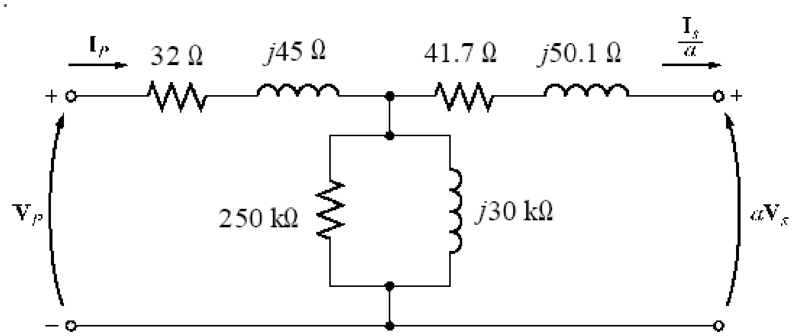
(b) The rated kVA of the transformer is 20 kVA, and the rated voltage on the primary side is 8000 V, so the rated current in the primary side is 20 kVA/8000 V = 2.5 A. Therefore, the base impedance on the primary side is

$$Z_{\text{base}} = \frac{V_{\text{base}}}{I_{\text{base}}} = \frac{8000\text{ V}}{2.5\text{ A}} = 3200\ \Omega$$

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



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



The secondary current in this transformer is

$$\mathbf{I}_S = \frac{20\text{ kVA}}{277\text{ V}}\angle -36.87^\circ\text{ A} = 72.2\angle -36.87^\circ\text{ A}$$

The secondary current referred to the primary side is

$$\mathbf{I}_S' = \frac{\mathbf{I}_S}{a} = \frac{72.2\angle -36.87^\circ\text{ A}}{28.89} = 2.50\angle -36.87^\circ\text{ A}$$

Therefore, the primary voltage on the transformer is

$$\mathbf{V}_P = \mathbf{V}_S' + (R_{EQ} + jX_{EQ})\mathbf{I}_S'$$
$$\mathbf{V}_P = 8000\angle 0° \text{ V} + (73.7 + j95.1)(2.50\angle -36.87° \text{ A}) = 8290\angle 0.55° \text{ V}$$

The voltage regulation of the transformer under these conditions is

$$\text{VR} = \frac{8290 - 8000}{8000} \times 100\% = 3.63\%$$

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

$$P_{OUT} = S\cos\theta = (20 \text{ kVA})(0.8) = 16 \text{ kW}$$
$$P_{CU} = \left(I_S'\right)^2 R_{EQ} = (2.5)^2(73.7) = 461 \text{ W}$$
$$P_{core} = \frac{V_S'^2}{R_C} = \frac{8290^2}{250{,}000} = 275 \text{ W}$$

The efficiency of this transformer is

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{CU} + P_{core}} \times 100\% = \frac{16{,}000}{16{,}000 + 461 + 275} \times 100\% = 95.6\%$$

3. A 2000-VA 230/115-V transformer has been tested to determine its equivalent circuit. The results of the tests are shown below.

Open-circuit test	Short-circuit test
$V_{OC} = 230$ V	$V_{SC} = 13.2$ V
$I_{OC} = 0.45$ A	$I_{SC} = 6.0$ A
$P_{OC} = 30$ W	$P_{SC} = 20.1$ W

All data given were taken from the primary side of the transformer.

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

(b) Find the transformer's voltage regulation at rated conditions and (1) 0.8 PF lagging, (2) 1.0 PF, (3) 0.8 PF leading.

(c) Determine the transformer's efficiency at rated conditions and 0.8 PF lagging.

Attention! The numbers in the problem statement above are different from the ones in problem 3-3 in the book. However, the solution process is the same. The solution is given her for the numbers in the above statement and NOT for the one in the book.

Solution

(a) <u>OPEN CIRCUIT TEST:</u>

$$|Y_{EX}| = |G_C - jB_M| = \frac{0.45\text{ A}}{230\text{ V}} = 0.001957\text{ S}$$

$$\theta = \cos^{-1}\frac{P_{OC}}{V_{OC}I_{OC}} = \cos^{-1}\frac{30\text{ W}}{(230\text{ V})(0.45\text{ A})} = 73.15^\circ$$

$$Y_{EX} = G_C - jB_M = 0.001957\angle -73.15^\circ\text{ S} = 0.000567\text{-}j0.001873\text{ S}$$

$$R_C = \frac{1}{G_C} = 1763\ \Omega$$

$$X_M = \frac{1}{B_M} = 534\ \Omega$$

<u>SHORT CIRCUIT TEST:</u>

$$|Z_{EQ}| = |R_{EQ} + jX_{EQ}| = \frac{13.2\text{ V}}{6.0\text{ A}} = 2.20\ \Omega$$

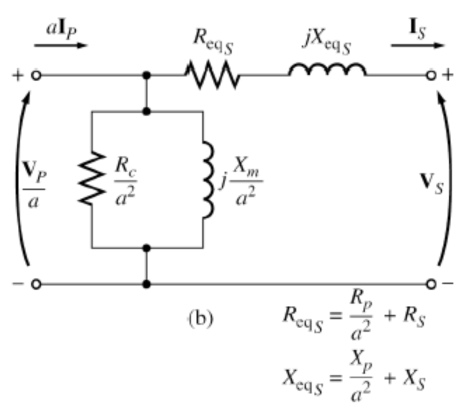
$$\theta = \cos^{-1}\frac{P_{SC}}{V_{SC}I_{SC}} = \cos^{-1}\frac{20.1\text{ W}}{(13.2\text{ V})(6\text{ A})} = 75.3^\circ$$

$$Z_{EQ} = R_{EQ} + jX_{EQ} = 2.20\angle 75.3^\circ\ \Omega = 0.558 + j2.128\ \Omega$$

$$R_{EQ} = 0.558\ \Omega$$

$$X_{EQ} = j2.128\ \Omega$$

To convert the equivalent circuit to the secondary side, divide each impedance by the square of the turns ratio (a = 230/115 = 2). The resulting equivalent circuit is shown below:



$R_{EQ,S} = 0.140\ \Omega$ $\qquad X_{EQ,S} = j0.532\ \Omega$

$R_{C,S} = 441\ \Omega$ $\qquad X_{M,S} = 134\ \Omega$

(b) To find the required voltage regulation, we will use the equivalent circuit of the transformer referred to the secondary side. The rated secondary current is

$$I_S = \frac{1000\text{ VA}}{115\text{ V}} = 8.70\text{ A}$$

We will now calculate the primary voltage referred to the secondary side and use the voltage regulation equation for each power factor.

(1) 0.8 PF Lagging:

$$\mathbf{V}_P' = \mathbf{V}_S + Z_{EQ}\mathbf{I}_S = 115\angle 0° \text{ V} + (0.140 + j0.532\ \Omega)(8.7\angle\text{-}36.87° \text{ A})$$

$$\mathbf{V}_P' = 118.8\angle 1.4° \text{ V}$$

$$\text{VR} = \frac{118.8 - 115}{115} \times 100\% = 3.3\%$$

(2) 1.0 PF:

$$\mathbf{V}_P' = \mathbf{V}_S + Z_{EQ}\mathbf{I}_S = 115\angle 0° \text{ V} + (0.140 + j0.532\ \Omega)(8.7\angle 0° \text{ A})$$

$$\mathbf{V}_P' = 116.3\angle 2.28° \text{ V}$$

$$\text{VR} = \frac{116.3 - 115}{115} \times 100\% = 1.1\%$$

(3) 0.8 PF Leading:

$$\mathbf{V}_P' = \mathbf{V}_S + Z_{EQ}\mathbf{I}_S = 115\angle 0° \text{ V} + (0.140 + j0.532\ \Omega)(8.7\angle 36.87° \text{ A})$$

$$\mathbf{V}_P' = 113.3\angle 2.24° \text{ V}$$

$$\text{VR} = \frac{113.3 - 115}{115} \times 100\% = -1.5\%$$

(c) At rated conditions and 0.8 PF lagging, the output power of this transformer is

$$P_{\text{OUT}} = V_S I_S \cos\theta = (115 \text{ V})(8.7 \text{ A})(0.8) = 800 \text{ W}$$

The copper and core losses of this transformer are

$$P_{\text{CU}} = I_S^2 R_{\text{EQ},S} = (8.7 \text{ A})^2 (0.140\ \Omega) = 10.6 \text{ W}$$

$$P_{\text{core}} = \frac{\left(V_P'\right)^2}{R_C} = \frac{(118.8 \text{ V})^2}{441\ \Omega} = 32.0 \text{ W}$$

Therefore the efficiency of this transformer at these conditions is

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{CU}} + P_{\text{core}}} \times 100\% = \frac{800 \text{ W}}{800 \text{ W} + 10.6 \text{ W} + 32.0 \text{ W}} = 94.9\%$$

4. A single-phase power system is shown in Figure 1 below. The power source feeds a 100-kVA 14/2.4-kV transformer through a feeder impedance of $38.2 + j140\ \Omega$. The transformer's equivalent series impedance referred to its low-voltage side is $0.12 + j0.5\ \Omega$. The load on the transformer is 90 kW at 0.85 PF lagging and 2300V.

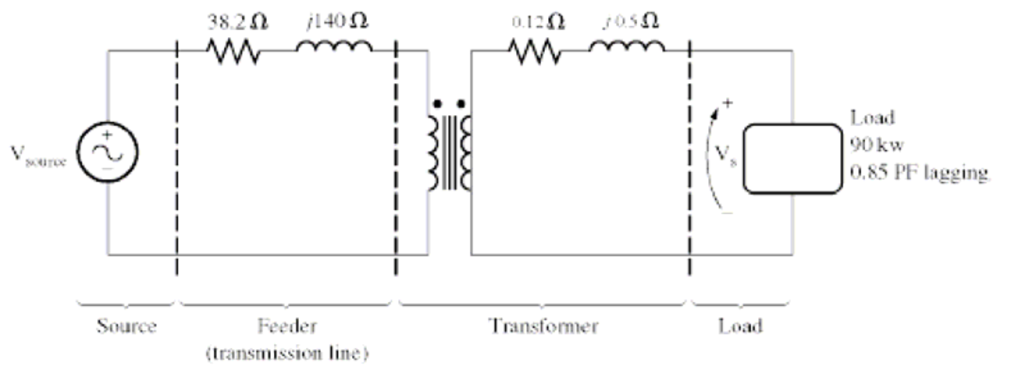


Figure 1

(a) What is the voltage at the power source of the system?
(b) What is the voltage regulation of the transformer?
(c) How efficient is the overall power system?

Solution

To solve this problem, we will refer the circuit to the secondary (low-voltage) side. The feeder's impedance referred to the secondary side is

$$Z_{\text{line}}' = \left(\frac{2.4\text{ kV}}{14\text{ kV}}\right)^2 (38.2\ \Omega + j140\ \Omega) = 1.12 + j4.11\ \Omega$$

The secondary current $\mathbf{I}_S$ is given by

$$I_S = \frac{90\text{ kW}}{(2300\text{ V})(0.9)} = 43.48\text{ A}$$

$$\mathbf{I}_S = 43.48\angle -25.8^\circ\text{ A}$$

(a) The voltage at the power source of this system (referred to the secondary side) is

$$\mathbf{V}_{\text{source}}' = \mathbf{V}_S + \mathbf{I}_S Z_{\text{line}}' + \mathbf{I}_S Z_{\text{EQ}}$$

$$\mathbf{V}_{\text{source}}' = 2300\angle 0^\circ\text{ V} + (43.48\angle -25.8^\circ\text{ A})(1.12 + j4.11\ \Omega) + (43.48\angle -25.8^\circ\text{ A})(0.12 + j0.5\ \Omega)$$

$$\mathbf{V}_{\text{source}}' = 2441\angle 3.7^\circ\text{ V}$$

Therefore, the voltage at the power source is

$$\mathbf{V}_{\text{source}} = (2441\angle 3.7^\circ\text{ V})\frac{14\text{ kV}}{2.4\text{ kV}} = 14.24\angle 3.7^\circ\text{ kV}$$

(b) To find the voltage regulation of the transformer, we must find the voltage at the primary side of the transformer (referred to the secondary side) under full load conditions:

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

$$\mathbf{V}_P' = 2300\angle 0° \text{ V} + (43.48\angle -25.8° \text{ A})(0.12 + j0.5\ \Omega) = 2314\angle 0.43° \text{ V}$$

There is a voltage drop of 14 V under these load conditions. Therefore the voltage regulation of the transformer is

$$\text{VR} = \frac{2314 - 2300}{2300} \times 100\% = 0.6\%$$

(c) The power supplied to the load is $P_{OUT} = 90$ kW. The power supplied by the source is

$$P_{IN} = V_{source}' I_S \cos\theta = (2441 \text{ V})(43.48 \text{ A})\cos 29.5° = 92.37 \text{ kW}$$

Therefore, the efficiency of the power system is

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% = \frac{90 \text{ kW}}{92.37 \text{ kW}} \times 100\% = 97.4\%$$

5. A 15-kVA 8000/230-V distribution transformer has an impedance referred to the primary of 80 + j300 Ω. The components of the excitation branch referred to the primary side are R_C = 350 kΩ and X_M = 70 kΩ.

    (a) If the primary voltage is 7967 V and the load impedance is $Z_L = 3.2 + j1.5\ \Omega$, 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 $-j3.5\ \Omega$ 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

$$Z_L' = (34.78)^2(3.2 + j1.5\ \Omega) = 3871 + j1815\ \Omega$$

The referred secondary current is

$$\mathbf{I}_S' = \frac{7967\angle 0° \text{ V}}{(80 + j300\ \Omega) + (3871 + j1815\ \Omega)} = \frac{7967\angle 0° \text{ V}}{4481\angle 28.2°\ \Omega} = 1.78\angle -28.2° \text{ A}$$

and the referred secondary voltage is

$$\mathbf{V}_S' = \mathbf{I}_S' Z_L' = (1.78\angle -28.2° \text{ A})(3871 + j1815\ \Omega) = 7610\angle -3.1° \text{ V}$$

The actual secondary voltage is thus

$$\mathbf{V}_S = \frac{\mathbf{V}_S'}{a} = \frac{7610\angle -3.1° \text{ V}}{34.78} = 218.8\angle -3.1° \text{ V}$$

The voltage regulation is

$$\mathrm{VR} = \frac{7967 - 7610}{7610} \times 100\% = 4.7\%$$

(b) As before, 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

$$Z_L{}' = (34.78)^2(-j3.5\,\Omega) = -j4234\,\Omega$$

The referred secondary current is

$$\mathbf{I}_S{}' = \frac{7967\angle 0°\ \mathrm{V}}{(80 + j300\,\Omega) + (-j4234\,\Omega)} = \frac{7967\angle 0°\ \mathrm{V}}{3935\angle -88.8°\,\Omega} = 2.025\angle 88.8°\ \mathrm{A}$$

and the referred secondary voltage is

$$\mathbf{V}_S{}' = \mathbf{I}_S{}' Z_L{}' = (2.25\angle 88.8°\ \mathrm{A})(-j4234\ \Omega) = 8573\angle -1.2°\ \mathrm{V}$$

The actual secondary voltage is thus

$$\mathbf{V}_S = \frac{\mathbf{V}_S{}'}{a} = \frac{8573\angle -1.2°\ \mathrm{V}}{34.78} = 246.5\angle -1.2°\ \mathrm{V}$$

The voltage regulation is

$$\mathrm{VR} = \frac{7967 - 8573}{8573} \times 100\% = -7.07\%$$

6. A 5000-kVA 230/13.8-kV single-phase power transformer has a per-unit resistance of 1 percent and a per-unit reactance of 5 percent (data taken from the transformer's nameplate).

The open-circuit test performed on the low-voltage side of the transformer yielded the following data:

V_{OC} = 138 kV, I_{OC} = 15.1 A, P_{OC} = 44.9 kW

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

(b) If the voltage on the secondary side is 13.8 kV and the power supplied is 4000 kW at 0.8 PF lagging, find the voltage regulation of the transformer. Find its efficiency.

SOLUTION

(a) The open-circuit test was performed on the low-voltage side of the transformer, so it can be used to directly find the components of the excitation branch relative to the low-voltage side.

$$|Y_{EX}| = |G_C - jB_M| = \frac{15.1 \text{ A}}{13.8 \text{ kV}} = 0.0010942$$

$$\theta = \cos^{-1}\frac{P_{OC}}{V_{OC}I_{OC}} = \cos^{-1}\frac{44.9 \text{ kW}}{(13.8 \text{ kV})(15.1 \text{ A})} = 77.56°$$

$$Y_{EX} = G_C - jB_M = 0.0010942\angle -77.56° \text{ S} = 0.0002358 - j0.0010685 \text{ S}$$

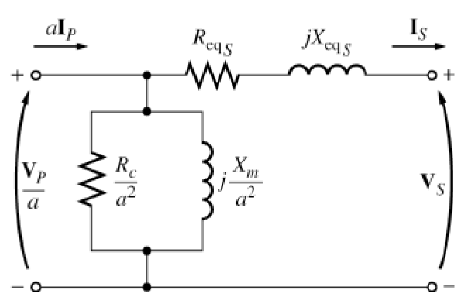
$$R_C = \frac{1}{G_C} = 4240\ \Omega$$

$$X_M = \frac{1}{B_M} = 936\ \Omega$$

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

$$Z_{base} = \frac{V_{base}{}^2}{S_{base}} = \frac{(13.8 \text{ kV})^2}{5000 \text{ kVA}} = 38.09\ \Omega$$

so $R_{EQ} = (0.01)(38.09\ \Omega) = 0.38\ \Omega$ and $X_{EQ} = (0.05)(38.09\ \Omega) = 1.9\ \Omega$. The resulting equivalent circuit is shown below:



$R_{eq,s} = 0.38\ \Omega$ $X_{eq,s} = j1.9\ \Omega$

$R_{C,s} = 4240\ \Omega$ $X_{M,s} = 936\ \Omega$

(b) If the load on the secondary side of the transformer is 4000 kW at 0.8 PF lagging and the secondary voltage is 13.8 kV, the secondary current is

$$I_S = \frac{P_{\text{LOAD}}}{V_S \text{ PF}} = \frac{4000 \text{ kW}}{(13.8 \text{ kV})(0.8)} = 362.3 \text{ A}$$

$$\mathbf{I}_S = 362.3\angle -36.87^\circ \text{ A}$$

The voltage on the primary side of the transformer (referred to the secondary side) is

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

$$\mathbf{V}_P' = 13{,}800\angle 0^\circ \text{ V} + (362.3\angle -36.87^\circ \text{ A})(0.38 + j1.9\ \Omega) = 14{,}330\angle 1.9^\circ \text{ V}$$

There is a voltage drop of 14 V under these load conditions. Therefore the voltage regulation of the transformer is

$$\text{VR} = \frac{14{,}330 - 13{,}800}{13{,}800} \times 100\% = 3.84\%$$

The transformer copper losses and core losses are

$$P_{\text{CU}} = I_S^{\ 2} R_{\text{EQ},S} = (362.3 \text{ A})^2 (0.38\ \Omega) = 49.9 \text{ kW}$$

$$P_{\text{core}} = \frac{\left(V_P'\right)^2}{R_C} = \frac{(14{,}330 \text{ V})^2}{4240\ \Omega} = 48.4 \text{ W}$$

Therefore the efficiency of this transformer at these conditions is

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{CU}} + P_{\text{core}}} \times 100\% = \frac{4000 \text{ W}}{4000 \text{ W} + 49.9 \text{ W} + 48.4 \text{ W}} = 97.6\%$$

7. A 150-MVA 15/200-kV single-phase power transformer has a per-unit resistance of 1.2 percent and a per unit reactance of 5 percent (data taken from the transformer's nameplate). The magnetizing impedance is j100 per unit (Rc not specified, can be assumed to be negligible).

   (a) Find the equivalent circuit referred to the low-voltage side of this transformer.
   (b) Calculate the voltage regulation of this transformer for a full-load current at power factor of 0.8 lagging.
   (c) Assume that the primary voltage of this transformer is a constant 15 kV, and plot the secondary voltage as a function of load current for currents from no-load to full-load. Repeat this process for power factors of 0.8 lagging, 1.0, and 0.8 leading.

SOLUTION

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

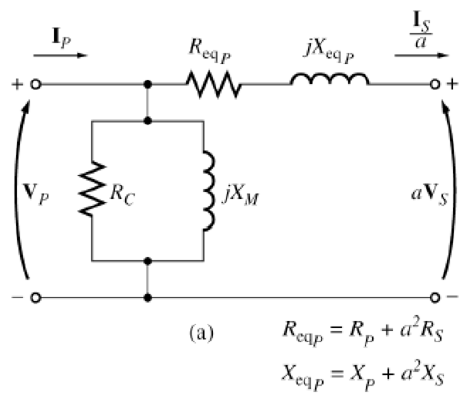
$$Z_{\text{base}} = \frac{V_{\text{base}}^{\ 2}}{S_{\text{base}}} = \frac{(15\text{ kV})^2}{150\text{ MVA}} = 1.5\ \Omega$$

so $R_{\text{EQ}} = (0.012)(1.5\ \Omega) = 0.018\ \Omega$

$$X_{\text{EQ}} = (0.05)(1.5\ \Omega) = 0.075\ \Omega$$

$$X_M = (100)(1.5\ \Omega) = 150\ \Omega$$

The equivalent circuit is



$R_{\text{EQ},P} = 0.018\ \Omega$	$X_{\text{EQ},P} = j0.075\ \Omega$
R_C = not specified	$X_M = 150\ \Omega$

(b) If the load on the *secondary* (high voltage) side of the transformer is 150 MVA at 0.8 PF lagging, and the referred secondary voltage is 15 kV, then the referred secondary current is

$$I_S' = \frac{P_{\text{LOAD}}}{V_S\ \text{PF}} = \frac{150\text{ MVA}}{(15\text{ kV})(0.8)} = 12{,}500\text{ A}$$

$$\mathbf{I}_S' = 12{,}500\angle -36.87^\circ\text{ A}$$

The voltage on the primary side of the transformer is

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

$$\mathbf{V}_P = 15{,}000\angle 0^\circ\text{ V} + (12{,}500\angle -36.87^\circ\text{ A})(0.018 + j0.075\ \Omega) = 15{,}755\angle 2.24^\circ\text{ V}$$

Therefore the voltage regulation of the transformer is

$$\text{VR} = \frac{15{,}755 - 15{,}000}{15{,}000} \times 100\% = 5.03\%$$

The resulting plot of secondary voltage versus load is shown below: