

3-8 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.

- Find the equivalent circuit referred to the low-voltage side of this transformer.
- Calculate the voltage regulation of this transformer for a full-load current at power factor of 0.8 lagging.

➤ modified so that $R_{C,pu} = 100$. For part b), also find the copper and core losses as well as efficiency.

a) Per (3-63), the base impedance is $Z_{base} = (V_{base})^2 / S_{base}$. On the primary (low-voltage) side-

$$Z_{base,P} = (15 \times 10^3)^2 / 150 \times 10^6 = 1.5 \, \Omega.$$

The primary (low-voltage) impedances are then-

$$R_{C,P} = Z_{base,P} (R_{C,pu}) = 1.5 (100) = 150 \, \Omega,$$

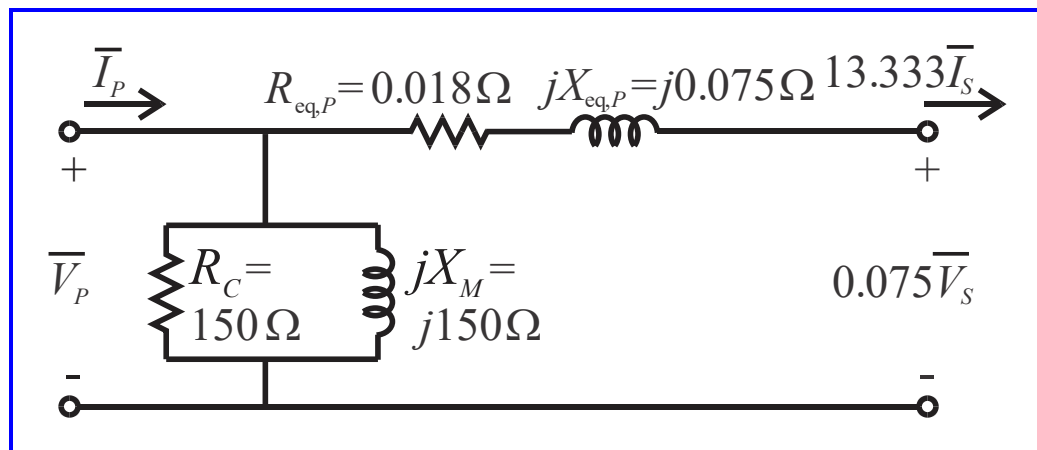
$$X_{M,P} = Z_{base,P} (X_{M,pu}) = 1.5 (100) = 150 \, \Omega,$$

$$R_{eq,P} = Z_{base,P} (R_{P,pu}) = 1.5 (0.012) = 0.018 \, \Omega, \text{ and}$$

$$X_{eq,P} = Z_{base,P} (X_{P,pu}) = 1.5 (0.05) = 0.075 \, \Omega.$$

The turns ratio is (3-5) $a = V_P / V_S = 15 / 200 = 0.075$.

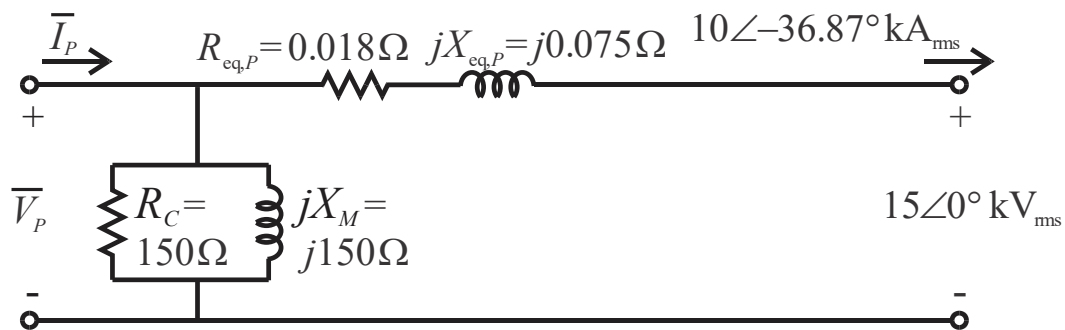
Approximate Primary (Low Side) Equivalent Circuit



- b) Assuming a phase angle of 0, $\bar{V}_L = \bar{V}_S = 250\angle 0^\circ$ (kV_{rms}). Per the circuit in part a), the referred secondary voltage is $0.075\bar{V}_S = 0.075(200\angle 0^\circ) = 15\angle 0^\circ$ (kV_{rms}).

For a full (i.e., rated) load, $I_L = S_{\text{rated}} / V_L = 150 \times 10^6 / 200,000 = 750$ (A_{rms}) with a phase angle found using $\theta_{VL} - \theta_{IL} = \cos^{-1}(\text{PF}) \Rightarrow -\theta_{IL} = -\cos^{-1}(0.8) = -36.87^\circ$.

So, $\bar{I}_L = \bar{I}_S = 750\angle -36.87^\circ$ (A_{rms}). Per the circuit in part a), the referred secondary current is $13.333\bar{I}_S = 13.333(750\angle -36.87^\circ) = 10\angle -36.87^\circ$ (kA_{rms}). This gives



Use KVL on the circuit to get the phasor input voltage,

$$\begin{aligned}\bar{V}_P &= (10000\angle -36.87^\circ)(0.018 + j0.075) + (15,000\angle 0^\circ) \\ &= 15,601.76\angle 1.807^\circ \text{ (V}_{\text{rms}}\text{)}\end{aligned}$$

Per (3-68), the voltage regulation is

$$\text{VR} = \frac{V_P / a - V_{S,\text{fl}}}{V_{S,\text{fl}}} \times 100\% = \frac{V_P - aV_{S,\text{fl}}}{aV_{S,\text{fl}}} \times 100\% = \frac{15,601.76 - 15,000}{15,000} \times 100\% \Rightarrow \underline{\text{VR} = 4.01\%}.$$

$$P_{\text{Cu}} = 10,000^2 (0.018) \Rightarrow \underline{P_{\text{Cu}} = 1.8 \text{ MW}}.$$

$$P_{\text{core}} = V_P^2 / R_{\text{core}} = 15,601.76^2 / 150 \Rightarrow \underline{P_{\text{core}} = 1.623 \text{ MW}}.$$

$$P_{\text{out}} = S_{\text{rated}} \cos(\theta) = S_{\text{rated}} \text{PF} = 150 (0.8) = 120 \text{ MW}$$

Per (3-72), the efficiency is

$$\eta = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{losses}}} \times 100\% = \frac{120}{120 + 1.8 + 1.623} \times 100\% \Rightarrow \underline{\eta = 97.23\%}.$$