3–11 A 100,000-kVA, 230/115-kV Δ–Δ three-phase power transformer has a per-unit resistance of 0.02 pu and a per-unit reactance of 0.055 pu. The excitation branch elements are $R_C = 110$ pu and $X_M = 20$ pu.

c. Sketch the equivalent circuit referred to the low-voltage side of one phase of this transformer. Calculate all the transformer impedances referred to the low-voltage side.

a. If this transformer supplies a load of 80 MVA at 0.85 PF lagging, draw the phasor diagram of one phase of the transformer.

b. What is the voltage regulation of the transformer bank under these conditions?

➢ Do part c first. Then, complete parts a & b assuming the load is getting the full rated secondary voltage at 0°.

c) The base impedance for one phase on the secondary side is

$$Z_{\text{base},S} = V_{\phi,S}^2 / S_\phi = (115\times10^3)^2 / (100{,}000\times10^3/3) = 396.75\ \Omega.$$

Use $Z_{\text{base},S}$ to compute actual values

$R_{eq,S} = 0.02\, Z_{\text{base}} = 0.02\,(396.75)$ $\Rightarrow \underline{R_{eq,S} = 7.935\ \Omega}$,

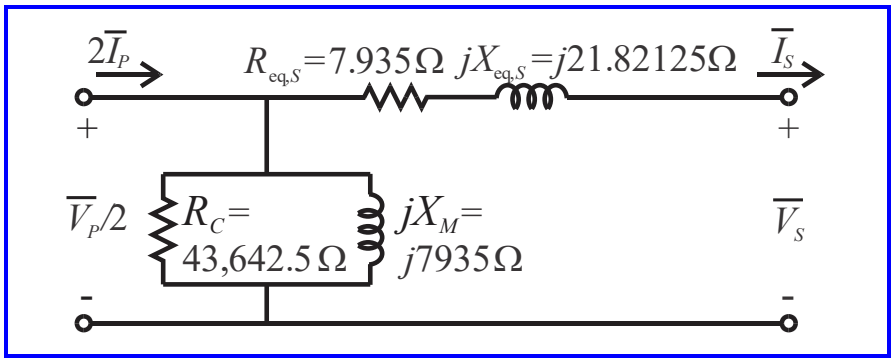
$X_{eq,S} = 0.055\, Z_{\text{base}} = 0.0055\,(396.75)$ $\Rightarrow \underline{X_{eq,\text{series}} = 21.82125\ \Omega}$,

$X_M = 20\, Z_{\text{base}} = 20\,(396.75)$ $\Rightarrow \underline{X_M = 7935\ \Omega}$, and

$R_C = 110\, Z_{\text{base}} = 110\,(396.75)$ $\Rightarrow \underline{R_C = 43{,}642.5\ \Omega}$.

The turns ratio is (3-5) $a = V_{\phi,P} / V_{\phi,S} = 230/115$ $\Rightarrow \underline{a = 2}$.

Approximate Secondary (low side) Equivalent Circuit per Figure 3-18b.



a) Assuming 0° phase, the rated secondary voltage is $\overline{V}_{\phi,S} = \overline{V}_S = 115\angle0°$ (kV_{rms}).

For an 80 MVA load with a 0.85 lagging PF, the current per phase is then

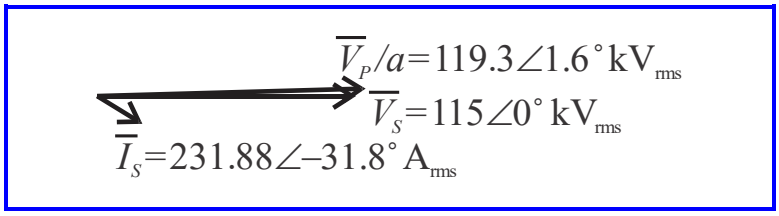
$$I_{\phi,S} = S_\phi / V_{\phi,S} = (80\times10^6/3)/115\times10^3 = 231.884\ \text{A}_{\text{rms}}.$$

Given a 0.85 lagging PF, we find $\theta_V - \theta_I = \cos^{-1}(0.85) = 31.78833°$. With $\theta_V = 0$, then $\theta_I = -31.78833°$ and the phase current is $\overline{I}_{\phi,S} = \overline{I}_S = 231.884\angle -31.788°\ (\mathrm{A_{rms}})$.

By KVL on the approximate secondary equivalent circuit-

$$\begin{aligned}\overline{V}_P / a = \overline{V}_P / 2 &= \overline{I}_S (R_{eq,S} + jX_{eq,S}) + \overline{V}_S = \overline{I}_S R_{eq,S} + jX_{eq,S}\overline{I}_S + \overline{V}_S \\ &= (231.884\angle -31.788°)(7.935 + j21.82125) + 115{,}000\angle 0° \\ &= 1840\angle -31.788° + 5060\angle 58.212° + 115{,}000\angle 0° \\ &= 119{,}276.062\angle 1.60064°\ (\mathrm{V_{rms}})\end{aligned}$$

Similar to Figure 3-26, the phasor diagram is shown below. The voltage drops across the series resistance and reactance were omitted (too small to be seen).

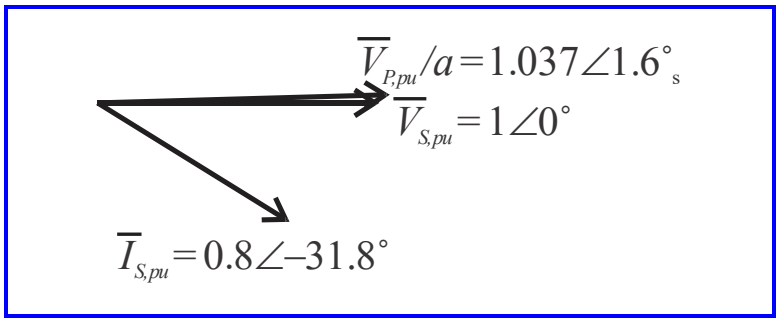


OR, to scale the current the same as the voltages, we can also do a per-unit phasor diagram. Using $V_{\text{base}} = 115\ \mathrm{kV_{rms}}$ and $I_{\text{base}} = S_{\text{base}} / V_{\text{base}} = (100{,}000\times 10^3/\sqrt{3}) / 115\times 10^3 = 289.855\ \mathrm{A_{rms}}$, we get-

$$\overline{I}_{S,pu} = \overline{I}_S / I_{\text{base}} = 231.884\angle -31.788° / 289.855 = 0.8\angle -31.8°,$$

$$\overline{V}_{S,pu} = \overline{V}_S / V_{\text{base}} = 115\angle 0° / 115 = 1\angle 0°, \text{ and}$$

$$\overline{V}_{P,pu} / a = (\overline{V}_P / a) / V_{\text{base}} = 119.276\angle 1.6° / 115 = 1.037\angle 1.6°.$$



b) Per (3-68), the voltage regulation is

$$\mathrm{VR} = \frac{V_P / a - V_{S,\mathrm{fl}}}{V_{S,\mathrm{fl}}} \times 100\% = \frac{119.276 - 115}{115} \times 100\% \quad \Rightarrow \quad \underline{\mathbf{VR = 3.72\%}}.$$