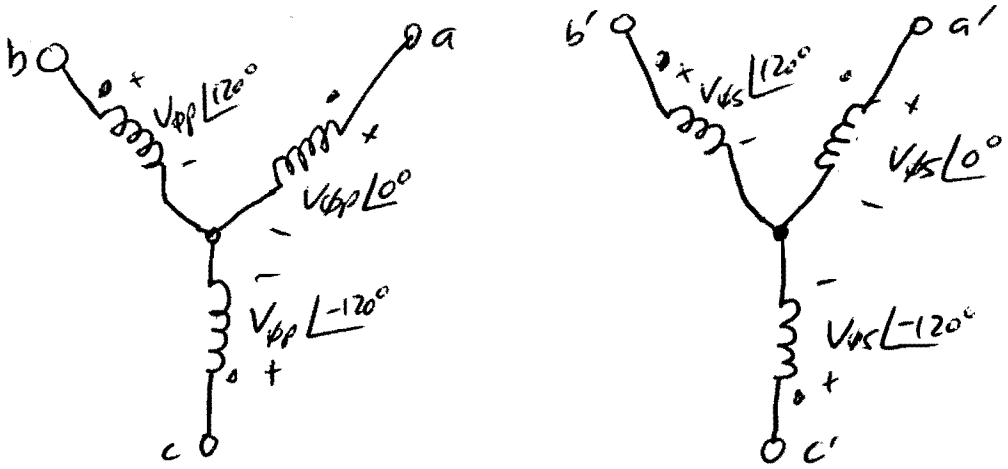
3–10 A Y-connected bank of three identical 100-kVA, 7967/480-V transformers is supplied with power directly from a large constant-voltage bus. In the short-circuit test, the recorded values on the high-voltage side for one of these transformers are

$$V_{SC} = 560 \text{ V} \qquad I_{SC} = 12.6 \text{ A} \qquad P_{SC} = 1700 \text{ W}$$

a. If this bank delivers a rated load at 0.88 PF lagging and rated voltage, what is the line-to-line voltage on the primary of the transformer bank?

b. What is the voltage regulation under these conditions?

➢ Hint: The measured current & voltage are line values measured on the 3ϕ transformer. The measured power is for the entire 3ϕ transformer.



The turns ratio is (3-5) $a = V_{\phi,P} / V_{\phi,S} = 7967 / 480$ $\Rightarrow \underline{a = 16.59792}$.

The measured short-circuit line-to-line voltage is $V_{SC} = 560 \text{ V}_{rms}$. Per (2-11), the measured phase voltage is $V_{\phi,SC} = 560 / \sqrt{3} = 323.31615 \text{ V}_{rms}$.

Per (2-10), the short-circuit line current $I_{SC} = I_{\phi,SC} = 12.6 \text{ A}_{rms}$. [Note: $100 \times 10^3 / 7967 = 12.55 \text{ A}_{rms}$.]

The short-circuit power per phase is $P_{\phi,SC} = P_{SC} / 3 = 1700 / 3 = 566.666 \text{ W}$.

With the per-phase short circuit test values, the equivalent series impedances on the high voltage (primary) side can be calculated.

Per (3-54), $Z_{SE} = |Z_{SE}| = V_{SC,\phi} / I_{SC,\phi} = 323.31615 / 12.6 = 25.66 \ \Omega$.

Per (3-55), $\text{PF}_{SC} = \dfrac{P_{SC,\phi}}{V_{SC,\phi} I_{SC,\phi}} = \dfrac{566.6666}{323.31615(12.6)} = 0.1391 \text{ lagging}$.

Per (3-52), $\theta = \theta_{SE} = \cos^{-1}\left(\dfrac{P_{SC,\phi}}{V_{SC,\phi} I_{SC,\phi}}\right) = \cos^{-1}(0.1391) = 82.0041815°$.

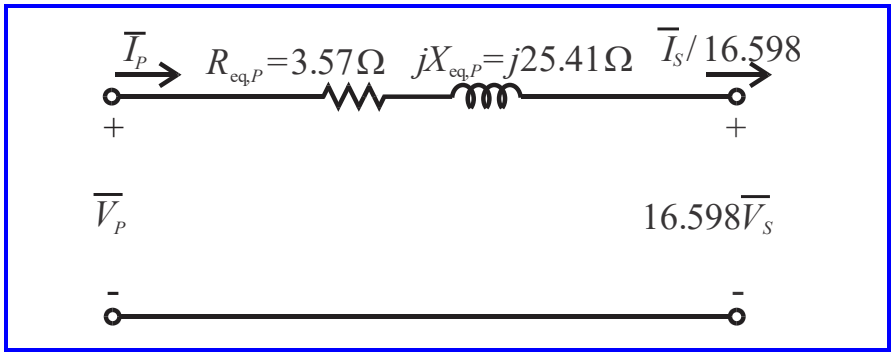
Per (3-57), put the magnitude and phase together to get

$$\bar{Z}_{SE} = Z_{SE}\angle\theta_{SE} = 25.66\angle 82.00^\circ\ \Omega = 3.56933 + j25.41054\ \Omega.$$

Per (3-58), $\bar{Z}_{SE} = 3.56933 + j25.41054\ \Omega = R_{eq,P} + jX_{eq,P}$

$$\Rightarrow \underline{R_{eq,P} = 3.5693\ \Omega}\ \&\ \underline{X_{eq,P} = 25.4105\ \Omega}.$$

Approximate Primary (High Side) Equivalent Circuit (neglect R_C & X_M.)



a) At rated load, the apparent power per phase is $S_\phi = S_{rated}$ = 100 kVA and the rated secondary voltage is $V_{\phi,S}$ = 480 V_{rms}. The rated current per phase is then

$$I_{\phi,S} = S_\phi / V_{\phi,S} = 100\times10^3 / 480 = 208.3333\ A_{rms}.$$

Given a 0.88 lagging PF, we find $\theta_V - \theta_I = \cos^{-1}(0.88) = 28.3576366^\circ$. Let $\theta_V = 0$, then $\theta_I = -28.3576366^\circ$ and $\bar{I}_{\phi,S} = 208.33\angle -28.358^\circ\ (A_{rms})$.

For our approximate primary equivalent circuit-

$$\bar{I}_{\phi,S} / a = 208.33\angle -28.358^\circ / 16.598 = 12.551776\angle -28.358^\circ\ (A_{rms})\ \text{and}$$
$$a\bar{V}_{\phi,S} = 16.598(480\angle 0^\circ) = 7967\angle 0^\circ\ (V_{rms}).$$

By KVL on the approximate primary equivalent circuit-

$$\bar{V}_{\phi,P} = (\bar{I}_{\phi,S} / a)(R_{eq,P} + jX_{eq,P}) + a\bar{V}_{\phi,S}$$
$$= (12.551776\angle -28.358^\circ)(3.57 + j25.41) + 7967\angle 0^\circ.$$
$$= 8162.04\angle 1.821^\circ\ (V_{rms})$$

Per (2-11), the line-to-line voltage is $V_{LL,P} = \sqrt{3}(8162.04)$ $\Rightarrow$ **$\underline{V_{LL,P} = 14{,}137.07\ V_{rms}}$**.

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

$$VR = \frac{V_P / a - V_{S,fl}}{V_{S,fl}}\times 100\% = \frac{V_P - aV_{S,fl}}{aV_{S,fl}}\times 100\% = \frac{8162.04 - 7967}{7967}\times 100\%$$

$$\Rightarrow \underline{\mathbf{VR = 2.45\%.}}$$