4-14

(a) $a = \frac{4800}{240} = 20$

$$Z_{E2} = \frac{1}{a^2} Z_{E1} = \frac{1}{(20)^2}(120 + j300) = 0.3 + j0.75\ \Omega$$

(b) $V_2 = 230\angle 0^\circ\ V$

$$I_{2,rated} = \frac{10{,}000}{240}\angle -\cos^{-1} 1 = 41.67\angle 0^\circ\ A$$

$$V_1 = aV_2 + \frac{I_2}{a} Z_{E1}$$

$$= 20(230\angle 0^\circ) + \left(\frac{41.67}{20}\angle 0^\circ\right)(120 + j300)$$

$$= 4600\angle 0 + 2{,}083\angle 0^\circ (120 + j300)$$

$$= 4890\angle 7.3^\circ\ V$$

4-15

$$V_2 = 230\angle 0^\circ \ V$$

$$I_2 = \frac{75{,}000}{(230)(0.85)} \angle -\cos^{-1} 0.85 = 383.63 \angle -31.8^\circ \ A$$

$$a = \frac{2300}{230} = 10$$

ⓐ $E_1 = aV_2 + \frac{I_2}{a}(a^2R_2 + ja^2X_2)$

$$= 10(230\angle 0) + \left(\frac{383.63}{10}\angle -31.8^\circ\right)(10)^2(0.003 + j0.0065)$$

$$= 2322.9 + j15.1 = 2322.97 \angle 0.37^\circ \ V$$

$$I_1 = \frac{I_2}{a} + E_1\left(\frac{1}{R_c} + \frac{1}{jX_m}\right) = \frac{383.63}{10}\angle -31.8^\circ + E_1\left(\frac{10^{-3}}{45} + \frac{10^{-3}}{j1}\right)$$

$$= 33.14 - j22.54 = 40.08 \angle -34.2^\circ \ A$$

ⓑ $V_1 = E_1 + I_1(R_1 + jX_1) = 2322.97\angle 0.37^\circ + (40.08\angle -34.2^\circ)(0.3 + j0.65)$

$$= 2347.5 + j29.78 = 2347.7 \angle 0.73^\circ \ V$$

ⓒ $P_1 = V_1 I_1 \cos \theta\Big]_{I_1}^{V_1} = (2347.7)(40.08)\cos(0.73 + 34.2)$

$$= 77.15 \ kW$$

$$PF = \cos(0.73^\circ + 34.2^\circ) = 0.82 \text{ lagging}$$

4-19

$$a = \frac{2400}{240} = 10$$

$$V_2 = 240\angle 0^\circ \quad V$$

$$I_2 = \frac{25{,}000}{240}\angle -\cos^{-1}0.85 = 104.167\angle -31.8^\circ \quad A$$

ⓐ $$V_1 = aV_2 + \frac{I_2}{a}(R_{E1} + jX_{E1}) = 10(240\angle 0^\circ) + \left(\frac{104.167}{10}\angle -31.8^\circ\right)(3.45 + j5.75)$$

$$= 2462.3\angle 0.74^\circ \quad V$$

ⓑ $$V.R. = \frac{V_1 - aV_2}{aV_2}\,100\% = \frac{2462.3 - 2400}{2400}\,100\% = 2.6\%$$

ⓒ $$P_{core} = 120\ W$$

$$P_{cu} = \left(\frac{I_2}{a}\right)^2 R_{E1} = \left(\frac{104.167}{10}\right)^2(3.45) = 374.3\ W$$

$$P_{out} = (25{,}000)(0.85) = 21{,}250\ W$$

$$\eta = \frac{P_{out}}{P_{out} + P_{core} + P_{cu}}\,100\% = \frac{(21{,}250)(100\%)}{21{,}250 + 120 + 374.3} = 97.7\%$$

4-21

(a) $P_{out} = (10)(0.8) = 8\ kW = 8000\ W$

$P_{in} = P_{out} + P_{core} + P_{cu}$

$= 8000 + 150 + 250 = 8400\ W$

$\eta = \dfrac{P_{out}}{P_{in}} = \dfrac{8000}{8400}\ 100\% = 95.2\%$

(b) $P_{out} = (\frac{3}{4})(10{,}000)(1.0) = 7500\ W$

$P_{in} = 7500 + 150 + (\frac{3}{4})^2(250) = 7790.6\ W$

$\eta = \dfrac{7500}{7790.6}\ 100\% = 96.3\%$

(c) $P_{out} = (\frac{1}{2})(10{,}000)(0.6) = 3000\ W$

$P_{in} = 3000 + 150 + (\frac{1}{2})^2(250) = 3212.5\ W$

$\eta = \dfrac{3000}{3212.5}\ 100\% = 93.4\%$

4-23

$$Z_{E1} = \frac{V_{sc}}{I_{sc}} = \frac{55}{10.4} = 5.29\ \Omega$$

$$R_{E1} = \frac{P_{sc}}{I_{sc}^2} = \frac{375}{(10.4)^2} = 3.47\ \Omega$$

$$X_{E1} = \sqrt{Z_{E1}^2 - R_{E1}^2} = \sqrt{(5.29)^2 - (3.47)^2} = 3.99\ \Omega$$

ⓐ $I_{FL} = \frac{25000}{240} = 104\ A$; $a = \frac{2400}{240} = 10$

$$\frac{I_{FL}}{a} = \frac{104}{10} = 10.4\ A \qquad V_2 = 240\angle 0^\circ$$

$$P_{core} = 165\ W = P_{oc}$$

$$P_{cu} = 375\ W = P_{sc}$$

$$P_{out} = (25000)(0.8) = 20{,}000$$

$$\eta = \frac{P_{out}}{P_{out} + P_{core} + P_{cu}} = \frac{20{,}000}{20{,}000 + 165 + 375}\ 100\% = 97.4\%$$

ⓑ $Z_{E1} = 3.47 + j3.99 = 5.29\angle 49^\circ$

$$I_2 = 104\angle -49^\circ$$

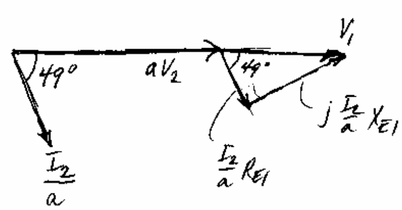
$$V_1 = aV_2 + \frac{I_2}{a}(R_{E1} + jX_{E1}) = 10(240\angle 0^\circ) + \left(\frac{104}{10}\angle -49\right)(5.29\angle 49^\circ)$$

$$= 2455\angle 0^\circ$$

$$V.R. = \frac{V_1 - aV_2}{aV_2}\ 100\%$$

$$= \frac{2455 - 2400}{2400}\ 100\%$$

$$= 2.29\%$$



$$P_{out} = V_2 I_2\, PF = (220)(156)(0.8) = 27{,}456\ W$$

$$P_{core} = \frac{V_2^2}{R_{C2}} = \frac{(220)^2}{128} = 378\ W$$

$$P_{cu} = \left(\frac{I_2}{a}\right)^2 R_{E1} = \left(\frac{156}{10}\right)^2 (1.39) = 338\ W$$

$$\eta = \frac{P_{out}}{P_{out} + P_{core} + P_{cu}} = \frac{27{,}456}{27{,}456 + 378 + 338}\, 100\% = 97.4\%$$

(b) $$I_2 = \frac{50{,}000}{240} \angle{-\cos^{-1} 0.8} = 208 \angle{-36.9^\circ}$$

$$a V_2 = 10(240 \angle 0^\circ)$$

$$V_1 = aV_2 + \frac{I_2}{a}(R_{E1} + jX_{E1})$$

$$= 10(240 \angle 0^\circ) + \left(\frac{208}{10} \angle{-36.9^\circ}\right)(1.39 + j\,2.24)$$

$$= 2451 \angle 0.5^\circ$$

$$V.R. = \frac{2451 - 2400}{2400}\, 100\% = 2.1\%$$

$$P_{out} = (50{,}000)(0.8) = 40{,}000\ W$$

$$P_{core} = 450\ W$$

$$P_{cu} = 600\ W$$

$$\eta = \frac{40{,}000}{40{,}000 + 450 + 600}\, 100\% = 97.4\%$$

4-24

$$a = \frac{2400}{240} = 10$$

$$I_{1,\text{rated}} = \frac{50{,}000}{2400} = 20.8\ A$$

$$R_{C2} = \frac{V_{OC}^2}{P_{OC}} = \frac{(240)^2}{450} = 128\ \Omega$$

$$G_{C2} = \frac{1}{R_{C2}} = 0.0078\ S$$

$$Y_{O2} = \frac{I_{OC}}{V_{OC}} = \frac{5}{240} = 0.02083\ S$$

$$B_{M2} = \sqrt{Y_{O2}^2 - G_{C2}^2} = \sqrt{(0.02083)^2 - (0.0078)^2} = 0.0193\ S$$

$$X_{M2} = \frac{1}{B_{M2}} = 51.8\ \Omega$$

$$R_{E1} = \frac{P_{SC}}{I_{SC}^2} = \frac{600}{(20.8)^2} = 1.39\ \Omega$$

$$Z_{E1} = \frac{V_{SC}}{I_{SC}} = \frac{55}{20.8} = 2.64\ \Omega$$

$$X_{E1} = \sqrt{Z_{E1}^2 - R_{E1}^2} = \sqrt{(2.64)^2 - (1.39)^2} = 2.24\ \Omega$$

(a) $V_2 = 220\angle 0^\circ$

$$I_2 = 156\angle -\cos^{-1} 0.8 = 156\angle -36.9^\circ$$

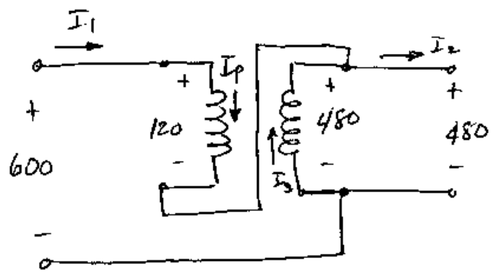
$$V_1 = aV_2 + \frac{I_2}{a}(R_{E1} + jX_{E1}) = 10(220\angle 0^\circ) + \left(\frac{156}{10}\angle -36.9^\circ\right)(1.39 + j\,2.24)$$

$$= 2238.4\angle 0.4^\circ$$

$$V.R. = \frac{V_1 - aV_2}{aV_2} = \frac{2238.4 - 2200}{2200}\,100\% = 1.7\%$$

4-29

(a)



$$I_p = \frac{5000}{120} = 41.67\,A$$

$$I_s = \frac{5000}{480} = 10.42\,A$$

(b) $I_1 = I_p = 41.67\,A$

$V_1 = 600\,V$

$$KVA_{rating} = V_1 I_1 = \frac{(600)(41.67)}{1000} = 25\ KVA$$

(c) $P_{out} = (5000)(0.8) = 4000\ W$

$$\eta_t = 0.95 = \frac{4000}{4000 + Losses}$$

$$Losses = \frac{4000}{0.95} - 4000 = 210\ W$$

$$\eta_{auto} = \frac{(25000)(0.8)\,100\%}{(25000)(0.8) + 210} = 99\%$$

4-31

$$a = \frac{20}{2.4} = 8.33$$

(a) Reference phasor: $V_{2p} = 2.4 \angle 0^\circ$ kV

$$I_{2p} = \frac{6000/3}{(2.4)(0.85)} \angle -\cos^{-1} 0.85 = 980 \angle -31.8^\circ \text{ A}$$

$$I_{2L} = \sqrt{3}\, I_{2p} \angle -30^\circ = 1698 \angle -61.8^\circ \text{ A}$$

$$I_{1p} = \frac{I_{2p}}{a} = 118 \angle -31.8^\circ$$

$$I_{1L} = I_{1p} = 118 \angle -31.8^\circ$$

(b)

$$V_{2p} = 2.4 \angle 0^\circ \text{ kV}$$

$$V_{2L} = V_{2p} = 2.4 \angle 0^\circ \text{ kV}$$

$$V_{1p} = a V_{2p} = 20 \angle 0^\circ \text{ kV}$$

$$V_{1L} = \sqrt{3}\, V_{1p} \angle 30^\circ = 34.5 \angle 30^\circ$$

4-35

$$P_{out} = (0.7)(300)(0.85) = 178.5 \text{ kW}$$

$$P_{core} = 2.2 \text{ kW}$$

$$P_{cu} = (0.7)^2(3.8) = 1.86 \text{ kW}$$

$$\eta = \frac{P_{out}}{P_{out} + P_{core} + P_{cu}} = \frac{178.5}{178.5 + 2.2 + 1.86} 100\% = 97.8\%$$