2 Transformers

2.1 Solutions To Exercises

EXERCISE 2-1

$$Z_L = \frac{(120)^2}{5000} = 2.88\,\Omega \qquad Z_1 = 288\left(\frac{240}{120}\right)^2 = \underline{\underline{11.52\ \Omega}}$$

EXERCISE 2-2

a) $Z_{e_H} = 0.5 + j1.2 + (2)^2(0.125 + j0.30) = \underline{\underline{1 + j2.4\ \Omega}}$

b) $Z_{eL} = \frac{1}{4}(1 + j2.4) = \underline{\underline{0.25 + j0.6\ \Omega}}$

c) $Z_{e\,p\,u} = (0.25 + j0.6)\frac{5000}{(240)^2} = \underline{\underline{0.022 + j0.052\ p\ u}}$

d)
$$\begin{aligned} V_{2_{n.\ell}} &= V_L + I\,Z_e \\ &= 1\angle 0° + 1\angle -36.9°(0.022 + j0.052) \\ &= 1.049\angle 1.56° \end{aligned}$$

$$\begin{aligned} V_s &= 1.049(480)\angle 1.56° \\ &= \underline{\underline{503.52\angle 1.56° V}} \end{aligned}$$

EXERCISE 2-3

$$V_{Z_{pu}} = I_{r_{pu}} Z_{e_{pu}} = 1.0\,Z_{e_{pu}} = Z_{e_{pu}}$$

EXERCISE 2-4

1. a) Primary:

$$I_L = \frac{1500}{\sqrt{3}(4.16)} = \underline{\underline{208.2\text{ A}}}$$

$$I_P = 208.2/\sqrt{3} = \underline{\underline{120.2\text{ A}}}$$

Secondary:

$$I_P = I_L = \frac{1500}{\sqrt{3}(0.48)} = \underline{\underline{1804.2\text{ A}}}$$

b) $Z_{bL} = \frac{(0.48)^2}{1.5} = 0.154\ \Omega\text{/Phase}$

$X_e = 0.06\ (0.154) = \underline{\underline{0.0092\ \Omega\text{/Phase}}}$

$Z_{eH} = \frac{(4.16)^2}{1.5} = 11.537\ \Omega\text{/Phase}$

$X_{e_H} = 0.06\ (11.537) = 0.69\ \Omega$/Phase, star connected

$= 3\ (0.69) = \underline{\underline{2.08\ \Omega}}$, delta connected

c) Secondary:

$$I_L = I_P = \frac{1500}{\sqrt{3}(0.48)}\left(\frac{1}{0.06}\right) = \underline{\underline{30.07\text{ kA}}}$$

Primary:

$$I_L = \left(\frac{1}{0.06}\right)\frac{1500}{\sqrt{3}(4.16)} = \underline{\underline{3.47\text{ kA}}}$$

$$I_P = 3.47/\sqrt{3} = 2.0\,\text{kA}$$

2. a) Primary

$$I_L = 208.2\ (1.333) = \underline{\underline{277.6\text{ A}}}$$

$$I_P = 277.6/\sqrt{3} = \underline{\underline{160.3\text{ A}}}$$

Secondary:

$$I_L = \frac{2000}{\sqrt{3}(0.48)} = \underline{\underline{2405.6 \text{ A}}}$$

b) No change.

c) No change.

EXERCISE 2-5

From

$I_A + I_C = I_B$; $I_C = I_T$

$I_A \pm I_T - I_S = 0$, $I_B \pm I_T - I_S = 0$

$I_T = \underline{\underline{0 \text{ A}}}$, $I_A = I_B = \underline{\underline{25 \text{ A}}}$

EXERCISE 2-6

Parameter	Δ-Δ	Δ-Y
Insulation level of secondary winding	nominal	lower for star winding
Exciting current	non-linear	non-linear
Output voltage waveforms	sinusoidal	sinusoidal

EXERCISE 2-7

c) 120 V coil: $\frac{500}{120} = 4.166$ A

240 V coil: 2.08 A

Load: $S = \sqrt{3}\, V_{L\text{-}L}\, I$
$= \sqrt{3}\,(0.48)\,(10.4167)$
$= \underline{\underline{8.66 \text{ kVA}}}$

EXERCISE 2-8

$S_b = 500$ kVA $\quad V_b = 480$ V $\quad I_b = \frac{500}{0.48} = 1041.67$ A

$Z_{e1} = (0.02 + j0.035)\frac{5}{3} = 0.0672\angle 60.3°$ p u

$Z_{e2} = (0.018 + j0.04)\frac{5}{2.5} = 0.0877\angle 65.8°$ p u

$V_1 = V_2$

$V_1 = 1\angle 0° + I_1 Z_{e_1}$

$V_2 = 1\angle 0° + I_2 Z_{e_2}$

Thus,

$$I_1 = I_2 \frac{Z_{e2}}{Z_{e1}}$$

$$I_1 = \left(\frac{0.0877}{0.0672}\right)\angle 65.8° - 60.3° I_2$$
$$= 1.31\angle 5.5° I_2$$

Also

$$I_1 + I_2 = 1\angle -25.8°$$

or

$$(1.31\angle 5.5°)\, I_2 + I_2 = 1\angle -25.8°$$

From which

$$I_2 = 0.434\angle -29° \text{ p u}$$

$$= 0.434\,(1041.67) = \underline{\underline{452.29 \text{ A}}}$$

and

$$I_1 = 0.567\angle -23.4° = 0.567\ (1041.67) = \underline{\underline{590.4\ A}}$$

$$S_2 = 452.29\ (0.48) = \underline{\underline{217.1\angle 29°\ kVA}}$$

$$S_1 = 590.4\ (0.48) = \underline{\underline{283.4\angle 23.4°\ kVA}}$$

EXERCISE 2-9

Shorting the load will increase by many folds the current through the primary winding of the CT. As a result, the CT will be damaged—if no precaution is taken—due to excessive copper losses. The PT's primary current will remain at its nominal level.

EXERCISE 2-10

a) PT. When the fuse is blown out the secondary winding becomes open circuited. There is no danger of fire.

CT. When the fuse is blown out the secondary winding becomes open circuited. There is a danger of fire.

b) Voltage and current are phasors while the meters read only scalar quantities.

2.2 Solutions To Problems

PROBLEM 2-1

a) $Z_{e_H} = 0.5 + j2.6 + 10^2\ (0.005 + j0.026) = 1 + j5.2\ \Omega$

$$Z_{eL} = 0.005 + j0.026 + \frac{1}{100}(0.5 + j2.6) = 0.01 + j0.052$$

$$= 0.053\angle 79.11°\Omega$$

b) $I_2 = \frac{50000}{(230)} = 217.39\angle -25.8°\ A$

$V_L = \angle 0° = 230\angle\beta - 217.39\ (0.053)\angle 79.11° - 25.8°$

$\beta = 2.3°$, $V_L = \underline{\underline{222.93\ V}}$

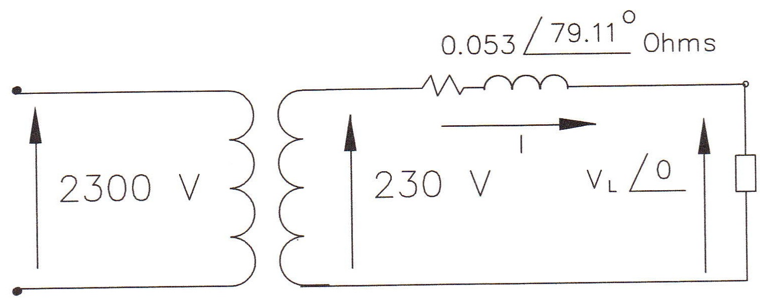

FIG. SP2-1

PROBLEM 2-2

a) $Z_{mH} = \frac{2400}{0.35} = 6857.1\ \Omega$

$R_m = \frac{150}{(0.35)^2} = 1224.49\ \Omega$

$X_m = \sqrt{6857.1^2 - 1224.49^2} = 6746.93\ \Omega$

$Z_{m_H} = 6857.1\angle 79.7°\Omega$, $Z_{m_L} = 68.57\angle 79.71°\Omega$

$Z_{eL} = \frac{12}{41.67} = 0.288\ \Omega$, $R_{eL} = \frac{320}{(41.67)^2} = 0.184\ \Omega$

$X_{e_L} = (0.288^2 - 0.184^2)^{1/2} = 0.2213\ \ \Omega$

$Z_{e_L} = 0.288\angle 50.2°$

$Z_{e_H} = 28.8\angle 50.2°$

b) $V = 10\ (240 + 0.288\angle 50.2°\ (41.67\angle -25.8°\ )$

$= \underline{\underline{2509.8\angle 1.1°V}}$

c) $$\text{Reg} = \left(\frac{2509.8}{10} - 240\right)\frac{1}{240}(100) = \underline{\underline{4.57\%}}$$

$$\eta = \frac{10(0.9)}{10(0.9) + 0.320 + 0.15\left(\frac{2509.8}{2400}\right)^2} = \underline{\underline{0.949}}$$

d) $$Z_{Bl} = \frac{(240)^2}{10000} = 5.76\ \Omega$$

$$Z_{epu} = \frac{0.288\angle 50.2°}{5.76} = \underline{\underline{0.05\angle 50.2°\,\text{pu}}}$$

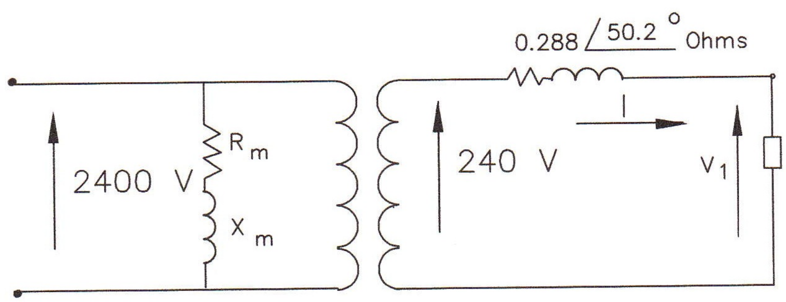

FIG. SP2-2

PROBLEM 2-3

a) $$Z_{Bl} = \frac{120^2}{50000} = 0.288\ \Omega, \qquad R_a = 0.023(0.288) = 0.0066\ \Omega$$

$$I^2\,(0.0066) = 600, \qquad I = \underline{\underline{300.96\ \text{A}}}$$

b) $$\eta = \frac{50}{50 + 0.6 + 0.6} = \underline{\underline{97.66\%}}$$

$$\eta = \frac{50}{50 + 0.6 + (416.67)^2(0.0066)} = \underline{\underline{96.6\%}}$$

c) $$Z_e = 0.023 + j0.05 = 0.055\angle 65.3°\ \text{p u}$$

$$V_s = V_L + I\,Z$$

$$1\angle\beta = 1\angle 0° + 1\angle\Theta\,(0.055\angle 65.3°)$$

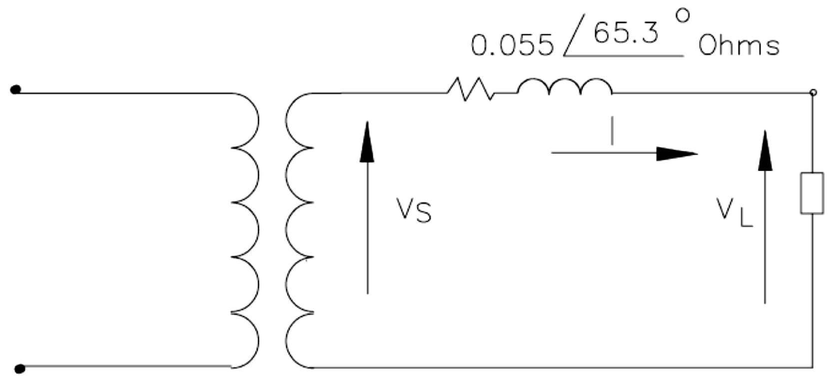

FIG. SP2-3

$1\angle\beta = 1\angle 0° + 0.055\angle\mu$; $\mu = \Theta + 65.3°$

$\cos\beta = 1 + 0.055\cos\mu$

$\sin\beta = 0.055\sin\mu$

From the last two relationships

$$\cos^2\beta + \sin^2\beta = 1 + (0.055)^2(\cos^2\mu + \sin^2\mu) + 2(0.055)\cos\mu$$

or

$$\cos\mu = -\frac{0.055}{2} = -0.0275$$

$$\mu = 91.5°$$

and

$$\Theta = 26.3°; \qquad \cos\Theta = \underline{\underline{0.90\text{ leading}}}$$

PROBLEM 2-4

$P_z = \frac{2.5}{100}(100) = 2.5$ kW, $P_m = P_T - P_z = 100{,}000\frac{1-0.9575}{0.9575} - 2500$

$P_m = 4438.6 - 2500 = 1938.6$ W

$$1938.6 = K_1(120)^2 + K_2 60\left(\frac{120}{60}\right)^h \qquad \textbf{...(1)}$$

$$1400 = K_1(100)^2 + K_2 50\left(\frac{100}{50}\right)^h \qquad \textbf{...(2)}$$

From (1) and (2),

$$K_1 = 107.75 \times 10^{-3}$$

a) $P_e = 107.75 \times 10^{-3}\,(120)^2 = \underline{\underline{1551.6\ \text{W}}}$

$P_h = 1938.6 - 1551.6 = \underline{\underline{387\ \text{W}}}$

b) $P_h = 1400 - 107.75 \times 10^{-3}\,(100)^2 = \underline{\underline{322.5\ \text{W}}}$

c) The hysteresis losses will be increased but not substantially.

Original: $P_h = K_2\,(60)\,2^h$

New: $P_h = K_2\,(50)(2.4)^h$

PROBLEM 2-5

a) 240/120 V

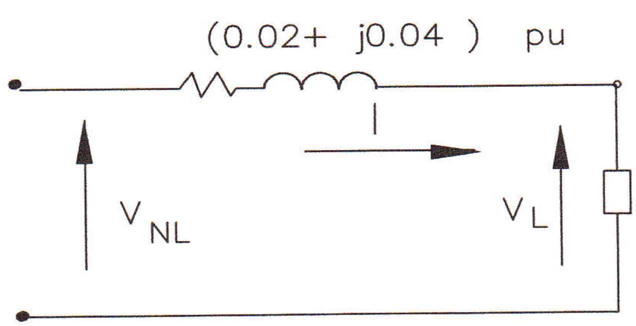

FIG. SP2-5

b) I) $V_L = V_{n\ell} - I\,Z$

$V_L \angle 0° = 1\angle\beta - 1\angle 0°\,(0.02 + j0.04)$

$\beta = 2.3°, \qquad V_L = 0.98$ p u

$$\text{Reg} = \frac{1 - 0.98}{0.98}(100) = \underline{\underline{2.04\%}}$$

II) $V_L \angle 0° = 1\angle\beta - 1\angle 36.9° (0.045\angle 63.4°)$

$V_L \angle 0° = 1\angle\beta - 0.045\angle 100.3°$

$\beta = 2.52°, \qquad V_L = 1.007 \text{ p u}$

$$\text{Reg} = \frac{1 - 1.007}{1.007}(100) = \underline{\underline{-0.698\%}}$$

III) $V_L \angle 0° = 1\angle\beta - 1\angle -36.9° (0.045\angle 63.4°)$

$V_L \angle 0° = 1\angle\beta - 0.045\angle 26.6°$

$\beta = 1.1°, \qquad V_L = 0.96 \text{ p u}$

$$\text{Reg} = \frac{1 - 0.96}{0.96}(100) = \underline{\underline{4.2\%}}$$

PROBLEM 2-6

a) $V_{n\ell} = 1\angle 0° + 1.0\angle -25.8° \times (0.015 + j0.06)$

$= 1.0407\angle 2.6° \text{ p u}$

$$\text{Regulation} = \frac{1.0407 - 1.0}{1.0}(100) = \underline{\underline{4.07\%}}$$

$$P_L = 0.9\left(\frac{1 - 0.97}{0.97}\right) = 0.0278 \text{ p u}$$

Actual:

$$P_{c\ell} = 0.0278 - 0.015 = 0.0128 \text{ p u}$$

X: nominal core loss

$$X\,(1.0407)^2 = 0.0128$$

$X = \underline{\underline{0.013 \text{ p u}}}$

b) Set the no-load voltage taps to 1.05 p u

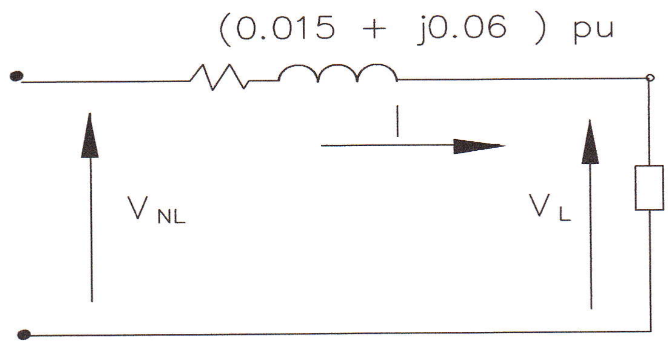

FIG. SP2-6

PROBLEM 2-7

a) $$I_{AB} = 60\left(\frac{480}{\sqrt{3}}\right)\frac{1}{4160}$$

$$= \underline{\underline{4.0\ \text{A}}}$$

b) $I_{AB} = I_{CB} = \underline{\underline{4.0\ \text{A}}}$

c) $$I_a = \frac{100}{\sqrt{3}(0.48)(0.80)(0.9)} = \underline{\underline{167.06\ \text{A}}}$$

$$I_{AB} = I_{BC} = I_{CA} = 167.06\left(\frac{480}{\sqrt{3}}\right)\frac{1}{4160} = \underline{\underline{11.1\ \text{A}}}$$

PROBLEM 2-8

a) $Z_{bL} = \frac{(0.48)^2}{2} = 0.1152\ \Omega/\emptyset$, $Z_{bH} = \frac{(25)^2}{2} = 312.5\ \Omega/\emptyset$

$$X_s = \frac{(25)^2}{500}\left(\frac{1}{312.5}\right) = 0.004\ \text{p u}$$

$$Z_A = \frac{5 + j8}{312.5} = \underline{\underline{(0.016 + j0.0256)\ \text{p u}}}$$

$$Z_B = \frac{0.005 + j0.01}{0.1125} = \underline{\underline{(0.0434 + j0.0867)\text{ p u}}}$$

b) $$I_1 = \frac{500}{\sqrt{3}(0.48)(0.95)} = 633.1\angle -36.9°\,A$$

$$I_2 = \frac{600}{\sqrt{3}(0.48)(0.9)(0.9)} = 891\angle -25.8°\,A$$

$$I_t = I_1 + I_2 = 1517.2\angle -30.4°\,A$$

$$I_{bL} = \frac{2000}{\sqrt{3}(0.48)} = 2405.6\text{ A}$$

$$|I_t| = \frac{1517.2}{2405.6} = 0.6307\text{ p u}$$

$$R_t = 0.016 + 0.01 + 0.0434 = 0.0694\text{ p u}$$

$$X_t = 0.004 + 0.0256 + 0.062 + 0.0867 = 0.1784$$

$$\text{Loss} = (0.6307)^2(0.0694) = 0.0276\text{ p u}$$

$$= 0.0276\,(2000) = \underline{\underline{55.2\text{ kW}}}$$

c) $$V_s = 1\angle 0° + 0.6307\angle -30.4°\,(0.069 + j0.1777)$$

$$= 1\angle 0° + 0.121\angle 38.5°;\quad |V_s| = 1.1\text{ p u} = \underline{\underline{27.4\text{ kV}}}$$

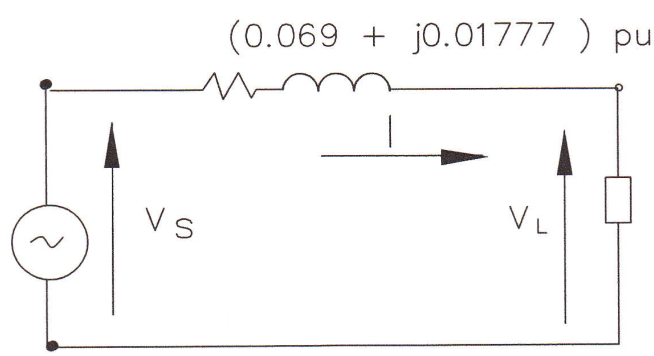

FIG. SP2-8

PROBLEM 2-9

b) The motor current is:

$$I_m = \frac{25}{\sqrt{3}(0.55)(0.8)(0.95)} = 34.53\,A$$

Take as reference V_{ab}, Phase sequence ABC.

$$I_{m_a} = 34.53\angle 6.9°\,A$$

$$I_{m_b} = 34.53\angle -113.1°\,A$$

$$I_{m_c} = 34.53\angle 126.9°\,A$$

Load P$_3$

$$I_{ab} = \frac{20}{0.55}\angle 0° = 36.36\angle 0°\text{ A}$$

Load P$_2$

$$I_{bn} = \frac{10\sqrt{3}}{0.55(0.9)(0.9)} = 38.88\angle -145.8° - 30 = 38.88\angle -175.8\,A$$

Load P$_1$

$$I_{cn} = \frac{12\sqrt{3}}{0.55(0.8)(0.95)} = 49.72\angle 53.1°\,A$$

The line currents through the secondary of the transformer are:

$$I_{a\text{-}a} = I_{ma} + I_{ab}$$

$$= 34.53\angle 6.9° + 36.36\angle 0° = \underline{\underline{70.77\angle 3.3°\,A}}$$

$$I_{b\text{-}b} = I_{mb} + I_{bn} - I_{ab}$$

$$= 34.53\angle -113.1° + 38.88\angle -175.8° - 36.36\angle 0°$$

$$= \underline{\underline{95.2\angle -158.7°\,A}}$$

$$I_{c\text{-}ca} = I_{mc} + I_{cn}$$

$$= 34.53\angle 126.9° + 49.72\angle 53.1°$$

$$= \underline{\underline{68\angle 82.3°\,A}}$$

<u>Primary of transformer</u>

The per-phase turn's ratio is:

$$\frac{4800}{550/\sqrt{3}} = 15.1$$

Then

$$I_A = \frac{70.77}{15.1} = \underline{\underline{4.68\text{ A}}}$$

$$I_B = \frac{95.2}{15.1} = \underline{\underline{6.30\text{ A}}}$$

$$I_C = \frac{68}{15.1} = \underline{\underline{4.5\text{ A}}}$$

a) The rating of the transformer must be based on the highest winding current requirement.

$$I_{b\text{-}b} = 95.2\text{ A}$$

$$|S| = \sqrt{3}\,(0.55)\,(95.2) = \underline{\underline{90.70\text{ kVA}}}$$

Use a commercially available transformer whose capacity is

3-Ø, 4800-550/317 V, 112.5 kVA

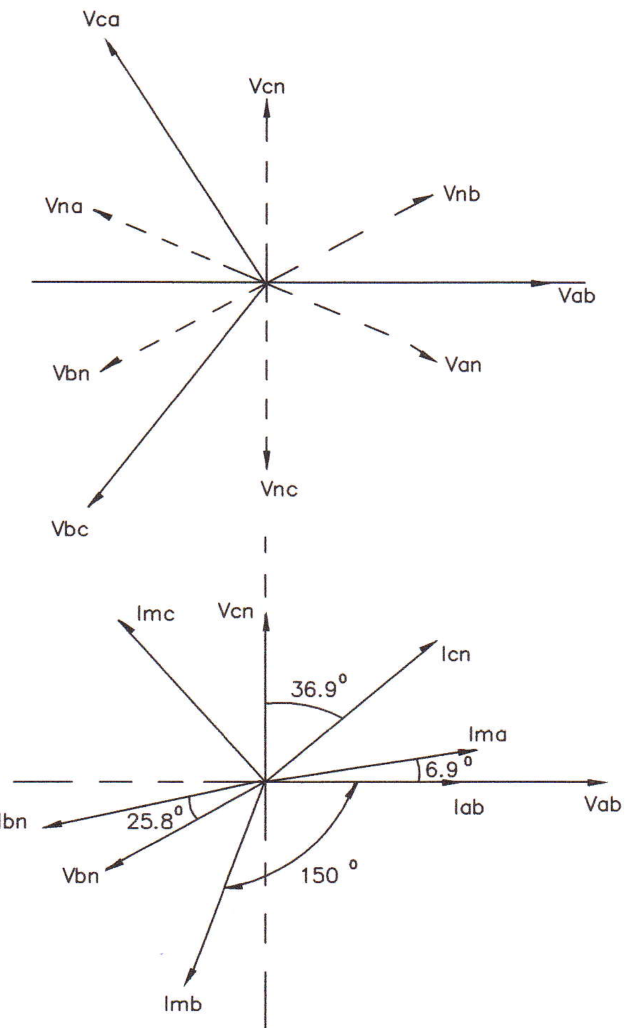

FIG. SP2-9

PROBLEM 2-10

a) $V_1 = 3\ I_a + 2\ I_b + I_c$ **…(1)**

$V_2 = 2\ I_a + 3\ I_b + I_c$ **…(2)**

$V_3 = I_a + I_b + I_c$ **…(3)**

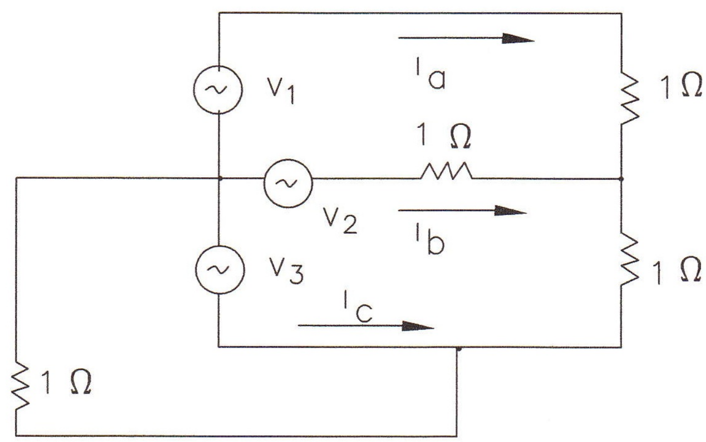

FIG. SP2-10(a)

$$D = \begin{vmatrix} 3 & 2 & 1 \\ 2 & 3 & 1 \\ 1 & 1 & 1 \end{vmatrix} = 3$$

$$N_1 = \begin{vmatrix} V_1 & 2 & 1 \\ V_2 & 3 & 1 \\ V_3 & 1 & 1 \end{vmatrix} = 2V_1 - V_3 - V_2$$

$$= \frac{480}{\sqrt{3}}\left(2\angle 0° - 1\angle 120° - 1\angle -120°\right)$$

$$= 3\left(\frac{480}{\sqrt{3}}\right)V$$

$$I_a = \frac{N_1}{D} = 3\frac{480}{\sqrt{3}}\left(\frac{1}{3}\right) = \underline{\underline{277.1\ A}}$$

Similarly

$$N_2 = -3\left(\frac{480}{\sqrt{3}}\right)\angle 60°$$

$$I_b = \underline{\underline{-277.1\angle 60°\,A}}$$

$$N_3 = \frac{480}{\sqrt{3}}(6)\angle 120°$$

$$I_c = \frac{6}{3}\frac{480}{\sqrt{3}}\angle 120°$$

$$= \underline{\underline{554.3\angle 120°\,A}}$$

To check

$$V_3 = I_a + I_b + I_c$$

$$= \frac{480}{\sqrt{3}}\angle 120° = 277.1\ \angle 0° - 277.1\ \angle 60° + 554.3\ \angle 120°$$

$$\text{R H S} = \frac{480}{\sqrt{3}}\angle 120°, \qquad \text{OK}$$

$V_{mf\text{-}g} = 0$, no danger to personnel.

Fuse in phase "c" will blow.

b)

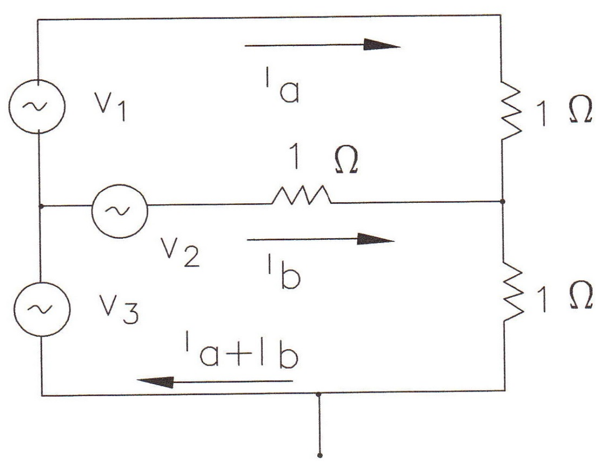

FIG. SP2-10(b)

$V_1 - I_a - (I_a + I_b) - V_3 = 0$ **…(4)**

$V_2 - I_b - (I_a + I_b) - V_3 = 0$ **…(5)**

From Eqs. (4) and (5):

$$I_a = -\frac{1}{3}\left[V_2 + V_3 - 2V_1\right] = -\frac{1}{3}\left(\frac{480}{\sqrt{3}}\right)\left[1\angle -120° + 1\angle 120° - 2\angle 0°\right]$$

$= \underline{\underline{277.1\ \text{A}}}$

$$I_b = V_1 - V_3 - 2\left(\frac{480}{\sqrt{3}}\right)$$

$$= \left(\frac{480}{\sqrt{3}}\right)[1\angle 0° - 1\angle 120° - 2] = 277.1\angle 120°\ \text{A}$$

$I_c = -(I_b + I_a) = 277.1\ (1\angle 0° + 1\angle 120°) = 277.1\angle 120°\ \text{A}$

$V_{mf\text{-}g} = 277.1\ \text{V}$

Fuses will not blow.

c) $I_c = \infty$

$V_{mf\text{-}g} = 0$

Fuse in line "c" will blow.

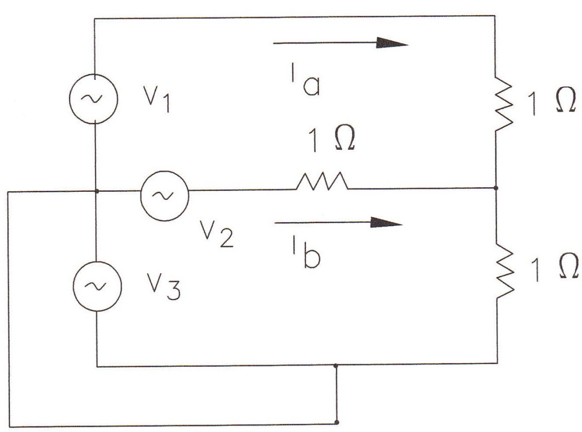

FIG. SP2-10(c)

d) Nominal three-phase operation.

$$V_{mf\text{-}g} \approx \underline{\underline{277.1\ \text{V}}}$$

None of the fuses will blow.

PROBLEM 2-11

a) S = 600 (41.67) = 25 kVA

b) 25 − 5 = 20 kVA

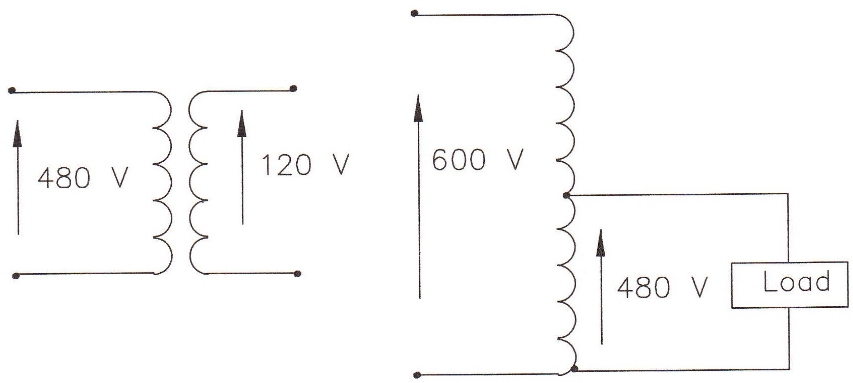

FIG. SP2-11

PROBLEM 2-12

a) S = 3.4 (200) = 680 kVA

680 − 200 = 480 kVA conducted

$\frac{480}{680}(100) = \underline{\underline{70.6\%}}$

b) $P_L = P_T \frac{(1-\eta)}{\eta} = 200(0.85)\left(\frac{1-0.96}{0.96}\right) = 7.08\text{ kW}$

$\eta = \frac{680\ (0.85)}{680\ (0.85) + 7.08} = \underline{\underline{0.99}}$

c) $Z_b = \frac{3400}{(0.02 + j0.06)5} = \underline{\underline{10.75\text{ kA}}}$

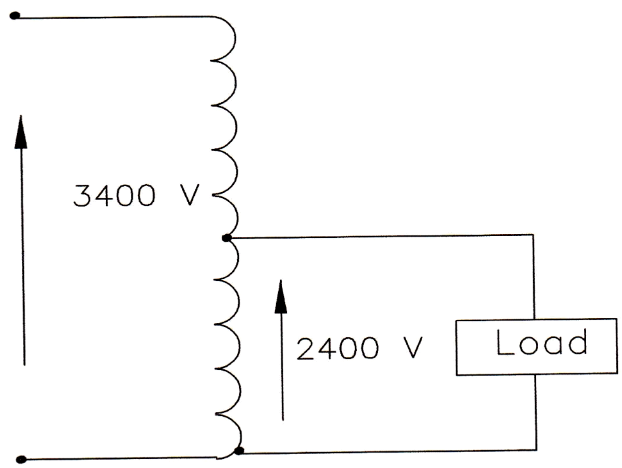

FIG. SP2-12

PROBLEM 2-13

$S_b = 1000$ kVA $\qquad V_b = 480$ V $\qquad I_b = \dfrac{1000}{0.480} = 2.08$ kA

T-1 $\quad Z_{e1} = (0.02 + j0.04)\dfrac{1000}{550} = 0.0364 + j0.0727 = 0.0813\angle 63.4°\,\Omega$

T-2 $\quad Z_{e2} = \left(0.02 + j0.05\right)\left(\dfrac{1000}{550}\right)\left(\dfrac{468}{480}\right)^2 = 0.0346 + j0.0864$

$$= 0.0931\angle 68.2°\,\Omega$$

$$\frac{V_1}{V_2} = \frac{480}{468} = 1.0256$$

$$V_1\angle\beta = 1\angle 0° + I_1 Z_{e1} \qquad \textbf{...(1)}$$

$$V_2\angle\beta = 1\angle 0° + I_2 Z_{e2} \qquad \textbf{...(2)}$$

$$\frac{V_1}{V_2} = 1.0256 = \frac{1\angle 0° + I_1 Z_{e1}}{1\angle 0° + I_2 Z_{e2}} \qquad \textbf{...(3)}$$

$$I = I_1 + I_2 \qquad \textbf{...(4)}$$

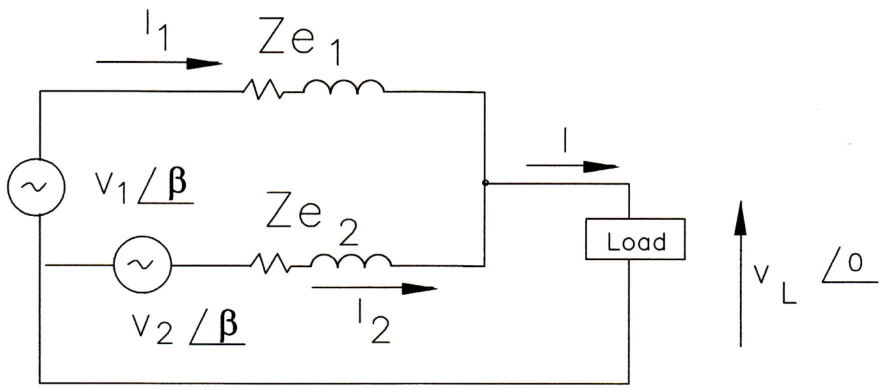

FIG. SP2-13

From (3) and (4)

$$I_1 = 0.655\angle -32.2°\text{ p u}$$

$$I_2 = 0.36\angle -14°\text{ p u}$$

a) $V_1\angle\beta = 1\angle 0° + 0.655\angle -32.2°\,(0.0813\angle 63.4°)$

$= 1.0455 + j0.0276 = 1.0459\angle 1.5°$

$= 1.0459\ (4160) = \underline{\underline{4350.8\text{ V, L-L}}}$

b) T-1 $I_1 = 0.655(2.08) = \underline{\underline{1.36\text{ kA}}}$

T-2 $I_2 = 0.36(2.08) = \underline{\underline{750\text{ A}}}$

c) T-1 $S_1 = 0.655\ (1)\ [1000] = \underline{\underline{655\text{ kVA}}}$

T-2 $S_2 = 0.36\ (1000) = \underline{\underline{360\text{ kVA}}}$

d) $V_2 = \dfrac{V_1}{1.0256} = \dfrac{1.0459}{1.0256} = 1.0198$

$$I = \frac{V_1 - V_2}{Z_1 + Z_2} = \frac{1.0459\angle 1.5° - 1.0198\angle 1.5°}{0.0364 + 0.0346 + j(0.0727 + 0.0864)}$$

$$= \frac{0.0261 + j0.0007}{(\ )} = \frac{0.0261\angle 1.5°}{0.1742\angle 66°}$$

$$= 0.1498\angle -64.5°$$

$$= 0.1498\ (2.08) = \underline{\underline{312\text{ A}}}$$

e) $$I = I_1 + I_2 = \frac{1.0459\angle 1.5°}{0.0813\angle 63.4°} + \frac{1.0198\angle 1.5°}{0.0931\angle 68.2°}$$

$$= 12.8647\angle -61.9° + 10.9538\angle -66.7°$$

$$= 10.3922 - j21.4088 = 23.799\angle -64.1°$$

$$= 23.799\ (138.8) = \underline{\underline{3.3\text{ kA}}}$$

PROBLEM 2-14

a) (1) $Z_{bH} = \frac{(25)^2}{1} = 625\ \Omega/\emptyset$

$Z_f = \frac{20 + j30}{625} = (0.032 + j0.048)$ p u

$Z_t = 0.032 + j0.048 + j0.06 = 0.032 + j0.108 = 0.1126\angle 73.5°$ p u

$V_L = \angle 0° = 1\angle\beta - 0.1126\angle 73.5°(1\angle -25.8°)$

$\beta = 4.77°$, $V_L = 0.92$ p u

$V_L = \underline{\underline{441.9\text{ V, L-L}}}$

$$I = \frac{1000}{\sqrt{3}(0.48)} = \underline{\underline{1202.8\text{ A}}}$$

$$I_m = 1202.8\left(\frac{5}{1500}\right) = \underline{\underline{4\text{ A}}}$$

(2) $I = \frac{1}{0.1126} = 8.88$ p u

$I = 0.88\ (1202.8) = \underline{\underline{10.7\text{ kA}}}$

$I_m = 10.7\left(\frac{5}{1.5}\right) = \underline{\underline{35.6\text{ A}}}$, V = 0 Volts

(3) $X_s = \frac{(25)^2}{500} = 1.25\ \Omega/\emptyset$ $X_{s\,p\,u} = \frac{1.25}{625} = 0.002$ p u

$X_t = 0.002 + 0.048 + 0.06 = 0.11$

$V_L = \angle 0° = 1\angle\beta - 1.0\angle 25.84° \, (0.032 + j0.11)$

$\beta = 6.5°$, $V_L = 1.02$ p u, $V_L = \underline{\underline{489.2 \text{ V}}}$

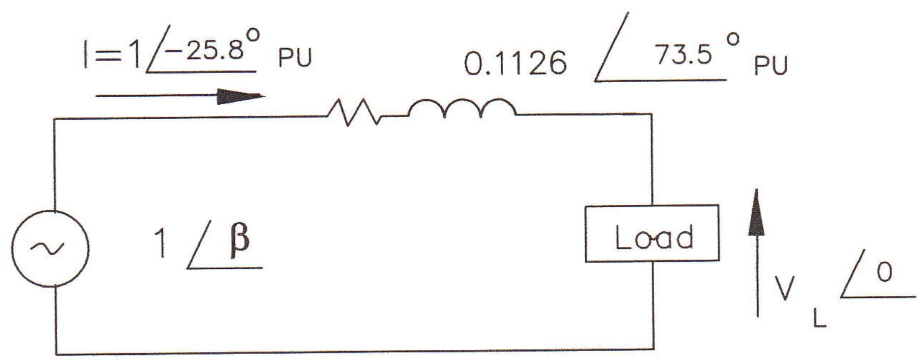

FIG. SP2-14

PROBLEM 2-15

Factor: $\dfrac{(1 + r_x)^n - 1}{r_x\,(1 + r_x)^n} = \dfrac{(1+0.0185)^5 - 1}{0.0185(1.0185)^5}$, $r_x = \dfrac{1.1}{1.08} - 1$

$= 4.77338$ $= 1.0185 - 1$

$= 0.0185$

<u>Note</u>: In some publications the exponent n in the denominator is replaced by $\left(n - \dfrac{1}{2}\right)$.

a) Manufacturer (A):

Losses $3 + \left(\dfrac{3}{4}\right)^2 (12) = 9.75$ kW

A = 9.75 (365)(24)(0.06) = \$5124.6

P = 5124.6 (4.7338) = \$24,258.8

$P_T = 30000 + 24258.8 = \underline{\underline{\$54{,}259}}$

Manufacturer (B):

$$\text{Losses } 2.5 + \left(\frac{3}{4}\right)^2 9.5 = 7.8438 \text{ kW}$$

A = 7.8438 (365)(24)(0.06) = $4122.675

P = 4122.675 (4.7338) = $19,515.9

P_T = 35000 + 19515.9 = $54,516

b) Similarly,

Manufacturer (A): $44,928

Manufacturer (B): $47,129

c) Manufacturer (A): $48,660

Manufacturer (B): $49,928

PROBLEM 2-16

The rms value (I) of the line current is

$$I = \sqrt{\left(\frac{100}{\sqrt{2}}\right)^2 + \left(\frac{30}{\sqrt{2}}\right)^2 + \left(\frac{15}{\sqrt{2}}\right)^2 + \left(\frac{10}{\sqrt{2}}\right)} = 74.9166\, A$$

The per unit values of the component line current are

$$I_1 = \left(\frac{100/\sqrt{2}}{74.9166}\right) = 0.9439$$

$$I_3 = \left(\frac{30/\sqrt{2}}{74.9166}\right) = 0.2832$$

$$I_5 = \left(\frac{15/\sqrt{2}}{74.9166}\right) = 0.1416$$

$$I_7 = \left(\frac{10/\sqrt{2}}{74.9166}\right) = 0.0944$$

and

$$k = (0.9439)(1)]^2 + [(0.2832 \times 3)^2 + (0.1416 \times 5)^2 + (0.0944 \times 7)^2$$

$$= \underline{\underline{2.55}}$$

A k-4 type of transformer is required.