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2 Transformers

2.1 Solutions To Exercises

EXERCISE 2-1

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

EXERCISE 2-2

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

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

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

d) $V_{2n.l} = V_L + I Z_e$

$= 1\angle 0° + 1\angle -36.9°(0.022 + j\,0.052)$
$= 1.049\angle 1.56°$

$V_S = 1.049(480)\angle 1.56°$
$= \underline{503.52\angle 1.56° V}$

EXERCISE 2-3

$V_{Z\,pu} = I_{rpu} Z_{epu}$

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$= 1.0 Z_{epu}$ $= Z_{epu}$

54

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

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

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

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

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

55

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

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

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Secondary:

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

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: $S = \sqrt{3}\, V_{L\text{-}L}\, I$

$= \sqrt{3}\,(0.48)\,(10.4167)$

$= \underline{8.66\text{ kVA}}$

57

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EXERCISE 2-8

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

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

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

V_1=V_2

V_1 = 1!0° + $I_1 Z_{e1}$

V_2 = 1!0° + I_2 Z_{e2}

Thus,

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

I_1 = # (! 0.0877 ∃ / ∀ 0.0672 %) & ∍65.8° (60.3° I_2

= 1.31∍5.5° I_2

Also

$I_1 + I_2$ = 1!∀25.8°

or

(1.31 !5.5°) $I_2 + I_2$ = 1 !∀25.8°

From which

I_2 = 0.434 !∀29° p u

= 0.434 (1041.67) = <u>452.29 A</u>

and

56

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$$I_1 = 0.567\ !\forall 23.4° = 0.567\ (1041.67) = \underline{590.4\ A}$$
$$S_2 = 452.29\ (0.48) = 217.1!29°\ kVA$$

$$S_1 = 590.4\ (0.48) = 283.4\ !23.4°\ kVA$$

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

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

$$= 0.053\ !79.11°\forall$$

57

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b) $I_2 = \dfrac{50000}{(230)}$ = 217.39 !∀25.8° A

V_L = !0° = 230 !∀ − 217.39 (0.053) !79.11° ∀ 25.8°

β = 2.3°, V_L = <u>222.93 V</u>

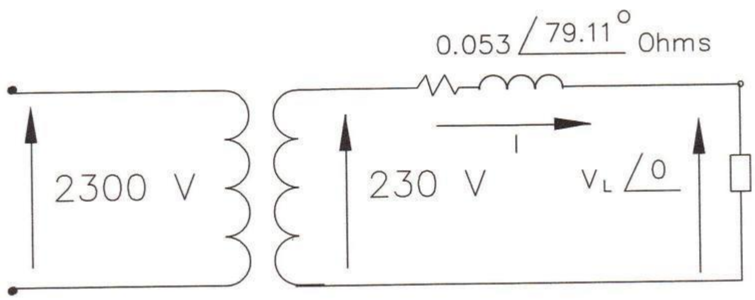

FIG. SP2---1

PROBLEM 2-2

a) $Z_{mH} = \dfrac{2400}{0.35}$ = 6857.1 Ω

$R_m = \dfrac{150}{(0.35)^2}$ = 1224.49 Ω

$X_m = \sqrt{6857.1^2 \quad 1224.49^2}$ = 6746.93 Ω

Z_{mH} = 6857.1!79.7°∀, Z_{mL} = 68.57 !79.71°∀

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

$X_{eL} = (0.288^2 - 0.184^2)^{½}$ = 0.2213 Ω

Z_{eL} = 0.288 !50.2°

Z_{eH} = 28.8 !50.2°

b) V = 10 (240 + 0.288 !50.2° (41.67 !∀25.8°)

58

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$$= 2509.8 \; !1.1^\circ V$$

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

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

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

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

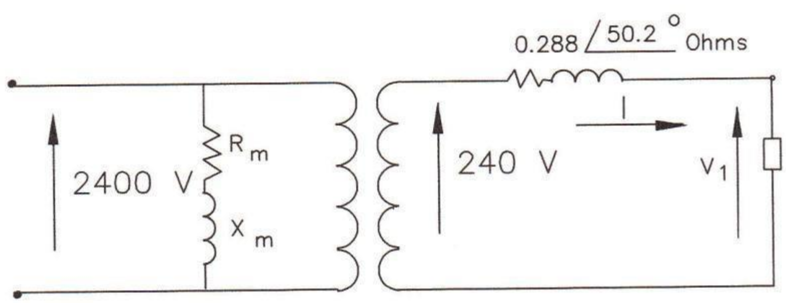

FIG. SP2---2

PROBLEM 2-3

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

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

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

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

60

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c) $Z_e = 0.023 + j0.05 = 0.055$!65.3° p u

$V_s = V_L + I\ Z$

1 !∀ = 1 !0° + 1 !∀(0.055 !65.3°)

61

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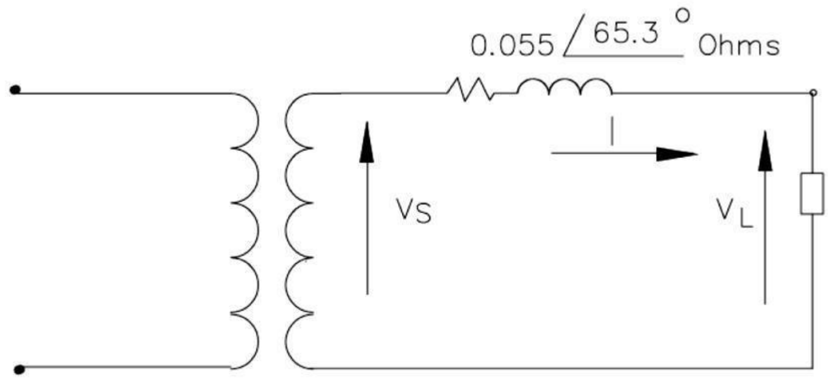

FIG. SP2---3

1!∀ = 1!0°+ 0.055!∝ ; $\mu = \Theta + 65.3°$

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

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

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

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

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

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

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

From (1) and (2),

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

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

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

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

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

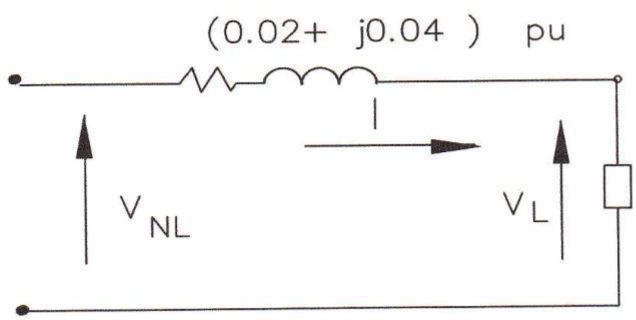

FIG. SP2---5

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

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

60

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$\beta = 2.3°, V_L = 0.98$ p u

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

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

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

$\beta = 2.52°, V_L = 1.007$ p u

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

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

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

$\beta = 1.1°, V_L = 0.96$ p u

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

PROBLEM 2-6

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

$= 1.0407 \angle 2.6°$ p u

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

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

Actual:

$P_{c\ell} = 0.0278 - 0.015 = 0.0128$ p u X: nominal core loss

$X(1.0407)^2 = 0.0128$

62

X = 0.013 p u

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

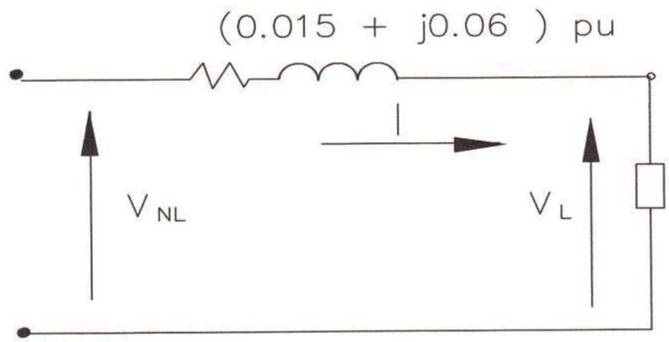

FIG. SP2---6

PROBLEM 2-7

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

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

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

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

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

PROBLEM 2-8

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

$$X_S = \frac{(25)^2}{\frac{500}{5 + j8}}\left(\frac{1}{312.5}\right) = 0.004\ \text{p u}$$

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$Z_A = \text{———} = \underline{(0.016 + j0.0256)\text{ p u}}$

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$$Z_B = \frac{0.005 + j\,0.01}{500} = \underline{(0.0434 + j0.0867)\text{ p u}}$$

b) $I_1 = \frac{500}{\sqrt{3}(0.48)(0.95)} = 633.1!\forall 36.9° A$

$I_2 = \frac{600}{\sqrt{3}(0.48)(0.9)(0.9)} = 891!\forall 25.8° A$

$I_t = I_1 + I_2 = 1517.2\ !\forall\ 30.4°\ A$

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

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

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

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

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

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

c) $V_s = 1\ !0° + 0.6307\ !\forall\ 30.4°\ (0.069 + j0.1777)$

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

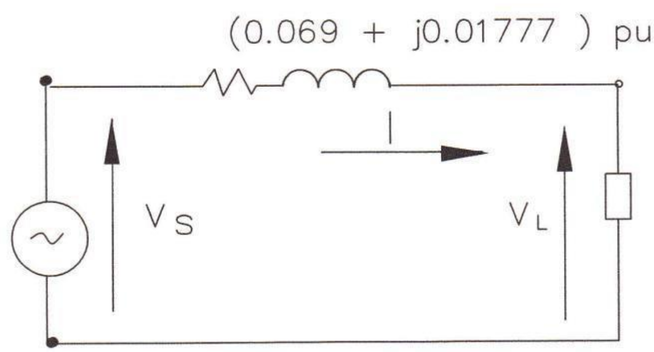

FIG. SP2---8

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_{ma} = 34.53!6.9° A I_{mb}

= 34.53!∀113.1° A

I_{mc} = 34.53!126.9° A

Load P_3

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

Load P_2

$I_{bn} = \frac{\sqrt{3}}{0.55(0.9)(0.9)} = 38.88$!∀145.8° ∀ 30= 38.88!∀175.8 A

Load P_1

$I_{cn} = \frac{\sqrt{3}}{\quad} = 49.72$!53.1° A

The line currents through the secondary of the transformer are:

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

= 34.53 !6.9° + 36.36 !0° = 70.77 !3.3° A

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

= 34.53 !∀113.1° + 38.88 !∀175.8° − 36.36 !0°

= 95.2 !∀158.7° A

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

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

$$= 68 \angle 82.3° \, A$$

<u>Primary of transformer</u>

The per-phase turn's ratio is:

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

Then

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

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

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

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

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

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

Use a commercially available transformer whose capacity is

3-Ø, 4800-550/317 V, 112.5 kVA

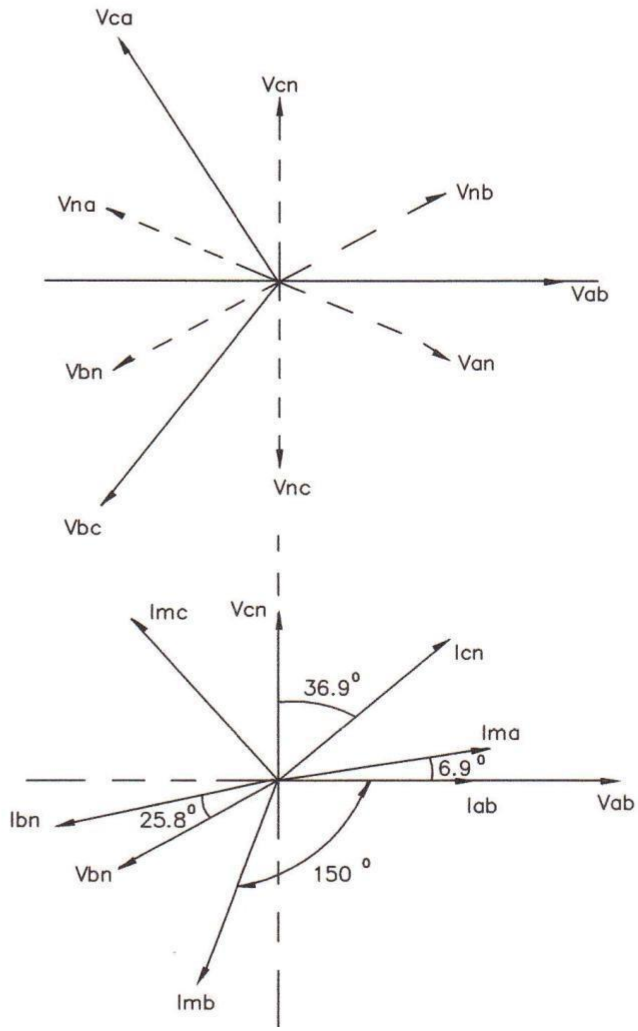

FIG. SP2---9

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)**

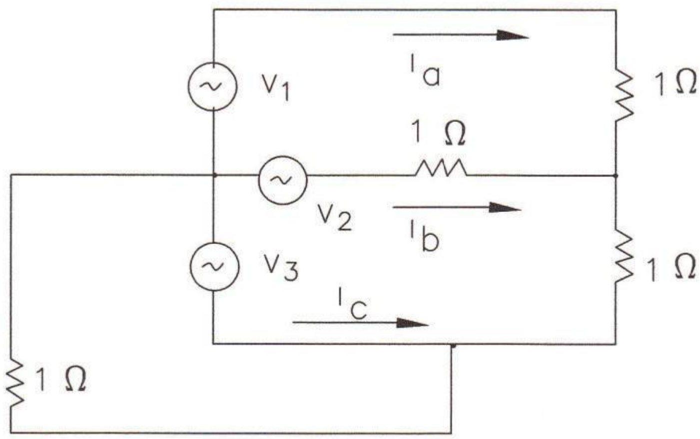

FIG. SP2---10(a)

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

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

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

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

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

Similarly

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

$$I_b = -277.1\angle 60°\ A$$

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

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

$$= \underline{554.3\angle 120°\ A}$$

To check

$V_3 = I_a + I_b + I_c$

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

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

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

Fuse in phase "c" will blow.

b)

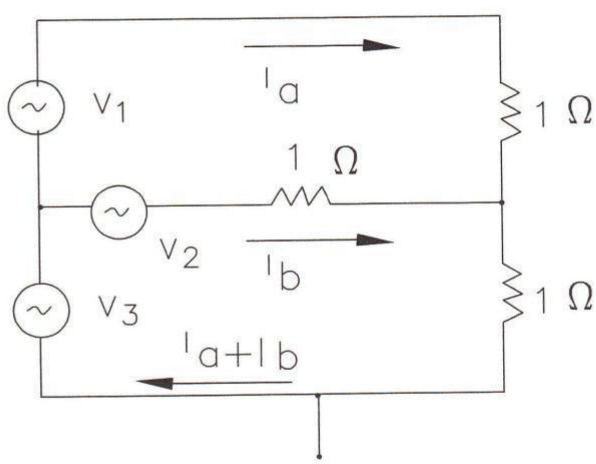

FIG. SP2---10(b)

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

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

From Eqs. (4) and (5):

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

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

$$I_b = \frac{1}{3}\left[V_1 - V_3 - 2V_2\right] = \frac{1}{3}\left(\frac{480}{\sqrt{3}}\right)\left[1\angle 0° - 1\angle 120° - 2\right] = 277.1\angle 120°\ \text{A}$$

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

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

Fuses will not blow.

c) $I_c = \infty$

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

Fuse in line “c” will blow.

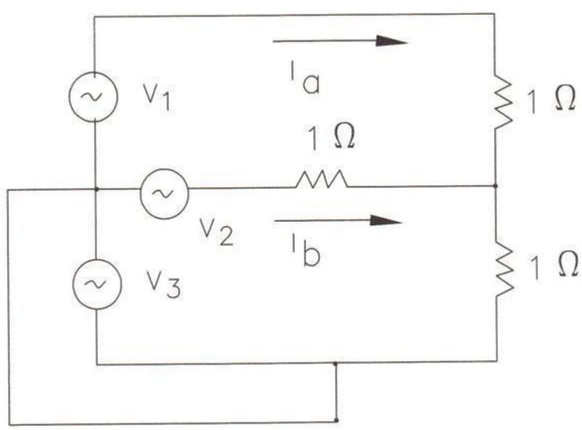

FIG. SP2---10(c)

d) Nominal three-phase operation.

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

None of the fuses will blow.

PROBLEM 2-11

a) S = 600 (41.67) = 25 kVA

b) 25 − 5 = 20 kVA

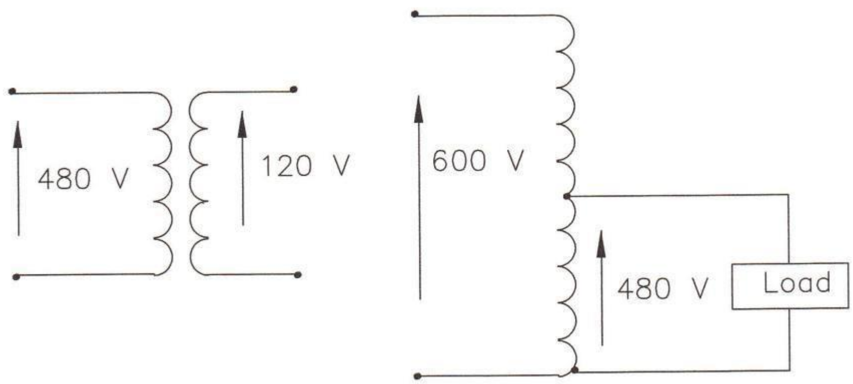

FIG. SP2---11

PROBLEM 2-12

a) S = 3.4 (200) = 680 kVA

680 − 200 = 480 kVA conducted

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

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

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

c) $$Z_b = (0.02 + j\,0.06)5 = \frac{3400}{} = \underline{\underline{10.75 \text{ kA}}}$$

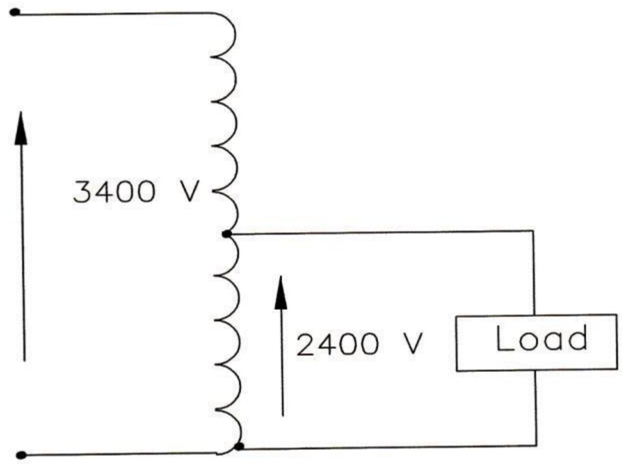

FIG. SP2---12

PROBLEM 2-13

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

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

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

$= 0.0931 \angle 68.2° \ \Omega$

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

$V_1 \angle \delta = 1 \angle 0° + I_1 Z_{e1}$ **…(1)**

$V_2 \angle \delta = 1 \angle 0° + I_2 Z_{e2}$ **…(2)**

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

$I = I_1 + I_2$ **…(4)**

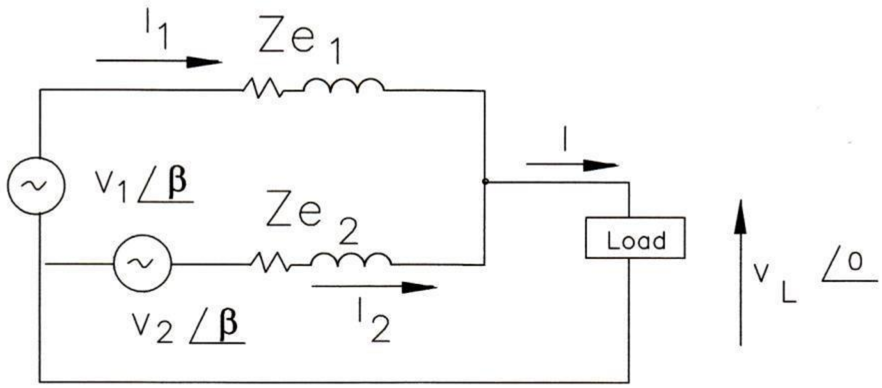

FIG. SP2---13

From (3) and (4)

$I_1 = 0.655$!∀ 32.2° p u

$I_2 = 0.36$!∀14° p u

a) V_1 !∀ = 1 !0° + 0.655 !∀32.2° (0.0813 !63.4°)

= 1.0455+j0.0276 = 1.0459 !1.5°

= 1.0459 (4160) = <u>4350.8 V, L-L</u>

b) T-1I_1 = 0.655(2.08) = <u>1.36 kA</u>

T-2I_2 = 0.36(2.08) = <u>750 A</u>

c) T-1S_1 = 0.655 (1) [1000] = <u>655 kVA</u>

T-2S_2 = 0.36 (1000) = <u>360 kVA</u>

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

$$I = \frac{V_1 ! V_2}{Z_1 + Z_2} = \frac{1.0459 \,\forall 1.5° ! 1.0198 \,\forall 1.5°}{0.0364 + 0.0346 + j\left(0.0727 + 0.0864\right)}$$

$$= \frac{0.0261 + j\,0.0007}{(\ )0.1742\angle 66^\circ} = \frac{0.0261\angle 1.5^\circ}{}$$

$$= 0.1498\angle -64.5^\circ$$

= 0.1498 (2.08) = <u>312 A</u>

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

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

$= 10.3922 - j\,21.4088 = 23.799\angle -64.1°$

= 23.799 (138.8) = 3.3 kA

PROBLEM 2-14

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

$Z_f = \frac{20 + j\,30}{625} = (0.032 + j0.048)$ 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

= 441.9 V, L-L

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

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

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

I = 0.88 (1202.8) = 10.7 kA

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

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

$X_t = 0.002 + 0.048 + 0.06 = 0.11$

V_L = !0° = 1 !∀ − 1.0 !25.84° (0.032 + j0.11)

β = 6.5°, V_L = 1.02 p u, V_L = 489.2 V

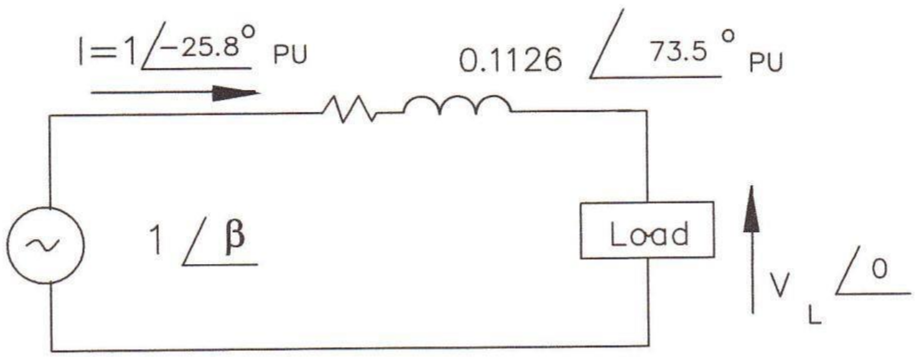

FIG. SP2---14

PROBLEM 2-15

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

= 4.77338 = 1.0185 − 1

= 0.0185

Note: In some publications the exponent n in the denominator is replaced by ∃ *n* ! ∀ 1% # 2&

a) Manufacturer (A):

Losses 3 + # $\frac{!\ 3\exists^2}{\forall\ 4\ \%}$ & (12) = 9.75 kW

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

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

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

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

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

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

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

$$= \underline{2.55}$$

A k-4 type of transformer is required.