higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

MARKING GUIDELINE

NATIONAL CERTIFICATE

ELECTROTECHNICS N6

14 April 2020

This marking guideline consists of 13 pages.

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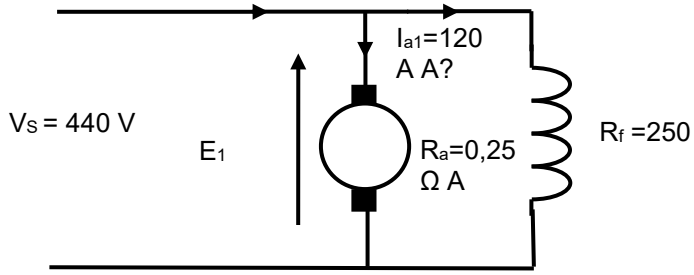
QUESTION 1: DC MACHINES

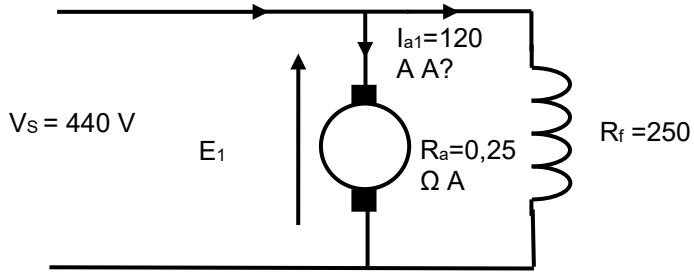
1.1
- Armature copper loss
- Inter-pole copper loss
- Series winding copper loss
- Brush resistance loss (Any 3 × 1) (3)

1.2 Given: A DC shunt motor



P = 65 kW

$E_1 = V_S - I_{a1}R_a = 440 - (120 \times 0,25) = 410\ V$ ✓



$T_1 \propto I_{a1}\emptyset_1$ and $T_2 \propto I_{a2}\emptyset_2$

$0,85T_1 \propto I_{a2}\emptyset_2$

$T_1 \propto \frac{I_{a2}\emptyset_2}{0,85}$ ✓

But $T_1 = T_1$ and $\frac{I_{a2}\emptyset_2}{0,85} = \frac{I_{a1}\emptyset_1}{1}$ $\therefore I_{a2} = \frac{0,85 \times 120 \times \emptyset_1}{\emptyset_2} = \mathbf{102\ A}$ ✓

Calculating E_2:

$\frac{E_2}{E_1} = \frac{N_2\emptyset_2}{N_1\emptyset_1}$

$\therefore E_2 = \frac{0,7N_1\emptyset_1}{N_1\emptyset_1} \times \frac{410}{1} = \mathbf{287\ V}$ ✓

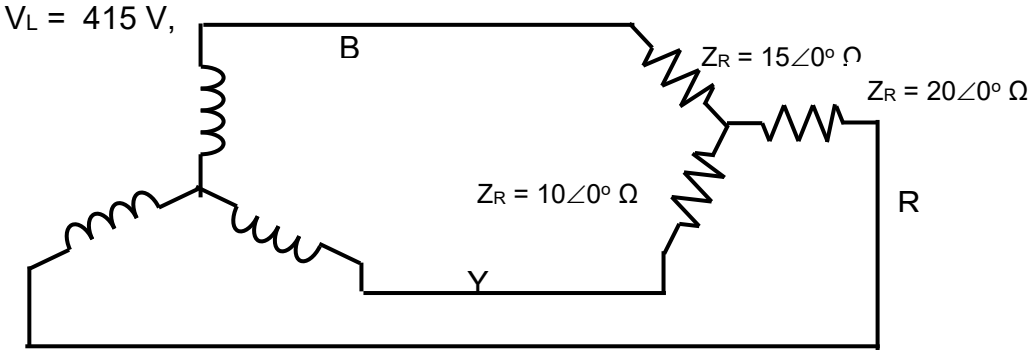
$E_2 = V_S - I_{a2}(R_a + R_{ser})$
$287 = 440 - ((102 \times 0.25) + 102R_{ser})$ ✓
$= 440 - 25,5 - 102R_{ser}$ ✓
$\therefore R_{ser} = \frac{440 - 25,5 - 287}{102}$ ✓ $= \mathbf{1,25\ \Omega}$ ✓ (8)

1.3
- Varying the value of the flux
- Varying the value of the voltage applied to the motor armature
- Varying the value of the effective number of conductors in series (3)

[14]

QUESTION 2: AC CIRCUIT THEORY

Given: A three-phase, star-connected alternator supplying an unbalanced star-connected load with no neutral connection.



2.1 $V_P = \frac{V_L}{\sqrt{3}} = \frac{415}{\sqrt{3}} = 239,6\ V$✓

$$\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} = \frac{1}{20\angle 0°} + \frac{1}{10\angle 0°} + \frac{1}{15\angle 0°}$$
$$= 0,05\angle 0° + 0,1\angle 0° + 0,067\angle 0°$$
$$= 0,217\angle 0°$$ ✓

$$\frac{V_{RN}}{Z_1} = \frac{239,6\angle 0}{20\angle 0} = 11,98\angle 0° = 11,98 + j0$$✓

$$\frac{V_{YN}}{Z_2} = \frac{239,6\angle -120°}{10\angle 0} = 23,96\angle -120° = -11,98 - j20,75$$✓

$$\frac{V_{BN}}{Z_3} = \frac{239,6\angle 120}{15\angle 0} = 15,973\angle 120° = -7,986 + j13,833$$✓

$$\frac{V_{RN}}{Z_1} + \frac{V_{YN}}{Z_2} + \frac{V_{BN}}{Z_3} = -7,986 - j6,917$$

$$= 10,565\angle -139,1°$$ ✓

$$V_{SN} = \frac{\frac{V_{RN}}{Z_1} + \frac{V_{YN}}{Z_2} + \frac{V_{BN}}{Z_3}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} = \frac{10,565\angle -139,1°}{0,217\angle 0°}$$
$$= 48,687\angle -139,1°\ V$$✓ (7)

2.2 $V_{RS} = V_{RN} - V_{SN}$
$= 239,6\angle 0° - 48,687\angle -139,1$
$= 278,232\angle 6,58°$ V✓

$V_{YS} = V_{YN} - V_{SN}$
$= 239,6\angle -120° - 48{,}687\angle -139,1°$
$= 194,248\angle -115,3°$ V✓

$V_{BS} = V_{BN} - V_{SN}$
$= 239,6\angle 120° - 48,687\angle -139{,}1°$
$= 253,358\angle 109,1°$ V✓ (3)

2.3 $I_R = \frac{V_{RS}}{Z_1} = \frac{278,232\angle 6,58°}{20\angle 0°}$
$= 13,912\angle 6,58°$ A✓

$I_Y = \frac{V_{YS}}{Z_2} = \frac{194,248\angle -115,3°}{10\angle 0°}$
$= 19,425\angle -115{,}3°$ A✓

$I_B = \frac{V_{BS}}{Z_3} = \frac{253,358\angle 109,1°}{15\angle 0°}$
$= 16,891\angle 109,1°$ A✓ (3)
[13]

QUESTION 3: TRANSFORMERS

3.1
- Increased dielectric stresses
- Electrostatic interference with communication circuits
- Resonance between inductance of transformer windings and capacitance of feeder to which they are connected. (Any 2 × 1) (2)

3.2 Rise or fall✓ in secondary terminal voltage when load is removed✓ with the applied voltage remaining constant.✓ (3)

3.3 Given: A single-phase transformer
S = 85 kVA pf = 0,75 lagging
V_p/V_s = 2 200/240 V iron losses = 940 W
%Z = (1, 5 + j4) %.

3.3.1

METHOD 1

$S = V_1 \cdot I_1$

$\therefore\ I_1 = \frac{S}{V_1} = \frac{85 \times 10^3}{2\,200}$

$= 38{,}636\ A$ ✓

$\%R = \frac{I_1 \cdot R_{E1}}{V_1}$

$\therefore\ R_{E1} = \frac{\%R \cdot V_1}{I_1}$

$= \frac{0{,}015 \times 2\,200}{38{,}636}$

$= 0{,}854\ \Omega$ ✓

$P_{sc} = I_1^{\,2} \cdot R_{e1}$

$= 38{,}636^2 \times 0{,}854$

$= 1\,274{,}8\ W$ ✓

METHOD 2

$S = V_2 \cdot I_2$

$\therefore\ I_2 = \frac{S}{V_2} = \frac{85 \times 10^3}{240}$

$= 354{,}167\ A$ ✓

$\%R = \frac{I_2 \cdot R_{e2}}{V_2}$

$\therefore\ R_{e2} = \frac{\%R \cdot V_2}{I_2} = \frac{0{,}015 \times 240}{354{,}167}$

$= 0{,}01\ \Omega$ ✓

$P_{sc} = I_2^{\,2} \cdot R_{e2} = 354{,}167^2 \times 0{,}01$

$= 1\,254{,}343\ W$ ✓

$\eta = \frac{S \cdot \cos\theta}{S \cdot \cos\theta + P_o + P_{sc}} \times 100\%$

$= \frac{85 \times 0{,}75}{(85 \times 0{,}75) + (0{,}94 + 1{,}275)} \times 100\%$ ✓

$= 96{,}642\ \%\ \ or\ \ 96{,}673\%$ ✓ (5)

3.3.2 $P_o = k^2 \cdot P_{sc}$

$k = \sqrt{\frac{P_o}{P_{sc}}} = \sqrt{\frac{0{,}94}{1{,}275}} = 0{,}859$ ✓

Method 1

$\eta = \frac{kS \cdot \cos\theta}{kS \cdot \cos\theta + P_o + k^2 P_{sc}} \times 100\%$

$= \frac{0{,}859 \times 85 \times 0{,}75}{(0{,}859 \times 85 \times 0{,}75) + [0{,}94 + (0{,}859^2 \times 1{,}275)]} \times 100\%$ ✓

$= 96{,}68\ \%$ ✓

Method 2

$\eta = \frac{kS \cdot \cos\theta}{kS \cdot \cos\theta + 2P_o} \times 100\%$

$= \frac{0{,}859 \times 85 \times 0{,}75}{(0{,}859 \times 85 \times 0{,}75) + (2 \times 0{,}94)} \times 100\%$ ✓

$= 96{,}681\ \%$ ✓ (3)

3.3.3 $$\%X = \frac{I_1 \cdot X_{e1}}{V_1}$$

$$\therefore X_{e1} = \frac{\%X \cdot V_1}{I_1} = \frac{0{,}04 \times 2\,200}{38{,}636}$$

$$= 2{,}278\ \Omega \checkmark$$

Method 1

$Z_{e1} = R_{e1} + X_{e1}$

$= 0{,}854 + j2{,}278$

$= 2{,}433\ \Omega \checkmark$

Method 2

$Z_{e1} = \sqrt{{R_{e1}}^2 + {X_{e1}}^2}$

$= \sqrt{0{,}854^2 + 2{,}278^2}$

$= 2{,}433\ \Omega \checkmark$

$V_{1sc} = I_1 \cdot Z_{e1} = 38{,}636 \times 2{,}433 \ = 94{,}001\ V \checkmark$ (3)

3.3.4 **Method 1**

$$\text{Voltage Regulation} = \frac{I_1(R_{e1} \cdot \cos\theta + X_{e1} \cdot \sin\theta)}{V_1} \times 100\%$$

$$= \frac{38{,}636[(0{,}854 \times 0{,}75) + (2{,}278 \times 0{,}66)]}{2\,200} \times 100\% \checkmark$$

$$= 3{,}765\ \% \checkmark$$

Method 2

$\text{Voltage Regulation} = \%R \cos\theta + \%X \cdot \sin\theta$

$= (1{,}5\% \times 0{,}75) + (4\% \times 0{,}66) \checkmark$

$= 3{,}765\ \% \checkmark$ (2)

[18]

QUESTION 4: AC MACHINES – ALTERNATORS

4.1
- To reduce temperature increase in the slots
- To improve the wave form
- Reducing EMF due to phase replacement between slots
- Reduced number of conductors per slot (Any 3 × 1) (3)

4.2 **Given:** A three-phase, short-chorded alternator

S = 750 kVA, Z = (3 + j15) %

V_L = 11 kV Pf = 0,7 lagging

4.2.1 $S = \sqrt{3} \cdot V_L \cdot I_L$

$I_L = \dfrac{S}{\sqrt{3}V_L}$

$= \dfrac{750 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = 39,365\text{A}$ ✓

$V_p = \dfrac{V_L}{\sqrt{3}} = \dfrac{11 \times 10^3}{\sqrt{3}} = 6\,350,853\text{ V}$ ✓

$\%R = \dfrac{IR_A}{V_P}$

$\therefore R_A = \dfrac{\%R \times V_P}{I}$ ✓

$= \dfrac{0,03 \times 6\,350,853}{39,365} = 4,84\,\Omega$ ✓

$\%X = \dfrac{IX_S}{V_P}$

$\therefore X_S = \dfrac{\%X \times V_P}{I} = \dfrac{0,15 \times 6\,350,853}{39,365}$ ✓

$= 24,2\,\Omega$ ✓ (6)

4.2.2 $IR_A = 39,365 \times 4,84 = 190,527\text{ V}$ ✓

$IX_S = 39,365 \times 24,2 = 952,633\text{ V}$ ✓

Method 1

$E_P = V_P\angle 45,6° + IR_A\angle 0° + IX_S\angle 90°$

$= 6\,350,853\angle 45,6° + 190,527\angle 0° + 952,633\angle 90°$

$= 7\,184,393\angle 49,8°\text{ V}$ ✓

$E_L = \sqrt{3} \times E_P = \sqrt{3} \times 7\,184,393 = 12\,443,734\text{ V}$ ✓

Method 2

$E_P = V_P + IR_A \cdot \cos\theta + IX_S \sin\theta$

$= 6\,350,853 + (190,527 \times 0.7) + (952,633 \times 0.714)$

$= 7\,164,402\text{ V}$ ✓

$E_L = \sqrt{3} \cdot E_P = \sqrt{3} \times 7\,164,402 = 12\,409,108\,V$ ✓

Method 3

$E_p = \sqrt{(V \cdot \cos\theta + IR_a)^2 + (V \cdot \sin\theta + IX_s)^2}$

$= \sqrt{([6\,350,853 \times 0.7] + +190,527)^2 + ([6\,350,853 \times 0,714] + 952,63)^2}$

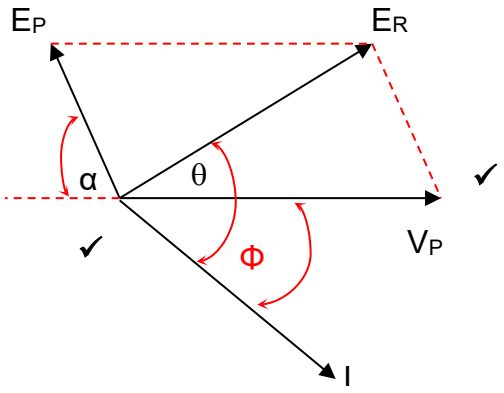
$= 7\,183,479\text{ V}$ ✓

$E_L = \sqrt{3} \cdot E_P = \sqrt{3} \times 7\,183,479 = 12\,442,15\,V$ ✓ (4)

[13]

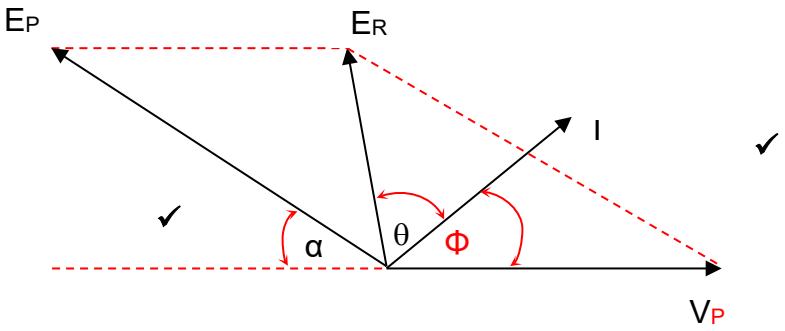
QUESTION 5: AC MACHINES – SYNCHRONOUS MOTORS

5.1 Lagging power factor



Leading power factor

Increase in excitation increases Ep✓ and causes resultant current to lead✓



(6)

5.2 Given: a three-phase, 50 Hz, star-connectedsynchronous motor.

S = 5 kVA P = 4 kW

V_L = 480 V %Z = (4 + j40)%

5.2.1 $\text{Cos}\,\theta = \frac{P}{S} = \frac{4}{5} = 0{,}8$✓ (1)

5.2.2 $V_L = \sqrt{3} \cdot V_p$

$\therefore\ V_p = \frac{V_L}{\sqrt{3}} = \frac{480}{\sqrt{3}} = 277{,}128\ V$✓

$\%R = \frac{IR}{V_p}$

$IR = \%R \cdot V_p = 0{,}04 \times 277{,}128$

$= 11{,}085$ V✓

$\%X = \frac{IX}{V_p}$

$IX = \%X \cdot V_p = 0{,}4 \times 277{,}128 = 110{,}851$ V✓ (3)

5.2.3 **Method 1**

$E_p = \text{Vp}\angle -\theta + \text{IRa}\angle 180° + \text{I.Xs}\angle -90°$
$= 277,128\angle -36,87° + 11,085\angle 180° + 110,851\angle -90°$ ✓
$= 348,08\angle -52,77°$ V✓
$\therefore E_L = \sqrt{3}\,.\,\text{Ep} = \sqrt{3} \times 348,08$
$= 602,892$ V ✓

Method 2

$\text{S} = \sqrt{3} \cdot \text{V}_\text{L} \cdot \text{I}_\text{L}$
$I_L = \dfrac{S}{\sqrt{3} \cdot V_L} = \dfrac{5 \times 10^3}{\sqrt{3} \times 480}$
$= 6,014$ A√

$\%\text{R} = \dfrac{\text{IR}}{\text{V}_\text{p}}$
$\text{R} = \dfrac{\%\text{R} \cdot \text{V}_\text{p}}{\text{I}} = \dfrac{0,04 \times 277,128}{6,014} = 1,843\ \Omega$√
$\%\text{X} = \dfrac{\text{IX}}{\text{V}_\text{p}}$
$\text{X} = \dfrac{\%\text{X} \cdot \text{V}_\text{p}}{\text{I}} = \dfrac{0,4 \times 277,128}{6,014}$
$= 18,432\ \Omega$

$Z_S = R + jX_S = 1,843 + \text{j}18,432$
$= 18,524\angle 84,29°\ \Omega$

$E_r = IZ_S = 6,014\angle 36,87° \times 18,524\angle 84,29°$
$= 111,403\angle 121,16°$ V√

$\text{Ep} = \text{Er} - \text{Vp} = 111,403\angle 121,16° - 277,128\angle 0°$
$= 348,08\angle 164,11°$ V√

$E_L = \sqrt{3} \cdot E_p = \sqrt{3} \times 348,08 = 602,892$ V✓ (3)

5.2.4 **Method 1**

$\alpha = 52,77° - 36,87°$
$= 15,9°$ ✓

Method 2

$\alpha = 180 - 164,11°$
$= 15,89°$ ✓ (1)

[14]

QUESTION 6: AC MACHINES – INDUCTION MOTORS

6.1 It is used to control the speed of the motor✓ by introducing an external resistance in the rotor circuit. ✓ (2)

6.2 **Given:** A three-phase, 6 pole induction motor with a star-connected rotor
E_0 = 480 V, 50 Hz,
Z_0 = (0,16 + j0,7) ohm per phase.

6.2.1 $E_{0_p} = E_0/\sqrt{3} = 480/\sqrt{3} = 277,128\ V$✓

$Z_2 = \sqrt{(R_2)^2 + (SX_0)^2} = \sqrt{(0,16)^2 + (0,05 \times 0,7)^2} = 0,164\ \Omega$✓

$I_2 = SE_0/Z_2 = 0,05 \times 480/0,164 = 146,341\ \Omega$ ✓

Rotor cu loss =$3(I_2)^2R_2$ = 3 × (146,341)^2 × 0,16 = 10 279, 53 W√

Rotor input = Rotor cu loss/S = 10 279, 593/0,05 = 205 590,6 W√

N_1 = 60f/p = 60 x 50/3 = 1 000 r/min✓

$$\text{Rotor input} = \frac{2\pi N_1 T}{60}$$

$$\therefore T = \frac{60 \times \text{rotor input}}{2\pi \times N_1} = \frac{60 \times 205\,590,6}{2\pi \times 1\,000}$$ ✓

$$= 1\,963,246\ \text{Nm}$$✓ (7)

6.2.2 $N_2 = N_1 - SN_1$ = 1 000 – (0,05 x 1 000) = 950 r/min ✓

$$\text{Gross rotor input} = \frac{2\pi \cdot N_2 T}{60} = \frac{2\pi \times 950 \times 1\,963,246}{60}$$

$$= 195\,311,108\ \text{W}$$ ✓

Power output = Gross rotor output + friction and windage losses
= 195 311,108 + 880
= 196 191,108 W ✓ (3)

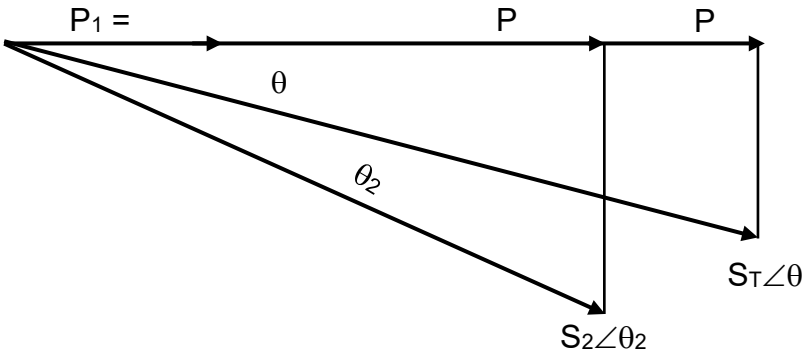
6.2.3 $S = R_2/X_0$ = 0,16/0,7 = 0,229 ✓

$N_2 = N_1 - SN_1$ = 1 000 – (0,229 x 1 000) = 771 r/min ✓ (2)
[14]

QUESTION 7: GENERATION AND SUPPLY OF AC

7.1
- The consumer pays less tariffs.
- The efficiency of their installation is high. (2)

7.2 Given: V_L = 400 V
f = 50 Hz,
P_1 = 2kW at unity pf
P_2 = 30 kW at 0, 8 pf lagging
η= 85%



7.2.1

$\cos\theta_1 = 1(\text{unity})$

$S_1 = P_1/\cos\theta_1 = 2/1 = 2\ \text{kVA}$ ✓

$\eta = P_{0ut2}/P_{in2}$

$\therefore P_{in2} = P_{out2}/\eta = 30\,000/0,85$

$= 35,294\ \text{kW}$ ✓

$\cos\theta_2 = 0,8$ (lagging)

$\therefore\ \theta_2 = \cos^{-1} 0,8 = -36,87°$

$S_2 = P_{in2}/\text{Cos}\ \theta_2 = 35,294/0,8$

$= 44,118\ \text{kW}$ ✓

$S_T = S_1 + S_2$

$= 2\angle 0° + 44,118\angle -36,87$

$= 37,294 - j26,471$ ✓

$= 45,734\angle -35,367°\ \text{kW}$ ✓

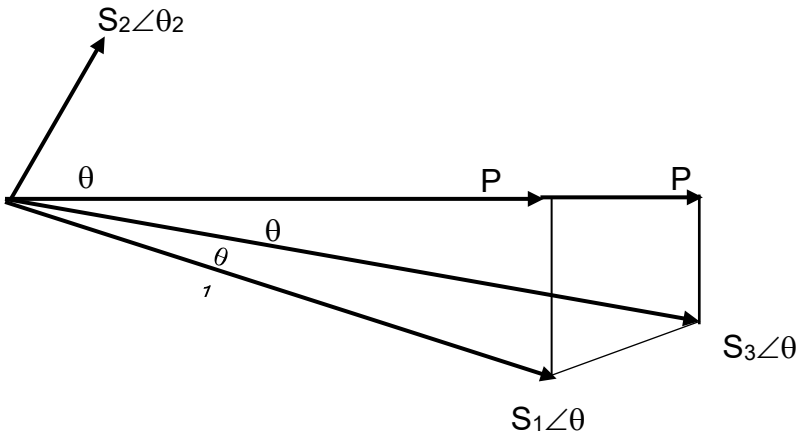
(5)

7.2.2 Power factor = Cos θ_T

= Cos (- 35, 367)

= 0,815 ✓ (1)

7.2.3 **Method 1**



Let S_1 = total kVA of the load, taken from QUESTION 7.1

S_1 = 45,734∠-35, 367° kW = 37,294 – j26,471

$S_3 = \sqrt{3}V_L I_L = \sqrt{3} \times 400 \times 60 = 41,569$ kW✓

$P_3 = P_1 + P_{in2} = 2 + 35,294 = 37,294$ kW✓

$\text{Cos}\ \theta_3 = P_3/S_3 = 37,294/41,569 = 0,897$ lagging ✓

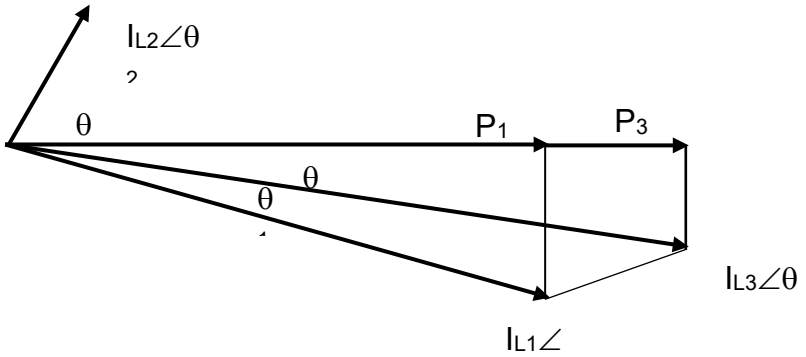
$\therefore\ \theta_3 = \text{Cos}^{-1}(0,897) = -26,234°$ ✓

$$S_2 = S_3 - S_1 = 41,569\angle -26,234° - 45,734\angle -35,367°$$
$$= 0,007 - j8,096$$
$$= 8,096\angle 90,05° \text{ kVA}$$ ✓

$S = \sqrt{3}V_L I_L$

$I_L = \dfrac{S}{\sqrt{3}V_L} = \dfrac{8,096 \times 10^3}{\sqrt{3} \times 400} = 11,686$ A ✓

Method 2



Let S_1 = total kVA of the load, taken from QUESTION 7.1

$S_1 = 45{,}734\angle -35,367^o$ kVA = 37,294 – j26,471 kVA ✓

$$S_1 = \sqrt{3}V_L I_1$$

$$I_1 = \frac{S_1}{\sqrt{3}V_L} = \frac{45{,}734 \times 10^3}{\sqrt{3} \times 400}$$

$$= 66,011 \angle -35,367 \text{ A} \checkmark$$

$I_{L3} = 60$ A, given

$P_3 = P_1 + P_{in2} = 2 + 35,294$

$= 37,294$ kW✓

$$P_3 = \sqrt{3}V_L I_{L3} \cos\theta_3$$

$$\cos\theta_3 = \frac{P_3}{\sqrt{3}V_L I_{L3}} = \frac{37{,}294 \times 10^3}{\sqrt{3} \times 400 \times 60}$$

$$= 0,897 \text{ lagging}$$

$\therefore\ \theta_3 = Cos^{-1}(0,897) = -26,234°$ ✓

$I_{L3} = 60\angle -26,234\ A$

$I_{L2} = I_{L3} - I_{L1} = 60\angle -26,234 - 66{,}011\angle -35,367$

$= -0,009 + j11,686$✓

$= 11,686\angle 90{,}044°$ A ✓ (6)

[14]

TOTAL: 100

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