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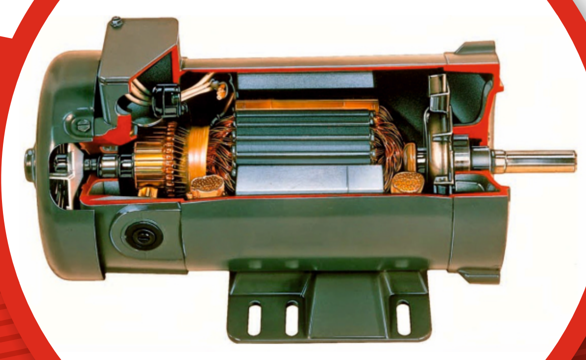


ELECTRICAL ENGINEERING

ELECTRICAL MACHINES

Text Book : Theory with worked out Examples and Practice Questions

Chapter 10 Electrical Machines

Solutions for Text Book Practice Questions

1. Transformers

Solutions for Objective Practice Questions

01. Ans: (b)

Sol: Given data: 400/200 V 50 Hz

$B_{max} = 1.2$ T

800V, 50 Hz linear dimension all double

$N_{12} = \frac{N_{11}}{2}$ $\quad N_{22} = \frac{N_{21}}{2}$

$B_{max2} = ?$

$l_2 = 2l_1$ and $b_2 = 2b_1$

$A_1 = l_1 b_1 \quad A_2 = 4A_1$

$$\frac{E_{12}}{E_{11}} = \frac{\sqrt{2}\pi\, B_{max_2} A_2 N_{12} \times f}{\sqrt{2}\pi\, B_{max_1} A_1 N_{11} \times f}$$

$$\frac{800}{400} = \frac{B_{max\,2}}{1.2} \times \frac{4A_1}{A_1} \times \frac{N_{12}}{N_{11}}$$

$$B_{max2} = \frac{2\times 1.2}{4} \times 2 = 1.2\text{ T}$$

02. Ans: (c)

Sol: Given data: $\ell = b = \frac{40}{\sqrt{2}}$ c.m

$$A_{net} = 0.9\times\left(\frac{40}{\sqrt{2}}\right)^2 \times 10^{-4} = 7.2\times10^{-2}\text{m}^2$$

$$\frac{\text{EMF}}{\text{TURN}} = 4.44 \times 1\times 7.2\times10^{-2}\times 50 = 16\text{ V}$$

03. Ans: (d)

Sol: Induced emf $E_2 = M\frac{di}{dt}$

(Where, $\frac{di}{dt}$ is slope of the waveform)

$$= \frac{400}{\pi}\times10^{-3}\times\frac{10}{5\times10^{-3}} = \frac{800}{\pi}\text{V}$$

As the slope is uniform, the induced voltage is a square waveform.

$\therefore$ Peak voltage = $\frac{800}{\pi}$V

Note: As given transformer is a 1:1 transformer, the induced voltage on both primary and secondary is same.

04. Ans: (a)

Sol: i(t) = 10 sin (100π t) A

Induced emf on secondary $E_2 = M\frac{di}{dt}$

$$E_2 = \frac{400}{\pi}\times10^{-3}\times10\times100\pi\cos(100\pi t)$$

$= 400\cos(100\pi t)$

$$E_2 = 400\sin\left(100\pi t + \frac{\pi}{2}\right)$$

When S is closed, the same induced voltage appears across the Resistive load

$\therefore$ Peak voltage across A & B = 400V

05. Ans: (a)

Sol: $E_1 = -N_1\frac{d\phi}{dt}$ (where $E_1 = -e_{pq}$)

$$E_1 = -200\times\left(\frac{0.009}{0.06}\right)$$

e_{pq} = 30 V (Between 0 & 0.06)

$$E_1 = 200\times\left(\frac{-0.009}{0.12-0.1}\right)$$

e_{pq} = – 90 V (Between 0.1 & 0.12)

06. Ans: (c)

Sol: Core loss ∝ core volume

$$W_2 \propto \left(\sqrt{2}\right)^3 \times 2400$$

$W_2 = 6788$ W

$I_0 = 3.2$ A

So $I_{w1} = \left(\sqrt{2}\right)^3 \times I_{w1}$

$$I_{w1} = \frac{W_0}{V} = \frac{2400}{11000} = 0.218$$

$$I_{w2} = \left(\sqrt{2}\right)^3 \times 0.218 = 0.617 \text{ A}$$

($\therefore$ I_w is core loss component)

Reluctance $R_l = \dfrac{\ell}{\mu A}$

$$R\ell_2 = \frac{R_{\ell 1}}{\sqrt{2}}$$

$$\phi_{m1} = \frac{11000}{4.44 N_1 f} \quad \phi_{m2} = \frac{22000}{4.44 N_1 f}$$

$\therefore$ N_1 = constant; f = constant

$\phi_{m2} = 2\ \phi_{m1}$

$$\phi_{m1} = \frac{\text{mmf}}{\text{Reluctance}} = \frac{N_1 I_{N1}}{R_{\ell 1}}$$

$$\phi_{m2} = \frac{N_2 I_{N2}}{\frac{R_{\ell 1}}{\sqrt{2}}}$$

$$\frac{N_1 I_{N2}}{\frac{R_{\ell 1}}{\sqrt{2}}} = \frac{2 \times N_1 I_{N1}}{R_{\ell 1}}$$

$I_{N2} = \sqrt{2} I_{N1}$ ($\therefore$ I_{N1} is the magnetizing current of the transformer)

$$I_{N1} = \sqrt{I_0^2 - I_w^2}$$

$$= \sqrt{(3.2)^2 - (0.218)^2}$$

$= 3.192$ A

$I_{N2} = 4.51$A

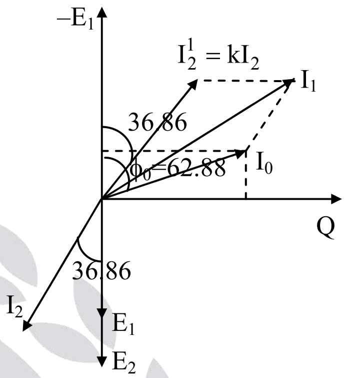
$$I_0 = \sqrt{I_w^2 + I_N^2}$$

$$= \sqrt{(0.617)^2 + (4.51)^2}$$

$= 4.556$ A

07. Ans: (b)

Sol:



$k = 0.1$

$W_0 = V_1 I_0 \cos\phi_0$

$$I_W = \frac{W_0}{V_1}$$

$$= \frac{700}{2400} = 0.291\text{A}$$

$I_w = I_o \cos\phi_o$

$$\cos\phi_0 = \frac{0.291}{0.64} = 0.455$$

$\phi_0 = 62.88$, and $\sin\phi_0 = 0.89$

$$I_1 = \sqrt{I_0^2 + I_2'^2 + 2 I_0 I_2' \cos\theta}$$

($\therefore$ $\theta = 62.88 - 36.86 = 26.02^o$)

$$I_1 = \sqrt{(0.64)^2 + 4^2 + (2 \times 0.64 \times 4 \times \cos(26.02)}$$

($\therefore$ $I_2' = KI_2 = 0.1 \times 40 = 4\text{A}$)

$I_1 = 4.58$ A

Power factor;

$4.58 \cos\phi_1 = 0.29 + I_2^1 \cos 36.86$

p.f = $\cos\phi_1 = 0.761$ lag

08. Ans: (c)

Sol: $Z_T = (0.18+j0.24)\Omega$ and $Z_L = (4+j3)\Omega$

$$I_{line} = \frac{480\angle 0°}{Z_T + Z_L} = \frac{480\angle 0°}{0.3\angle 53.13 + 5\angle 36.86}$$

$= 90.76\angle{-37.77}A$

Voltage at the load,

$V_{load} = (90.76\angle{-37.77}) \times (5\angle 36.86)$

$= 453.8\ \angle{-0.91}\ V$

And power loss in tr.line $= (I_{line})^2 \times 0.18$

$= (90.76)^2 \times 0.18$

$= 1482\ W$

09. Ans: (b)

Sol: 200V, 60Hz, $Wh_1 = 250W$, $Wh_2 = ?$

$W_{e1} = 90W$ $W_{e2} = ?$

$$\frac{V_1}{f_1} \neq \frac{V_2}{f_2}$$

$$\frac{W_{h2}}{W_{h1}} = \left(\frac{V_2}{V_1}\right)^{1.6} \times \left(\frac{f_1}{f_2}\right)^{-0.6}$$

$$\frac{W_{h2}}{250} = \left(\frac{230}{200}\right)^{1.6} \times \left(\frac{60}{50}\right)^{-0.6}$$

$W_{h2} = 348.79$

When $\frac{V}{f}$ ratio is not constant

$W_e \propto v^2$

$$\frac{W_{e2}}{W_{e1}} = \left(\frac{V_2}{V_1}\right)^2$$

$$W_{e2} = \left(\frac{230}{200}\right)^2 \times 90 = 119.02W$$

$W_i = W_{h2} + W_{e2} = 467.81\ W$

10. Ans: (a)

Sol: $V_1 = 440\ V$; $f_1 = 50Hz$; $W_i = 2500\ W$

$V_2 = 220\ V$; $f_2 = 25Hz$; $W_i = 850\ W$

$$\frac{V_2}{f_2} = \frac{V_1}{f_1} = \text{Constant}$$

$W_i = Af + Bf^2$

$2500 = A \times 50 + B \times 50^2$ ………. (1)

$850 = A \times 25 + B \times 25^2$ ..………(2)

By solving (1) & (2)

$A = 18$; $B = 0.64$

$W_e = Bf^2 = 0.64 \times 50^2$

$= 1600\ W$

$W_h = Af = 18 \times 50$

$= 900\ W$

11. Ans: (b)

Sol: Given data: $W_{h1} = \frac{W_i}{2}$; $W_{e1} = \frac{W_i}{2}$

$$\frac{W_{h2}}{W_{h1}} = \left(\frac{V_2}{V_1}\right)^{1.6}$$

$$W_{h2} = \left(\frac{0.9V_1}{V_1}\right)^{1.6} \times W_{h1}$$

$W_{h2} = 0.844\ W_{h1} = 0.422\ W_i$

$$\frac{W_{e2}}{W_{e1}} = \left(\frac{V_2}{V_1}\right)^2$$

$W_{e2} = 0.81\ W_{e1} = 0.81 \times \frac{W_i}{2}$

$W_{e2} = 0.40\ W_i$

$W_{i2} = W_{h2} + W_{e2} = 0.422\ W_i + 0.40\ W_i$

$W_{i2} = 0.822\ W_i$

Reduction in iron loss is $= 1 - 0.822$

$= 0.178$

≈ 0.173

i.e., 17.3% reduction

12. Ans: (a)

Sol: At 50 Hz;

Given, $P_{cu} = 1.6\%$, $P_h = 0.9\%$, $P_e = 0.6\%$

We know that, $P_h \propto f^{-0.6}$

$$\frac{P_{h_1}}{P_{h_2}} = \left(\frac{f_2}{f_1}\right)^{0.6} = \left(\frac{60}{50}\right)^{0.6} = 1.115$$

$$\therefore P_{h_2} = \frac{0.009}{1.115} = 0.806\ \%$$

Eddy current loss = constant, (since $P_e \propto V^2$) and given total losses remains same.

$$\therefore P_{h_1} + P_{cu_1} + P_{e_1} = P_{h_2} + P_{cu_2} + P_{e_2}$$

$$3.1\% = 0.806\% + P_{cu_2} + 0.6\%$$

$$\therefore P_{cu_2} = 1.694\ \%$$

P_{cu_2} is directly proportional to I^2

$$\therefore \frac{P_{cu_1}}{P_{cu_2}} = \left(\frac{I_1}{I_2}\right)^2$$

$$\Rightarrow I_2 = 1.028 I_1$$

Output kVA = $VI_2 = 1.028\ VI_1$

13. Ans: (d)

Sol: Given data: 20 kVA, 3300/220V, 50Hz

No load at rated voltage i,e $W_0 = 160$Watt

$\cos\theta_0 = 0.15$

% R = 1%   %X = 3%

Input power

= output Power + Total loss of power

$$\%.R = \%\text{FL cu loss} = \frac{\text{FL cu loss}}{\text{VA rating}} \times 100$$

FL cu loss = %R × VA rating

= 0.01 ×20,000 = 200 Watt

$$I_{F2} = \frac{\text{VA rating}}{E_2} = \frac{20{,}000}{220} = 90.9\text{A}$$

$$I_{load} = \frac{14.96\text{k}}{220 \times 0.8} = 85\text{A}$$

At 90.9A ⇒ Cu loss = 200 W

85A ⇒ Cu loss = ?

Cu loss at

$$85\text{A} = \left(\frac{85}{90.9}\right)^2 \times 200 = 174.8\,\text{Watt}$$

Total loss when 14.96 kW o/p

= Iron *l*oss + cu *l*oss at 85A

= 160+174.8

= 334.8 W

Input power = 14.96 kW+334.8W

= 15294.8W

14. Ans: (a)

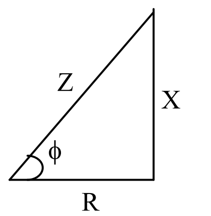
Sol: Given data:

At 50Hz: 16 V, 30 A, 0.2 lag

At 25 Hz , 16 V, I_{sc} = ? and p.f = ?

$$Z = \frac{V}{I}$$

$$Z = \frac{16}{30} = 0.533$$



$R = Z\cos\phi$

$R = 0.533 \times 0.2$

$R_1 = 0.106\ \Omega$

$X_1 = Z\sin\phi = 0.533 \times 0.979 = 0.522\ \Omega$

Reactance at f = 25 Hz

$$\frac{X_2}{X_1} = \frac{25}{50}$$

$X_2 = 0.2611\ \Omega$

$$Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{(0.106)^2 + (0.2611)^2}$$

$Z = 0.281\Omega$

$$I = \frac{V}{Z} = \frac{16}{0.281} = 56.78A \approx 56.65A$$

$$p.f = \cos\phi_{sc} = \frac{R}{Z} = \frac{0.106}{0.2817} = 0.376 \text{ lag}$$

15. Ans: (a)

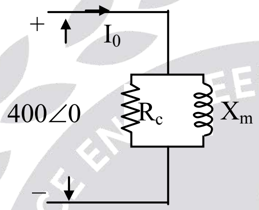
Sol: Given data:

10 kVA, 400/200 V,

W_0 = 100 watt and M =2H.

$$a = \frac{\text{HV voltage}}{\text{LV voltage}} = \frac{400}{200} = 2,$$

$$R_c = \frac{400^2}{100} = 1600\ \Omega$$



$X_m = 2\pi f\,(aM)$

$\Rightarrow 2\times\pi\times 50\times 4 = 400\pi\Omega$

$$I_0 = \frac{400}{1600} + \frac{400}{j400\pi}$$

$$|I_0| = \sqrt{\left(\frac{1}{4}\right)^2 + \left(\frac{1}{\pi}\right)^2}$$

$= 0.41$ A

16. Ans: (d)

Sol: Given that, no load loss components are equally divided

$W_h = W_e = 10W$

Initially test is conducted on LV side

Now $\frac{V}{f}$ ratio is $\frac{100}{50} = 2$

In HV side, applied voltage is 160V; this voltage on LV side is equal to 80V.

Now $\frac{V}{f}$ ratio is constant, $W_h \propto f$ and $W_e \propto f^2$.

$$W_{h2} = W_{h1} \times \frac{f_2}{f_1} = 10 \times \frac{40}{50} = 8W$$

$$W_{e2} = W_{e1} \times \left(\frac{f_2}{f_1}\right)^2 = 10 \times \left(\frac{40}{50}\right)^2 = 6.4 \text{ W}$$

Therefore,

$W_1 = W_{h2} + W_{e2} \Rightarrow 8 + 6.4 = 14.4$ W

In SC test,

I(HV side) = 5A and loss = 25W

$\Rightarrow$ Current in LV side is $\frac{5}{k}$ i.e 10A

For 10A $\rightarrow$ 25 watt

5 A $\rightarrow$?

$$W_{c2} = \left(\frac{I_2}{I_1}\right)^2 W_{c1}$$

$$= \left(\frac{5}{10}\right)^2 \times 25 = 6.25 \text{ W}$$

17. Ans: (b)

Sol: Given data, 4 kVA, 200/400 V and 50 Hz

OC: 200V, 0.7 A & 60W

SC: 9 V, 6A & 21.6 W

$$\eta = \frac{kVA \times \cos\phi}{kVA \times \cos\phi + W_i + W_{Cu}}$$

$W_i = 60W$

$W_{Cu} \propto I^2$

$$I_1 = \frac{4000}{400} = 10A$$

$$W_{Cu} = \left(\frac{10}{6}\right)^2 \times 21.6$$

$= 60W$

$W_i + W_{Cu} = 120$ W

$$\%\eta = \frac{4k \times 1}{4k \times 1 + 120} \times 100$$

$= 97.08\%$

18. Ans: (c)

Sol: Given data: $\eta = 98\%$

Lets take kVA = 1p.u and p.f = 1

$$\eta \text{ at full load} : 0.98 = \frac{1\times1}{1\times1 + W_i + W_{Cu}}$$

$W_i + W_{Cu} = 0.0204$ ……..(1)

For 1/2 full load

$$0.98 = \frac{1\times1\times0.5}{0.5\times1\times1 + W_i + 0.25W_{Cu}}$$

$W_i + 0.25\, W_{Cu} = 0.0102$ ……… (2)

By solving equation (1) & (2)

$W_i = 6.8 \times 10^{-3}$; $W_{Cu} = 0.0136$

$$\eta_{3/4} = \frac{0.75\times1\times1}{0.75\times1\times1 + 6.8\times10^{-3} + (0.75)^2\times0.0136}$$

$= 98.1\%$

19. Ans: (a)

Sol: Percentage of load at which maximum efficiency possible is $= \sqrt{\dfrac{W_i}{W_{Cu}}}$

$$= \sqrt{\frac{6.8\times10^{-3}}{0.0136}} = 0.707$$

$$\eta_{max} = \frac{0.707\times1\times1}{0.707\times1\times1 + (2\times6.8\times10^{-3})}\times100$$

$= 98.1\ \%$

20. Ans: (d)

Sol: Given data: 10 kVA,2500/250 V

OC: 250V, 0.8A, 50W

SC: 60V, 3A, 45W

Iron losses = 50 W = W_I

$$I_{(HV)} = \frac{10000}{2500} = 4A \text{ (Rated current)}$$

Copper loss at 3A = 45W

Copper loss at 4A = ?

$$\Rightarrow \left(\frac{4}{3}\right)^2 \times 45 = \frac{16}{9}\times45 \Rightarrow 80W$$

$$\text{kVA at } \eta_{max} = \sqrt{\frac{\text{Iron loss}}{\text{cu loss}}}\times \text{kVA}_{FL}$$

$$= \sqrt{\frac{50}{80}}\times10\,\text{kVA} = 7.9\,\text{kVA}$$

21. Ans: (c)

Sol: $$\eta_{\substack{max\\0.8pf}} = \frac{7.9\times0.8\times10^3}{7.9\times08\times10^3 + (2\times50)}\times100$$

$= 98.44\ \%$

22. Ans: (c)

Sol: Given data: 1000/ 200 V, $R_1 = 0.25\ \Omega$;

$R_2 = 0.014\ \Omega$, Iron loss = 240W

$$R_{02} = R_1^1 + R_2 = K^2R_1 + R_2$$

$$= \left(\frac{200}{1000}\right)^2 \times 0.25 + 0.014$$

$= 0.024$

$$I_{2\,max} = \sqrt{\frac{\text{Iron loss}}{R_{02}}}$$

$$= \sqrt{\frac{240}{0.024}} = 100A$$

23. Ans: (c)

Sol: Given data: Max. η = 98 %, at 15 kVA, full load kVA = 20, UPF for 12 hours

$$0.98 = \frac{15k\times0.1}{15k\times1 + 2W_i}$$

$W_i = 153.06W$

$$\eta_{all\,day} = \frac{\text{output in kWh}}{\text{output kwh} + \text{losses}}$$

$kW = kVA \times \cos\phi$

$kW = 20 \times 1 = 20$ kW

kWh output $= 20 \times 12 = 240$ kWh

$W_i = 153.06 \times 24 = 3.673$ kWh

$W_{Cu} \propto S^2$

$$W_{Cu2} = \left(\frac{20}{15}\right)^2 \times 153.06$$

$W_{Cu2} = 272.106$

Transformer is ON load for 0 to 12 hrs.

So, $W_{Cu2} = 272.106 \times 12 = 3.265$ kWh

$$\eta_{all\,day} = \frac{240 \times 10^3}{240 \times 10^3 + 3.673 \times 10^3 + 3.265 \times 10^3}$$

$\%\eta_{all\ day} = 97.19\% \approx 97.2\%$

24. Ans: (*)

Sol: Given Iron loss = 1.25 kW, $\cos\phi = 0.85$

Find equivalent resistance R_{01} on H.V side

$$k = \frac{231}{11000} = 0.021$$

$$R_{01} = 8.51 + \frac{0.0038}{k^2} \Rightarrow 17.126\ \Omega$$

$$\text{Full load current on H.V side} = \frac{100 \times 10^3}{11000}$$

$= 9.09$ A

Full load Cu loss $= (9.09)^2 \times 17.126$

$= 1.415$ kW

$$\text{Efficiency} = \frac{100 \times 0.85}{100 \times 0.85 + 1.415 + 1.25} \times 100$$

$= 96.95$ %

25. Ans: (c)

Sol: Given data:

1100/400 V, 500 kVA, $\eta_{max} = 98\%$

80% of full load UPF

$$\%Z = 4.5\% \text{ PF} \Rightarrow \text{max V.R} = \frac{\%R}{\%Z}$$

For min. secondary 10%

$$0.98 = \frac{0.8 \times 500 \times 10^3}{0.8 \times 500 \times 10^3 + 2\text{Iron Loss}}$$

Iron loss = 4081.63 W

$\Rightarrow$ Cu loss at 80 % of FL = 4081.63

$(.8)^2$ Cu loss of FL = 4081.63

FL cu loss = 6377. 54 W

$$\%R = \%\text{ FL cu loss} = \frac{\text{FL cu loss}}{\text{VA Rating}}$$

$$= \frac{6377.5}{500 \times 10^3} \times 100$$

$= 1.27$ %

$$\text{PF} \Rightarrow \text{max. VR} = \frac{\%R}{\%Z} = \frac{1.27}{4.5} = 0.283\,\text{lag}$$

26. Ans: (b)

Sol: Terminal voltage = ?

$$\%X = \sqrt{\%Z^2 - \%R^2}$$

$$= \sqrt{(4.5)^2 - (1.27)^2} = 4.317\%$$

$\%VR = \%R \cos\phi_2 + \%X \sin\phi_2$

$= (1.27 \times 0.283) + (4.317 \times 0.959)$

% VR = 4.49% = 0 .0449 Pu

Total voltage drop on secondary side

$= \text{PU VR} \times E_2$

$= 0.0449 \times 400 = 18$V

$V_2 = E_2 -$ Voltage drop $= 400 - 18 = 382$V

27. Ans: (a)

Sol: $R_{02} = R_1' + R_2$ and $X_{02} = X_1' + X_2$

$R_1' = K^2 R_1 \rightarrow$ (Resistance referred to secondary side)

$R'_1 = \left(\frac{1}{10}\right)^2 \times 3.4 = 0.034$

$X'_1 = k^2 X_1 = (0.01 \times 7.2) = 0.072$

$R_{02} = 0.034 + 0.028 = 0.062\Omega$

$X_{02} = 0.072 + 0.060 = 0.132\Omega$

$\% \text{ Reg} = \frac{I_2 R_{02}\cos\phi_2 \pm I\ X_2 \sin\phi_2}{V_2}$

$I_2 = 22.72$ A

$\text{Reg} = \frac{22.72 \times 0.062 \times 0.8 + 22.72 \times 0.132 \times 0.6}{220}$

Reg = 0.0133

% Reg = 1.33% is same on both sides

$\frac{V_{\text{full voltage}} - V}{V} = 0.0133$

$V_{\text{full Load}} = 2229.26$V

The voltage applied across terminals.

28. Ans: (b)

Sol: 6600/440V p.u. R = 0.02 pu

p.u.X = 0.05 pu

$V_1 = 6600$ V

pu VR = %R $\cos\theta_2$ +% X$\sin\theta_2$

$= 2 \times 0.8 + 5 \times 0.6 = 4.6\%$

= 0.046 pu

Voltage drop when with respect to secondary

= p.u. VR × secondary Voltage

= 0.046 × 440 = 20.2V

Terminal voltage

$V_2 = 440 - 20.2 = 419.75$ V

29. Ans: (b)

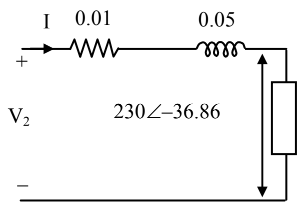
Sol: If voltages are not nominal values % Reg will be zero

$R_{Pu}\cos\phi - X_{pu}\sin\phi = 0$

$\phi = \tan^{-1}(R/X) = 21.801$

p.f = $\cos\phi$ = cos (21.80) = 0.928 lead

30. Ans: (c)



Sol: $R_{pu} = 0.01$

$X_{pu} = 0.05$

$V_1 = 600$V

$V_2 = 230$V, 0.8 lag

Take rated current as 1pu

Drop (Iz) = $1\angle{-36.86} \times (0.01 + j0.05)$

$= 0.0509\angle 41.83$pu

Convert this in volts

$= 0.0509\angle 41.83 \times 230$

$= 11.707\angle 41.83$ V

$E_2 = V + Iz$

$= 230\angle 0 + 11.707\angle 41.83$

$= 238.85\angle 1.87$

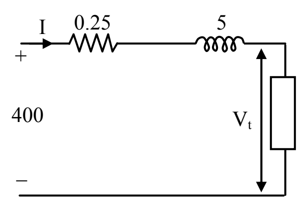
Turns ratio $= \frac{E_1}{E_2} = \frac{600}{238.85} = 2.5$

31. Ans: (c)

Sol: P = VI$\cos\phi$

$5 \times 10^3 = 400 \times 16 \cos\phi$

$\Rightarrow \phi = 38.624$



From given data,

$-400 + (0.25 + j5)16\angle{-38.624} + V_t = 0$

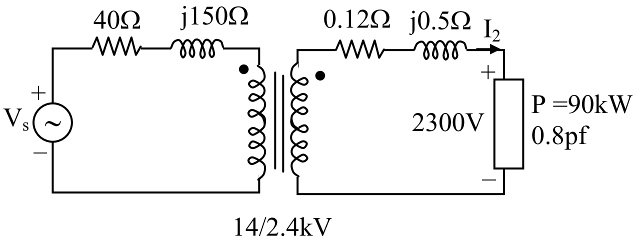
$\Rightarrow V_t = 352.08\angle{-9.81}$

Refer LV side $V_t = \frac{352.08}{5}$

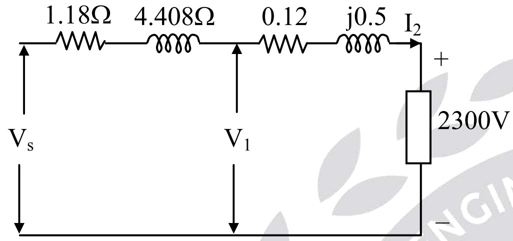
= 70.4 V

32. Ans: (*)

Sol:



The equivalent circuit refer to L.V side is



$$I_2 = \frac{90\times10^3}{2300\times0.8} = 48.91\text{A}$$

Where V_1 = voltage applied across the transformer.

$V_1 = V_2 + I_2\,(0.12 \times \cos\phi + 0.5 \times \sin\phi)$

$= 2300 + 48.91[0.12\times0.8 + 0.5\times0.6)$

$= 2300 + 19.36$

$V_1 = 2319.36\text{V}$

$$\%\ \text{Regulation} = \frac{2319.36-2300}{2400}\times100$$

$= 0.807\%$

33. Ans: 96.7%

Sol: copper losses $= I_2^2(1.18+0.12)$

$= (48.91)^2\times1.3$

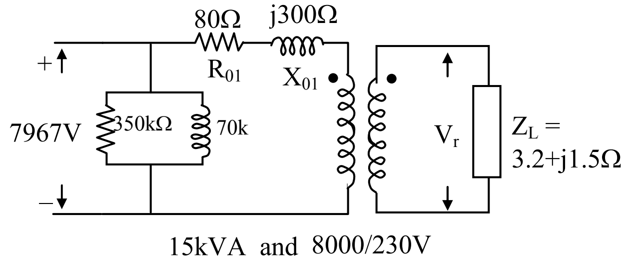
$= 3109.8$ W

$$\%\ \eta = \frac{90\times10^3}{90\times10^3+3109.8}\times100$$

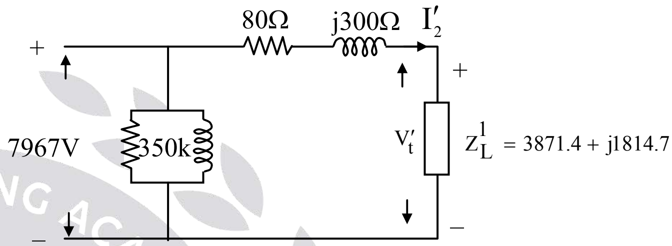
$= 96.67\%$

34. Ans: 218.8

Sol:



Equivalent circuit refer to H.V side is



$Z_L^1 = 4275.6\angle25.11$

Transformer impedance $= R_{01} + jX_{01}$

$= 310.48\angle75.06$

$$I_2^1 = \frac{7967}{310.48\angle75.06 + 4275.6\angle25.11}$$

$= 1.78\angle-28.15\text{A}$

$V_1' = I_2' \times Z_L'$

$= (1.78\angle-28.15)\times(4275.6\angle25.11)$

$= 7600.6\angle-3.04$

$$\text{Now } V_t = \frac{7600.6\times230}{8000}$$

$= 218.52\angle-3.04$

35. Ans: 4.9%

Sol: Voltage regulation $= \dfrac{E_2 - V_t}{E_2}\times100$

$$= \frac{230-218.52}{230}\times100$$

$= 4.9\%$

36. Ans: (*)

Sol: Given data, f = 60 Hz, 30 kVA,

4000 V/120 V, Z_{pu} = 0.0324 pu,

I_0 = 0.0046 pu, W_0 = 100 W, W_{cu} = 180 W

P_0 = 20 kW & cosϕ = 0.8lag

Load current $I_2 = \dfrac{20\times10^3}{120\times0.8} = 208.33$ A

Rated load current $= \dfrac{30\times10^3}{120} = 250$ A

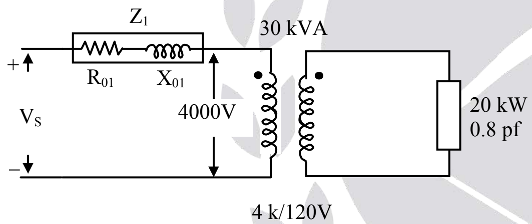
The copper losses for 208.33 A is

$$\left(\frac{208.33}{250}\right)^2\times180 = 124.99 \text{ watt}$$

$$\text{Efficiency} = \frac{20\times10^3}{20\times10^3+124.99+100}\times100$$

= 98.88%

The equivalent circuit wrt primary is



Primary rated current

$$I_P = \frac{30\times10^3}{4000} = 7.5 \text{ A}$$

Given cu losses = 180 W

$$\Rightarrow R_1 = \frac{180}{I_P^2} = \frac{180}{(7.5)^2} = 3.2\ \Omega$$

Given, Z_{pu} = 0.0324

$$\therefore Z_1 = 0.0324\times\frac{(kV)^2}{MVA} = 0.0324\times\frac{4^2}{0.03}$$

$$= 17.28\ \Omega$$

$$X_1 = \sqrt{Z_1^2-R_1^2} = \sqrt{17.28^2-3.2^2}$$

$$= 16.98\ \Omega$$

Load current wrt primary is

$$I_2' = I_2\times\frac{120}{4000}$$

$$= 208.33\times\frac{120}{4000} = 6.24 \text{ A}$$

Necessary primary voltage

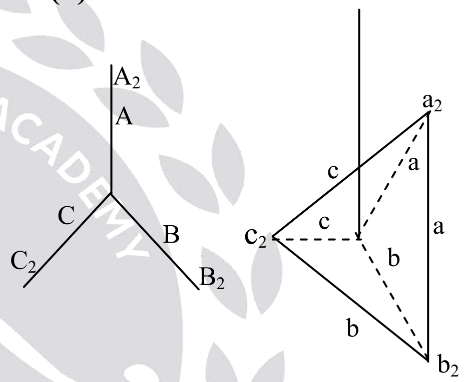
$$V_S = V_2' + I_2'\left[R_1\cos\phi + X_1\sin\phi\right]$$

= 4000 + 6.24[3.2 × 0.8 + 16.98 ×0.6]

= 4079.5 V

37. Ans: (b)

Sol:

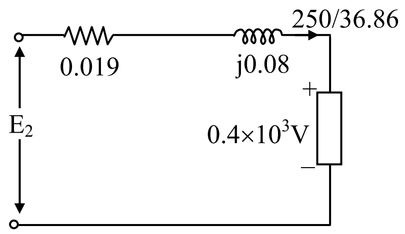


∴ The Possible Connection is Yd1

38. Ans: (a)

Sol: $R = 0.012\times\left(\dfrac{0.4^2}{0.1}\right) = 0.0192\Omega$

$$X = 0.05\times\left(\frac{0.4^2}{0.1}\right) = 0.08\Omega$$



$$I_2 = \frac{P}{V} = \frac{100\times10^3}{0.4\times10^3} = 250\angle+36.86$$

$E_2 = 392\angle 2.75$ V

$$E_1 = \left(\frac{6.6}{0.4}\right)\times 392 = 6468\text{V}$$

$= 6.46$ kV

40. Ans: (d)

Sol: The induced voltages in primary winding are

$V_{BC} = E\angle 0^o$

$V_{CA} = E\angle 120^o$

$V_{AB} = E\angle -120^o$

By observing two phasor diagrams, the phase shift between primary and secondary is 180°

The induced voltages in secondary are

$V_{bc} = E\angle 180^o$

$V_{ca} = E\angle 300^o$

$V_{ab} = E\angle 60^o$

If any one terminal X_1 and X_2 are interchanged, the polarity will be changed.

Let V_{bc} windings is interchanged.

Resultant voltage

$= -E\angle 180^o + E\angle 300^o + E\angle 60^o$

$= 2E\angle 0^o$

This voltage can burn out the transformer

41. Ans: (b)

Sol: Turns ratio = $\dfrac{\text{primary induced voltage}}{\text{secondary induced voltage}}$

secondary induced phase voltage

$$= \frac{\text{terminal phase voltage}}{(1-\%\text{Reg})}$$

% Reg = % R cosϕ + % X sinϕ

[∵ Lagging Load]

$= 1 \times 0.8 + 5 \times 0.6$

$= 3.8\%$

$$E_2 = \frac{V_2(\text{phase})}{1-0.038} = \frac{415}{\sqrt{3}\times 0.962} = 249.06$$

$$\therefore \text{ Turns ratio} = \frac{V_{1ph}}{V_{2ph}} = \frac{6000}{249.06} = 24$$

42. Ans: (a)

Sol: $P_{o/p} = 50$ hp

$= 50 \times 735.5 = 36.775$ kW

$P_{o/p}$ of induction motor = 36.77 kW

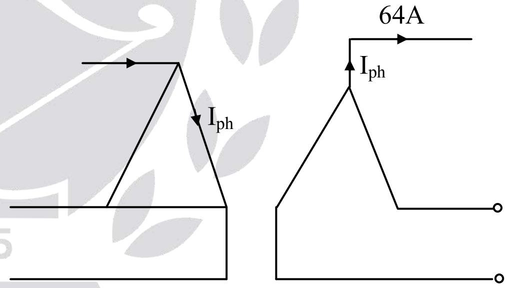
$P_{i/p}$ to induction motor (or) power output of

$$\text{transformer} = \frac{P_{o/p}}{\eta} = \frac{36.77}{0.85} = 40.85\text{kW}$$

$$I_L = \frac{P}{\sqrt{3}\times V_L \times \cos\phi} = \frac{40.85\times 10^3}{\sqrt{3}\times 440\times 0.85}$$

$= 63.06\angle 31.78^o$

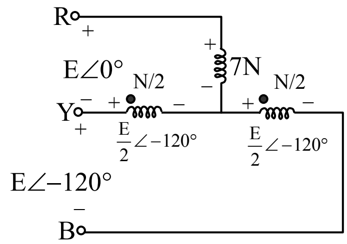
≈ 64 A



$$I_{ph} = \frac{440}{\sqrt{3}\times 6600}\times 64 = 2.46\text{A}$$

43. Ans: (c)

Sol:



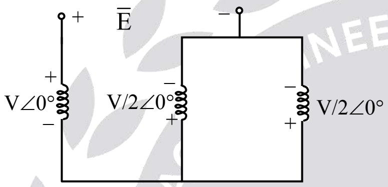
$$E\angle 0° = \bar{V}_{Rs} - \frac{E}{2}\angle -120°$$

$$\Rightarrow \bar{V}_{Rs} = E\angle 0° + \frac{E}{2}\angle -120°$$

$$= \frac{\sqrt{3}}{2}E\angle -30°$$

44. Ans: (d)

Sol: The flux linkages in phase 'b' and 'c' windings is $\frac{\phi}{2}$. Therefore induce voltage is also becomes half



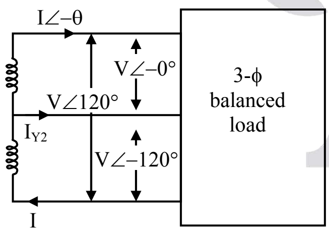
KVL:

$$V\angle 0° + \frac{V}{2}\angle 0° = \bar{E}$$

$$\Rightarrow \bar{E} = \frac{3}{2}V\angle 0°$$

45. Ans: (b)

Sol:



I_{Y2} is −120° lagging w.r.t $I\angle -\theta$ (from 3ϕ system)

$\therefore I_{Y2} = I\angle -\theta - 120°$

And $\bar{I} = I\angle -\theta + 120° - 180°$

$= I\angle -\theta - 60°$

46. Ans: (a)

Sol: $I_{rated} = I_{base} = 1.00$

$V_{rated} = V_{base} = 1.00$

Under short circuit, $I_{sc}z_{e1} = V_{sc}$

Since $I_{sc} = I_{rated}$; $1z_{e1} = (0.03)(1)$

Or $z_{e1} = 0.03$

Short circuit pf = $\cos\theta_{sc} = 0.25$,

$\therefore \sin\theta_{sc} = 0.968$

In complex notation,

$$\bar{z}_{e1} = 0.03(0.25 + j0.968)$$

$$= (0.0075 + j0.029) \text{ pu}$$

Similarly $\bar{z}_{e2} = 0.04(0.3 + j0.953)$

$$= 0.012 + j0.0381 \text{ pu}$$

(a) When using pu system, the values of z_{e1} and z_{e2} should be referred to the common base kVA. Here the common base kVA may be 200 kVA. 500 kVA or any other suitable base kVA. Choosing 500 kVA base arbitrarily, we get

$$\bar{z}_{e1} = \frac{500}{200}(0.0075 + j0.029)$$

$$= 0.01875 + j0.0725$$

$$= 0.075\angle 75.52$$

$$\bar{z}_{e2} = \frac{500}{500}(0.012 + j0.0381)$$

$$= 0.04\angle 72.54°$$

$$S = \frac{560}{0.8} = 700 \text{ kVA}$$

$$\therefore \bar{S} = 700\angle -\cos^{-1}0.8$$

$$= 700\angle -36.9°$$

From Eq. $\bar{S}_1 = \bar{S}\frac{\bar{z}_{e2}}{\bar{z}_{e1} + \bar{z}_{e2}}$

$$= (700\angle -36.9)\frac{0.04\angle 72.54°}{0.114\angle 74.74°}$$

$= 460\angle -36.1°$ kVA

$S_2 = (460)(\cos 36.1^o)$ at pf $\cos 36.1^o$ lag

= 372 kW at pf of 0.808 lag

(Check. Total power = 190 + 372 = 562 kW, almost equal to 560 kW)

47. Ans: (d)

Sol: Current shared by transformer 1 = $\frac{245}{200}$

= 1.225 pu

Transformer 1 is, therefore, overloaded by 22.5%, i.e., 45 kVA

Current shared by transformer 2 = $\frac{460}{500}$

= 0.92 pu

Transformer 2 is, therefore, under loaded by 8%, i.e. 40 kVA.

Voltage regulation, from Eq. (1.40), is given by $\varepsilon_r\cos\theta_2 + \varepsilon_x\sin\theta_2$

For transformer 1, the voltage regulation at 1.225 pu current is

$= 1.225\,(\varepsilon_r \cos\theta_2 + \varepsilon_x\cos\theta_2)$

$= 1.225\,(0.0075 \times 0.76 + 0.0290 \times 0.631)$

$= 1.225(0.024119) = 0.029546$

Or $\frac{E_2 - V_2}{E_2} = 0.029546$

Or $V_2 = (0.970454)(400)$

$= 388.182$ V

48. And: (c)

Sol: Here $\left(I_{Z_e}\right)_{f\ell 1} = 360\,\text{V}, \left(I_{Z_e}\right)_{f\ell 2} = 400\,\text{V}$

and $\left(I_{Z_e}\right)_{f\ell 3} = 480\,\text{V}$

Transformer 1 is loaded first to its rated capacity, because $\left(I_{Z_e}\right)_{f\ell 1}$ has lowest magnitude. Thus the greatest load that can be put on these transformers without overloading any one of them is,

$$\left(I_{Z_e}\right)_{f\ell 3} = (\text{kVA})_1 + \frac{\left(I_{Z_e}\right)_{f\ell 1}}{\left(I_{Z_e}\right)_{f\ell 2}}(\text{kVA})_2 + \frac{\left(I_{Z_E}\right)_{f\ell 1}}{\left(I_{Z_e}\right)_{f\ell 3}}(\text{kVA})_3 + ...$$

$$= 400 + \frac{360}{400}\times 400 + \frac{360}{480}\times 400$$

$$= 1060\,\text{kVA}$$

The total load operates at unity p.f. and it is nearly true to say that transformer 1 is also operating at unity p.f.

49. Ans: (c)

Sol: Secondary rated current

$$= \frac{400}{6.6} = 60.6\,\text{Amp}$$

Since transformer 1 is fully loaded, its secondary carries the rated current of 60.6 A.

For transformer 1, $r_{e_2} = \frac{3025}{(60.6)^2} = 0.825\Omega$

Full-load voltage drop for transformer 1,

$E_2 - V_2 = I_2 r_{e2}\cos\theta_2 + I_2 x_{e2}\sin\theta_2$

$= (60.6)\,(0.825)\,(1) + 0$

$= 50$ V

$\therefore$ Secondary terminal voltage

$V_2 = 6600 - 50 = 6550$ V

50. Ans: (a)

Sol: Voltage rating of two winding transformer = 600 / 120V, 15 KVA voltage rating of auto transformer = 600 V / 720 V from the auto transformer ratings, can say windings connected in "series additive polarity".

From two winding transformer

$$I_1 \text{rated} = \frac{15000}{600}$$

$$= 25 \text{ A}$$

$$I_2 \text{ rated} = \frac{15000}{120}$$

$$= 125 \text{ A}$$

In AT, due to series additive polarity

$I_{pry} = 125 + 25 = 150$ A

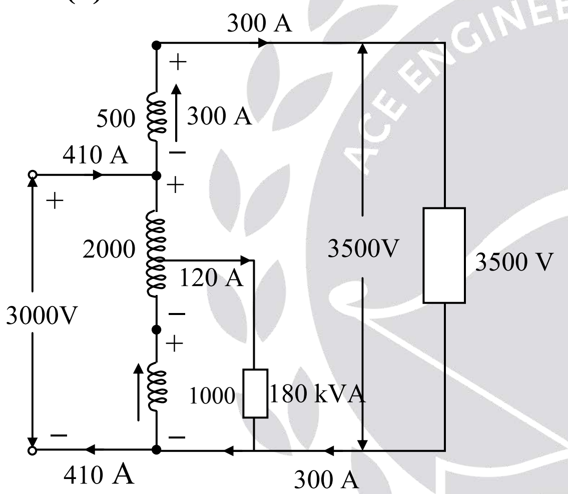
$\therefore$ Rating of AT $= E_{pry} \times I_{pry}$

$= 600 \times 150$

$= 90$ kVA

51. Ans: (b)

Sol:



The current through the load of 1050 kVA at 3500 V is $= \frac{1050000}{3500} = 300\text{A}$

The current through the load of 180 kVA at 1500 V is $= \frac{180000}{1500} = 120$

The kVA supplied = 1050 + 180

= 1230 kVA

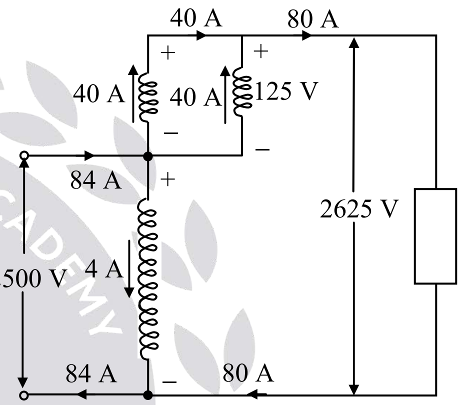
The total current taken from the supply main is $= \frac{1230{,}000}{3000} = 410\text{A}$

52. Ans: (b)

Sol: From above solution, current taken by 180 kVA load is 120A

53. Ans: (c)

Sol: The two parts of the l.v. winding are first connected in parallel and then in series with the hv. winding, so that the output voltage is 2500 + 125 = 2625 V.



The rated current of l.v. winding is

$$40\text{A} = \frac{10{,}000}{250}$$

$\therefore$ Total output current is 40 + 40 = 80A

$\therefore$ Auto –transformer kVA rating

$$= \frac{80 \times 2625}{1000} = 210\text{kVA}$$

54. Ans: (a)

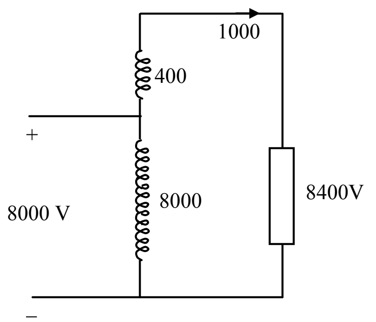
Sol: The rated current of h.v winding is 4 A. Therefore, the current drawn from the supply is 84A.

kVA transformed = (1−K) kVA_{AT} and kVA conducted = 210–10

= 200 kVA.

55. Ans: (d)

Sol:



Current through 480 V winding is

$$I_2 = \frac{480\times10^3}{480} = 1000\text{A}$$

kVA rating of auto transformer

$= 8400 \times 1000 = 8.4$ MVA

For two winding transformer

$$= 0.978 = \frac{480\times10^3\times1}{480\times10^3 + W}$$

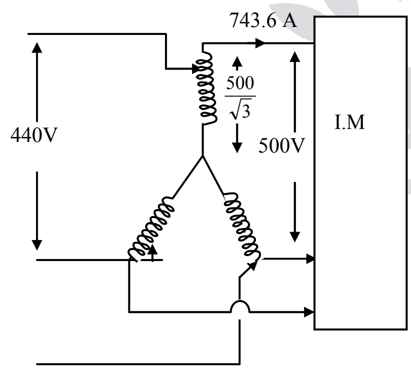
W = 10.79 kW

$$\text{Efficiency} = \frac{8.4\times10^6\times1}{8.4\times10^6\times1+10.79\times10^3}\times100$$

= 99.87%

56. Ans: (a)

Sol:



$$I_2 = \frac{610\times0.745\times10^3}{\sqrt{3}\times500\times0.8\times0.882}$$

$= 743.69$A

By equation

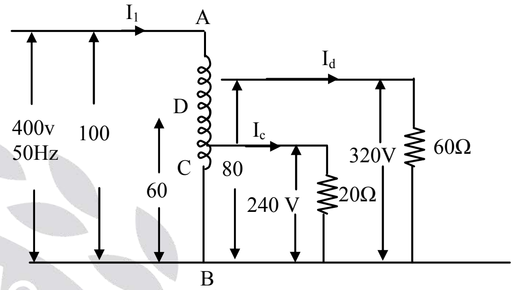
$$\frac{500}{\sqrt{3}}\times743.6 = \frac{440}{\sqrt{3}}\times I_1$$

$I_1 = 845.11$ A

$I_1 - I_2 = \approx100$ A

57. Ans: (a)

Sol:



$$\text{The voltage per turn} = \frac{400}{100} = 4\text{V}$$

For 80 turns = $80 \times 4 = 1320$ V

For 60 turns = $60 \times 4 = 240$ V

$$I_d = \frac{320}{60} = 5.33 \text{ A}$$

$$I_c = \frac{240}{20} = 12 \text{ A}$$

VA rating fo 20Ω load is $240\times I_c = 240\times12 =$ 2880VA

VA rating for 60 Ω load is $320\times I_d$

$= 320\times5.33$

= 1705.6 VA

$$\text{Primary current } I_1 = \frac{\text{Total load VA}}{400}$$

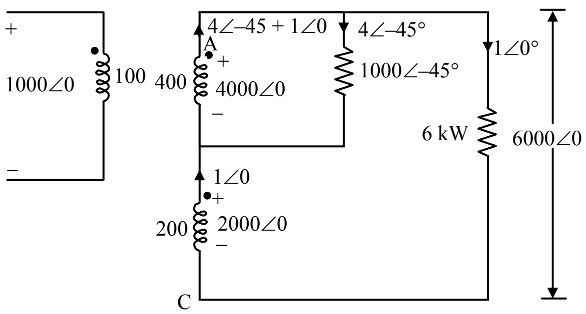
$$= \frac{2880+1705.6}{400}$$

$I_1 = 11.464$ A

For resistive load power factor is at unity.

58. Ans: (c)

Sol:



Load current = $4\angle{-45} + 1\angle 0$

$= 4.75\ \angle{-36.55}$

mmf = $400 \times 4.75\ \angle{-36..55} + 200\angle 0$

$= 1900\ \angle{-36.55} + 200$

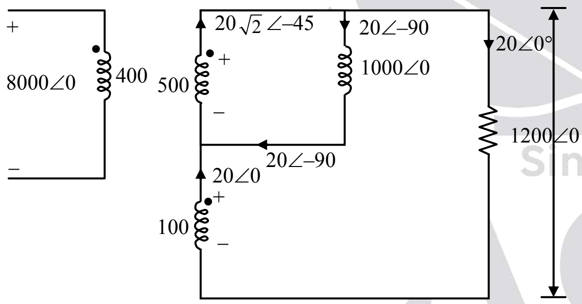
$= 1726.3 - j\ 1131.5$

Total secondary mmf = $2064.07\angle{-33.24}$

Primary current = $\frac{2064}{100} = 20.64$ A

59. Ans: (b)

Sol:



Sec. mmf = $2000\ \angle 0 + 20\sqrt{2}\ (500)\angle{-45}$

$= 2000\angle 0 + 10000\sqrt{2}\ \angle{-45}$

$= 1000\ [2\angle 0 + 10\sqrt{2}\ \angle{-45}]$

$= 1000[2+10-j\ 10]$

$= 1000[12 - j\ 10]$

mmf = $15620.4\ \angle{-39.8}$

Primary current = $\frac{15620.4\angle{-39.8}}{400}$

= 39 A at 0.76 lag

60. Ans: (b)

Sol: From power balance

$V_1I_1\cos\phi_1 = V_2I_2\cos\phi_2 + V_3I_3\cos\phi_3$

10 : 2 : 1

$\frac{N_2}{N_1} = \frac{1}{5}\ ;\ \frac{N_3}{N_1} = \frac{1}{10}$

$\cos\phi_2 = 0.8 \Rightarrow \phi_2 = 36.86$

$\cos\phi_3 = 0.71 \Rightarrow \phi_3 = 44.76$

$V_1I_1\cos\phi_1 = \frac{1}{5}V_1I_2\cos\phi_2 + \frac{1}{10}V_1I_3\cos\phi_3$

$I_1\cos\phi_1 = 9\angle{-36.86} + 5\angle{-44.76}$

$= 13.969\ \angle{-39.6^o}$

$I_1 = 14$A

p.f = cos(39.6) = 0.77 lag

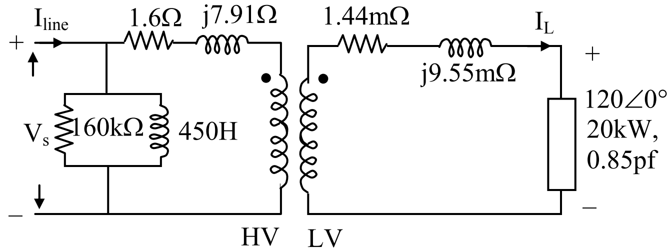
61. Ans: (a)

Sol: Given $R_1 = 1.6\Omega$, $L_1 = 21$mH, $R_2 = 1.44$mΩ, f = 60Hz, $L_2 = 19\mu$H, $R_c = 160$kΩ, L_m = 450 H, P = 20 kW, V_2 = 120V and $\cos\phi = 0.85$lag.

$X_1 = 2\pi fL_1 = 2\times\pi\times60\times21\times10^{-3} = 7.91\ \Omega$

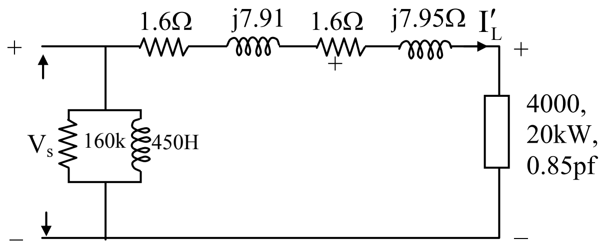
$X_2 = 2\pi fL_2 = 2\times\pi\times60\times19\times10^{-6} = 9.55\ m\Omega$

The equivalent circuit is,



4000/120

Equivalent circuit referred to H.V side.



$$I'_L = \frac{20\times10^3}{4000\times0.95} = 5.88\text{A}$$

$$V_s = V_2 + I'_L[2\times1.6\times\cos\phi + (7.91+7.95)\sin\phi]$$

$= 4000+5.88[2\times1.6\times0.85+15.86\times0.526]$

$= 4000+65.12$

$= 4065.12$

$V_s \approx 4066\text{V}$

Input power can be calculated by adding losses to the output power.

Cu losses:

$= (I'_L)^2\times2\times1.6$

$\Rightarrow 5.88\times2\times1.6 = 110.63\text{W}$

Core losses:

$$P_c = \frac{V_s^2}{160\times10^3} = \frac{(4066)^2}{160\times10^3} = 103.32\text{W}$$

$$\%\ \text{efficiency} = \frac{P_0}{P_0+\text{losses}}\times100$$

$$= \frac{20\times10^3}{20\times10^3+110.6+103.32}\times100$$

$= 98.94\%$

62. Ans: (b)

Sol: Given N =500, A = 100 cm^2 = 100×10^{-4} m^2

$l = 40\pi$ c.m = $40\ \pi\times10^{-2}$m

and $\mu_r = 1000$

$$\text{Inductance } L = \frac{\mu N^2 A}{\ell}$$

$$= \frac{\mu_0\mu_r N^2 A}{\ell}$$

$$= \frac{4\pi\times10^{-7}\times1000\times500^2\times100\times10^{-4}}{40\pi\times10^{-2}}$$

$= 500^2\times100\times10^{-7}$

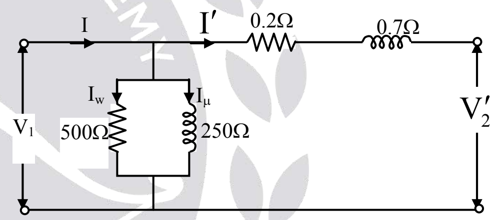
$= 2.5\text{H}$

Solutions for Conventional Practice Questions

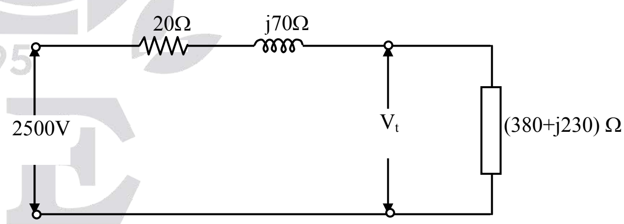
01.

Sol: (a) LV 250/2500 V

$$k = \frac{2500}{250} = 10$$



Referred HV side



$R'_1 = k^2\times R_1 = 0.2\times(10)^2 = 20$

$X'_1 = k^2\times X_1 = 10^2\times0.7 = 70$

terminal voltage (V_t)

$$= \frac{2500\times(380+j230)}{(20+j70)+(380+j230)}$$

$V_t = 2220\angle-5.68°$

(b) I_1 = ? pf = ?

$I_2 = \dfrac{V_2}{Z} = \dfrac{2500}{(20+j70)+(380+j230)}$

$I_2 = 5\angle{-36.86°}$

Secondary current referred to primary)

$I'_2 = kI_2 = 10 \times 5\angle{-36.86} = 50\angle{-36.86°}$

$I_0 = \bar{I}_w + \bar{I}_\mu$

$I_w = \dfrac{V_1}{R_w} = \dfrac{250}{500} = \dfrac{1}{2}$ A

$I_\mu = \dfrac{250}{j250} = -j1$

$I_0 = 0.5 - j1$

$I_1 = I'_2 + I_0$

$I_1 = 50\angle{-36.86} + 1.118\angle{-63.43}$

$I_1 = 51\angle{-37.42}$

pf = $\cos\phi = \cos(37.42) = 0.794$ lag

(c) Power output = ?

$P = V_t I_2 \cos\phi \left(\tan\phi = \dfrac{X}{R}, \phi = \tan^{-1}\left(\dfrac{230}{380}\right) = 31.185^o \right)$

$P = 2220 \times 5 \times \cos(31.185)$

$P_{o/p} = 9496.05$W

$P_{i/p} = V_1 I_1 \cos\phi$

$= 250 \times 51 \times 0.8$

$= 10200$ W

Efficiency $= \dfrac{o/p}{i/p} = \dfrac{9496.05}{10200} \times 100$

$= 93.10\%$

02.

Sol: On LV side $W = V_1 I_0 \cos\phi_0$

(a) $\cos\phi_0 = \dfrac{150}{200 \times 1.25} = 0.6$

$\sin\phi_0 = 0.8$

$I_0 R_0 = \dfrac{V_1}{I_w} = \dfrac{200}{0.75}$

$= 266.667\ \Omega$

$X_0 = \dfrac{V_1}{I_\mu} = \dfrac{200}{1} = 200\ \Omega$

ON HV side (from SC test data)

$Z_{SC} = \dfrac{V_{SC}}{I_{SC}} = \dfrac{20}{12.5} = 1.6\ \Omega$

$I_{SC}^2 R_{SC} = W_{SC}$

$R_{SC} = \dfrac{175}{(12.5)^2} = 1.12\ \Omega$

$X_{SC} = \sqrt{Z_{SC}^2 - R_{SC}^2}$

$= 1.142\ \Omega$

(R_{SC} & X_{SC} can be written as R_{01} and X_{01})

(i) Equivalent circuit referred to LV side

$R_{01} = \dfrac{R_{02}}{k^2}$ $\quad k = \dfrac{400}{200} = 2$

$R'_{02} = \dfrac{1.12}{4} = 0.28$

$X'_{02} = \dfrac{1.142}{4} = 0.2855$

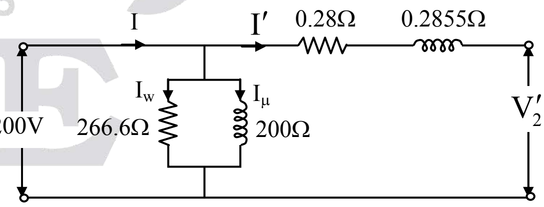


Fig (a)

(ii) Equivalent circuit referred to HV side

$R_{02} = 1.12\ \Omega$

$X_{02} = 1.142\ \Omega$

$R_0 = 266.67 \times 4 = 1066.68\ \Omega$

$X_0 = 200 \times 4 = 800$

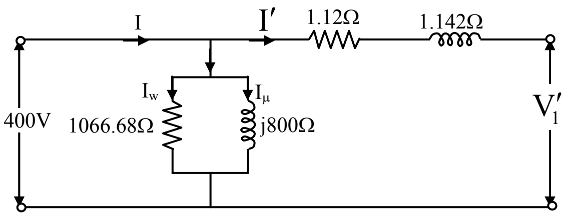


Fig (b)

(i) Efficiency = ?

pf = 0.7

Full load current on HV side = $\frac{5000}{400}$

= 12.5 A

Cu loss = 175 W

Efficiency

$$= \frac{x \times kVA \times \cos\phi}{x \times kVA \times \cos\phi + x^2 W_{cu} + W_i} \times 100$$

(x = 0.75)

$$= \frac{0.75 \times 5000 \times 0.7}{0.75 \times 5000 \times 0.7 + (0.75)^2 \times 175 + 150} \times 100$$

= 91.35%

(b) kVA at maximum efficiency

$$= \text{kVA} \times \sqrt{\frac{\text{iron loss}}{\text{cu loss}}}$$

$$= 5 \times \sqrt{\frac{150}{175}} = 4.625 \text{ kVA}$$

The load at $\eta_{max} = \sqrt{\frac{150}{175}} = 92.58\%$

At 92.58% loading we can get maximum efficiency.

Maximum efficiency

$$= \frac{4.625 \times 10^3 \times 0.7}{4.625 \times 10^3 \times 0.7 + (2 \times 150)}$$

= 91.51%

(c) Regulation = ?

$$\frac{I_2(R_{02}\cos\phi + X_{02}\sin\phi)}{V_2}$$

Load current $I_2 = \frac{kVA}{V_2} = \frac{5 \times 10^3}{400}$

= 12.5 A

% Regulation

$$= \frac{12.5 \times (1.12 \times 0.8 + 1.142 \times 0.6)}{400} \times 100$$

= 4.941%

(d) Consider circuit referred to LV side

$I_2^1 = kI_2$

$I_2^1 = 25\angle -45.57°$

Consider circuit referred to LV side

$I_2' = kI_2$

Voltage applied at Lv side

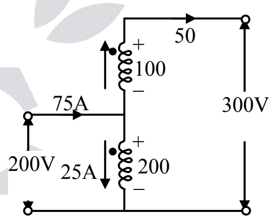
V = 200 + 25∠–45.57 × (0.28 + j0.285)

V = 209.995 ≈ 210 V

04.

Sol: P = 5 kVA, 200/100V, f = 50 Hz

200 to 300 V



Maximum kVA supplied = 300 × 50

= 15 kVA

kVA transferred magnetically (or)

Inductively = 100 × 50 = 5 kVA

kVA transferred conductively

= 200 × 50 = 10 kVA

05.

Sol: **(a)** Let us assume unity power factor load on both the transformers

$$I_T = \frac{500\times10^3}{80\times1} = 6250\text{ A}$$

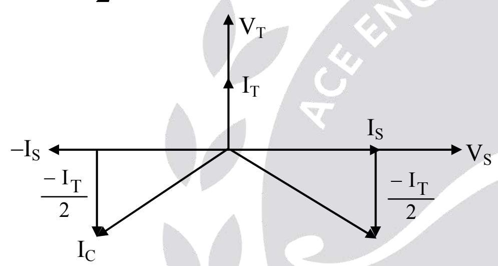
Teaser transformer primary current=I_{TP}

$$I_{TP} = 1.155 \times 6250 \times \frac{80}{6600} = 87.5\text{ A}$$

$$I_s = \frac{800\times10^3}{80\times1} = 10000\text{ A}$$

$$I_{BC} = 10000 \times \frac{80}{6600} = 121.21$$

$$I_B = I_{BC} - \frac{I_A}{2}$$



$I_B = 121.21 - j\,43.75$

$= 128.86\ \angle{-19.846}$

$I_c = -\,I_{BC} - \frac{I_A}{2}$

$= -\,121.21 - j\,43.75$

$= 128.86\ \angle{-\,160.153}$

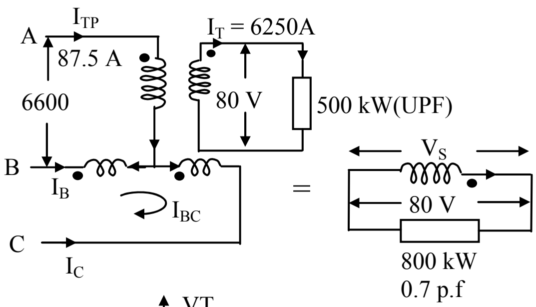
(b) Let us assume 500 kW load on teaser secondary

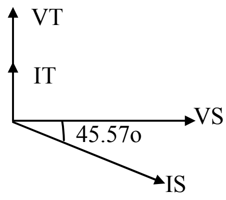
$$I_T = \frac{500\text{kW}}{80\times1} = 6250\text{ A.}$$

(UPF on teaser secondary load)

Teaser transformer primary current = I_{TP}

$$I_{TP} = 6.25 \times 1.155 \times \frac{80}{6600} = 87.5\text{ A}$$





Secondary side

Main Transformer secondary current = I_s

$$I_{secondary} = I_s = \frac{800}{80\times0.7} = 14285.7\text{A}$$

Main Transformer primary current = I_{BC}

$$I_{BC} = 14285.7 \times \frac{80}{6600}$$

$= 173.160$ A

$$I_B = I_{BC} - \frac{I_A}{2}$$

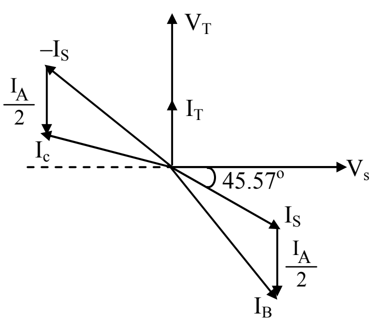
$= 173.160\ \angle{-\,45.57} - j\ \frac{87.5}{2}$

$= 206.68\ \angle{-54.09^o}$

$$I_c = -\,I_{BC} - \frac{I_A}{2}$$

$= (173.160\angle -\,45.59) - j\,43.75$

$= 145.185\ \angle 146.607$



06.

Sol: Power = 4 kVA

$W_0 = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \frac{60}{200\times0.7} = 0.428$

(a) $I_w = I_0\cos\phi_0 = 0.3$ A

$I_\mu = I_0\sin\phi_0 = 0.632$ A

(b) Efficiency = ?

$$\%\,\eta = \frac{x\times kVA\times\cos\phi}{x\times kVA\times\cos\phi + W_i + x^2W_{cu}}$$

$W_i = 60$ W

$W_{cu} \propto I^2$

$I_{\text{full-load}}$ current $= \frac{4000}{400} = 10$ A

$\frac{W_{cu2}}{21.6} = \left(\frac{10}{6}\right)^2$

$W_{cu2} = 60$ W

$$\%\eta = \frac{4\times10^3\times1}{4\times10^3+60+60}\times100 = 97.08\%$$

(c) $\cos\phi = 1$

From short circuit data of high voltage side

$Z_{Sc} = \frac{V_{SC}}{I_{SC}} = \frac{9}{6} = 1.5\ \Omega$

$R_{SC} = \frac{W_{SC}}{I_{SC}^2} = 0.6\ \Omega$

$X_{SC} = 1.374\ \Omega$

Voltage Drop = $I_2R_{02}\cos\phi \pm I_2X_{02}\sin\phi_2$

$I_2 = \frac{P}{V} = \frac{4000}{400} = 10$A

Voltage drop for UPF

$= 10 \times 0.6 \times 1 + 10 \times 1.374 \times 0$

= 6 V

Secondary terminal voltage

$= E_2 - \text{Drop}$

$= 400 - 6 = 394$ V

Voltage drop for 0.8 lag

$= 10 \times 0.8 \times 0.6 + 10 \times 1.374 \times 0.6$

$= 13.04$ V

Secondary terminal voltage (V_2)

$= E_2 - \text{Drop}$

$= 386.96$ V

Voltage drop for 0.8 lead

$= 10\times0.8\times0.6 - 0\times1.374\times0.6$

$= -3.44$V

Secondary terminal voltage (V_2)

$= E_2 - \text{Drop}$

$= 403.44$V

07.

Sol: $I_0 = 0.64$ A, $W_0 = 700$ W

$I_w = ?$ $\quad I_\mu = ?$

$\cos\phi = \frac{700}{2400\times0.64} = 0.455$

$I_w = I_0\cos\phi_0 = 0.2916$ A

$I_\mu = I_0\sin\phi_0 = 0.569$ A

08.

Sol: $V_d = 1000$ V

$I_0 = 3.0$ A

$\cos\phi_0 = 0.5$ lag

If V = 400 V, $I_0 = ?$

pf = ?, Power i/p = ?

$W_0 = V_1I_0\cos\phi_0 = 1000 \times 3 \times 0.5$

$= 1500$ W

No load power will not charge It’s 1500 W

No load power factor also won’t change

$\cos\phi_0 = 0.5$ lag

$I_0\cos\phi_0 = \dfrac{1500}{400} = 3.75$

$I_0 = \dfrac{3.75}{0.5} = 7.5$ A

09.

Sol: a) Transformers T_1 and T_2 in parallel are shown in fig. 1.

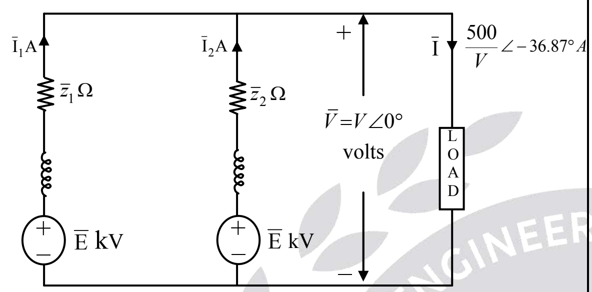


Fig. 1

The load voltage (assumed to be the rated secondary voltage of each of the transformers) is shown in the fig. as V kV.

i) per unit impedance of T_1

$= (1.5 + j6)/100.$

Base impedance $T_1 = V(1000)/(300/V)$

$= (10V^2/3)\ \Omega.$

Actual impedance of $T_1 = \bar{Z}_1$

$= \dfrac{(1.5 + j6)}{100}\dfrac{10V^2}{3}$

$= 0.2062\ V^2\angle 75.96°\ \Omega$

ii. Since T_1 and T_2 actually deliver (192 + j117) kVA and (210 + j184) kVA respectively,

$$\frac{\bar{V}\bar{I}_1^*}{\bar{V}\bar{I}_2^*} = \frac{\bar{I}_1^*}{\bar{I}_2^*} = \frac{192 + j117}{210 + j184} = 0.805\angle -9.87°$$

Hence $\bar{I}_1 / \bar{I}_2 = 0.805\angle 9.87°$

But from the fig, $\bar{I}_1\bar{Z}_1 = \bar{I}_2\bar{Z}_2$. So

$$\left(\frac{\bar{I}_1}{\bar{I}_2}\right) = \left(\frac{\bar{Z}_2}{\bar{Z}_1}\right) = 0.805\angle 9.87°$$

iii. $\bar{Z}_1 = 0.2062V^2\angle 75.96°\ \Omega$. So

$\bar{Z}_2 = 0.166V^2\angle 85.83°\ \Omega$

$= V^2(0.012 + j0.1656)\ \Omega$

When T_2 is delivering rated kVA at 0.8 pf lag, its voltage regulation is

$$\frac{400}{V}\frac{(V^2)}{V}\frac{[(0.012\times 0.8 + 0.1656\times 0.6)]100}{1000}$$

$= 4.3584\%.$

Maximum load without overloading:

(b) Rated currents of transformers 1 and 2 are $I_{r1} = (300/V)$ A and $I_{r2} = (400/V)$ A respectively.

The rated current impedance drops of the two transformers can be calculated to be 61.8 V and 66.4 V respectively (in magnitude).

As the load current I increases, I_1 and I_2 both increase, I_1Z_1 always remaining equal to I_2Z_2. For some I, say I_L, let $I_1 = I_{r1}$. Then $I_1Z_1 = 61.8$ V volts $= I_2Z_2$. Transformer 1 is fully loaded while transformer 2 is not yet at its full load. But any further increase of I will take I_1 beyond I_{r1} and transformer 1 will be overloaded. Hence I_L is the total load current which can be delivered without overloading any transformer.

Calculation of I_L:

$I_1 = I_{r1} = (300/V)$ A

$I_2 = (61.8V)/Z_2 = (372.3/V)$ A

Ignoring the phase difference between $\overline{I}_1$ and $\overline{I}_2$ (which will be small),

$I_L = (I_1 + I_2)$

$= (672.3/V)$ A.

Corresponding load kVA = 672.3.

At 0.9 pf lag, the load in kW will be 672.3 0.9 = 605.1 kW.

10.

Sol:

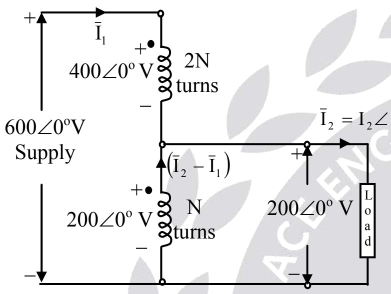


Fig. 1

(The transformer is assumed to be ideal. It has no resistances, no leakage lreactances, and no core losses. Magnitizing reactance is infinite).

For working as a 600V/200 V autotransformer, the windings have to be connected with dots as shown in fig. 1.

200 I_2 = 25000 (given). Hence I_2 = 125 A.

At 0.8 lag pf.

Load current $\overline{I}_2 = 125\angle -36.87°$ A

From transformer theory, and the dot convention, $\overline{I}_1(2N) = (\overline{I}_2 - \overline{I}_1)N$. Hence

Current in the hv winding = $\overline{I}_1 = (\overline{I}_2 / 3)$

$= (125/3)\angle -36.87°$ A

Current in the lv winding = $(\overline{I}_2 - \overline{I}_1)$

$= (250/3)\angle -36.87°$ A.

The transformer kVA rating is 400 (125/3)

= 16.67 kVA

(It can also be found as (load voltage 200 V)(load current I_2 = 250/3 A).

11.

Sol: **1. Assumptions:**

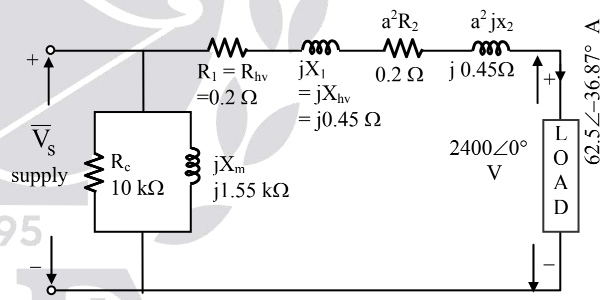
1.1. Primary means the hv winding.

1.2. R_c & X_m are specified ref hv. (Only then will core losses and magnetizing current have values reasonable for a 150-kVA transformer).

1.3. The approximate equivalent circuit is used, where the R_c–X_m parallel branch is shifted to be directly across the supply terminals.

1.4. The load voltage is assumed to be the rated value.

2. Equivalent circuit ref hv:



$$a = \frac{\text{hv turns}}{\ell\text{v turns}} = 10$$

a^2R_2 = leakage resistance of the ℓv winding ref hv= 0.45 Ω

a^2x_2 = leakage reactance of the ℓv winding ref hv = 0.45 Ω

Load voltage ref hv = 2400 V. Its phase angle is arbitrarily chosen as zero.

Fig.1

3. Analysis:

Rated load current ref hv $= \dfrac{150\times 10^3}{2400}$ =62.5 A.

This current lags the load voltage by $\cos^{-1}(0.8) = 36.87°$ as shown in fig.1.

3.1. Voltage regulation:

From fig.1, we have, (by KVL)

$\overline{V}_s = 2400\angle 0° + 62.5\angle -36.87°(0.4 + j0.9)$

$= 2453.9\ \angle 0.7°.$

Voltage regulation is then given by

$\dfrac{2453.9 - 2400}{2400} 100\% = 2.24\%$

Note:

1. Using the approximate expression,

regulation $= \dfrac{I(r_{eq}\cos\theta + x_{eq}\sin\theta)}{V} 100\%$

We get regulation $= \dfrac{62.5(0.4\times 0.8 + 0.9\times 0.6)}{24}$

$= 2.24\%$

The error is scarcely noticeable and the approximate expression is simpler to use.

2. Equivalent circuit ref ℓv could have been used equally well and with the same result.

3.2 Efficiency:

Output = 150×0.8 = 120 kW

Copper losses = $62.5^2 \times 0.4$ = 1562.5 W

Core loss = 602.1 W . Input =122.2 kW.

Efficiency = 98.2%

Ans: (a) 2.24% (b) 98.23%

12.

Sol: 1. Circuit:

Transformer 1: (T_1)

Impedance ref ℓv $= \left(\dfrac{230}{2300}\right)^2 1.84\angle 84.2°$

$= 0.0184\angle 84.2°\Omega$

Transformer 2: (T_2)

Impedance ref ℓv

$lv = \left(\dfrac{225}{2300}\right)^2 0.77\angle 82.5°\ \Omega$

$= 0.0074\ \angle 82.5°\ \Omega.$

Let a common voltage $\overline{E}$ be applied to the hv sides of both the transformers. Since all impedances are shifted to the ℓv sides, the induced emfs on the ℓv sides are

$T_1 : \overline{E}\left(\dfrac{230}{2300}\right) = 0.1\overline{E}$

$T_2 : \overline{E}\left(\dfrac{225}{2300}\right) = 0.0978\ \overline{E}$

The circuit diagram of connections is shown in fig.1.

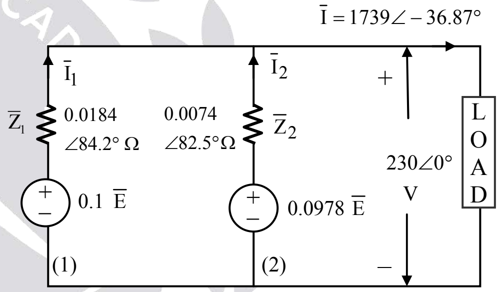


Fig.1

2. Solution with simplifying approximations:

If the **difference in turns ratios is neglected,** the two sources of fig.1 have the same value. Then we have

$I_1 Z_1 = I_2 Z_2$ (magnitudes)

Again, if **we neglect the phase difference between $\overline{I}_1$ & $\overline{I}_2$** (which will be small),

$\overline{I}_1, \overline{I}_2$ & $\overline{I}$ are in phase.

Then $I_1 + I_2 = 1739$ and

$I_1 (0.0184) = I_2 (0.0074)$

Solving, I_1 = 499 A and I_2 = 1240 A.

Power delivered by $T_1 = 230 \times 499 \times 0.8$

$= 91.82$ kW.

Power delivered by $T_2 = 230 \times 1240 \times 0.8$

$= 228.2$ kW.

The answers do not quite agree with answers given.

2. Solution without any simplifying approximations:

$0.1\bar{E} - 0.0184\angle 84.2° \bar{I}_1 = 230\angle 0°$ …… (1)

$0.0978\bar{E} - 0.0074\angle 82.5° \bar{I}_2 = 230\angle 0°$ ….(2)

$\bar{I}_1 + \bar{I}_2 = 1739\angle -36.87°$ …….. (3)

The 3 unknows can be solved from the above 3 equations.

We get $\bar{I}_1 = 661.7 \angle -50.5°$A and

$\bar{I}_2 = 1107 \angle -28.77°$A.

Power delivered by T_1

$= 230 \times 661.7 \cos 50.5° = 96.81$ kW.

Power delivered by T_2

$= 230 \times 1107 \cos 28.77°$

$= 223.2$ kW.

13.

Sol: The question consists of two parts:

1. Back-to-back 'load' test on two mesh-star 3-phase transformers;
2. Temperature rise of a transformer during its operation. The two parts will be discussed separately.

Back-to-back test:

1.1 Back-to-back test on any electrical equipment needs two separate units of the same equipment, with identical ratings. Currents which would flow in either of these units when the unit is separately loaded using an actual external load, are made to flow in both the units, **without using any actual load.** Thus full-load conditions can be simulated in both the units.

1.2. **The advantages and disadvantages of this method of testing:**

The advantages are,

a. an actual load, (which can be costly when the ratings of the units are large), is not needed.

b. Since no actual load is used, load power is not wasted during testing.

Still, full load conditions are simulated for each device, and its performance characteristics such as temperature rise can be studied. The disadvantage of this method is that two devices of identical ratings are needed. (However, this may not be a major problem in a large organization).

2. Back-to-back test on two separate delta-star 3-phase tranformers of identical ratings, circuit diagram of connections:

1.2.1. Circuit:

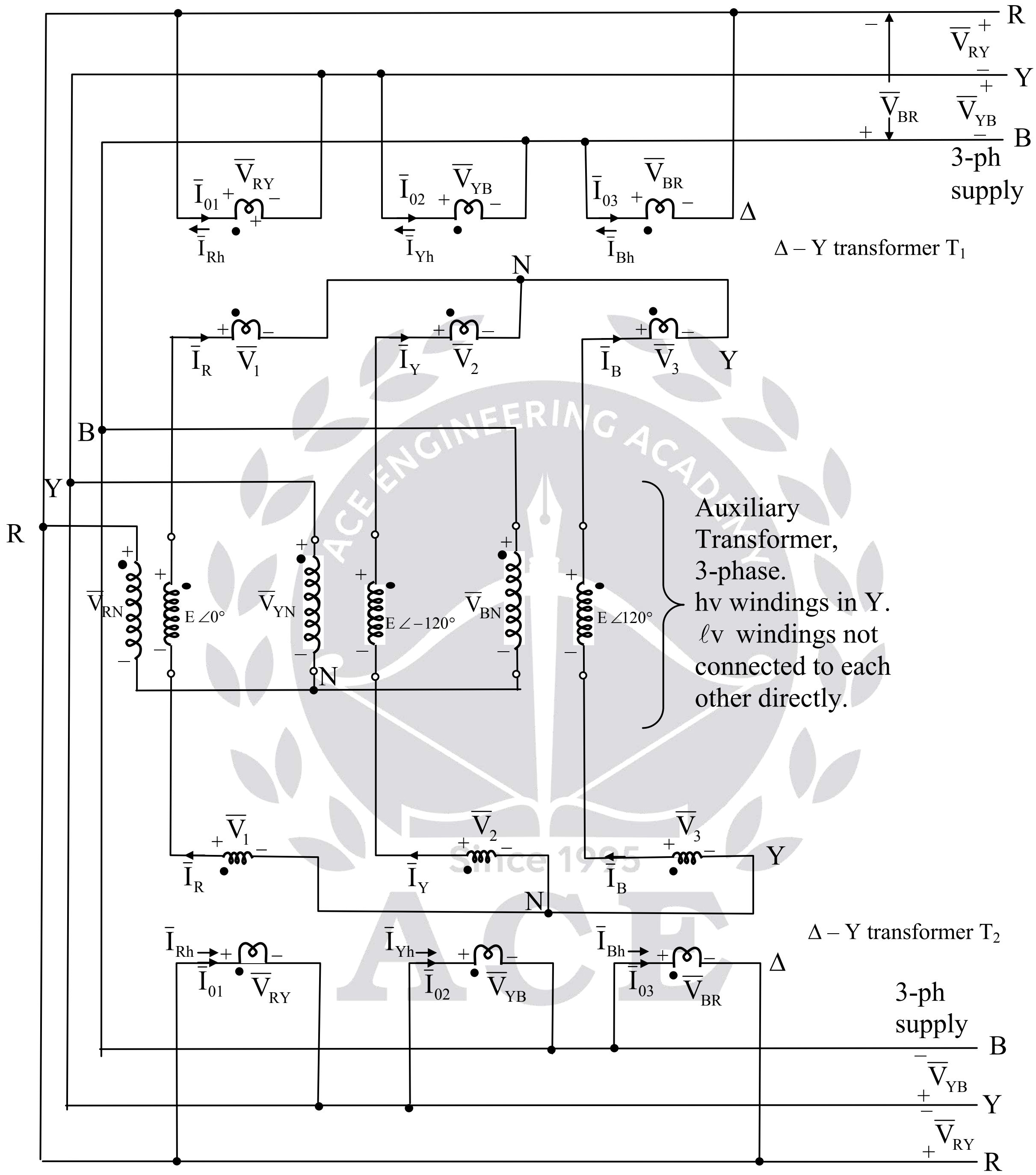


Fig.1.

2.2. Description:

(a) T_1, T_2 : Two 6600 V/420V, Δ-Y, 300 kVA transformers, under test.

(b) $\overline{V}_{RY} = 6600\angle 30°\ \text{V}$, $\overline{V}_{YB} = 6600\angle -90°\ \text{V}$,

$\therefore\ \overline{V}_{BR} = 6600\angle 150°\,\text{V}$.

(c) $\overline{V}_{RN} = \dfrac{6600}{\sqrt{3}}\angle 0°$, $\overline{V}_{YN} = \dfrac{6600}{\sqrt{3}}\angle -120°$,

and $\overline{V}_{BN} = \dfrac{6600}{\sqrt{3}}\angle 120°\ \text{V}$.

(d) E depends on the turns ratio chosen for the phases of the auxiliary transformer.

(e) $\overline{V}_1 = \dfrac{420}{\sqrt{3}}\angle 30°$, $\overline{V}_2 = \dfrac{420}{\sqrt{3}}\angle -90°$,

and $\overline{V}_3 = \dfrac{420}{\sqrt{3}}\angle 150°\,\text{V}$.

(f). $\overline{Z}$ = impedance of each phase of the transformers T_1&T_2, ref ℓv.

(g). Since the entire system is assumed to be balanced, the three neutrals marked N in fig.1 are at the same potential. (They can be joined together if desired).

2.3 Operation of the circuit:

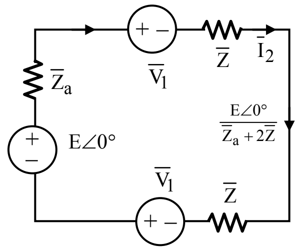
(a). The Δ - connected primaries of T_1 &T_2 draw no-load currents

$\bar{I}_{01} = I_0\angle(30° - \theta_0)$,

$\bar{I}_{02} = I_0\angle(-90° - \theta_0)$ and

$\bar{I}_{01} = I_0\angle(150° - \theta_0)$.

Here, $\theta_0 = \tan^{-1}\dfrac{R_c}{X_m}$. ($R_c$ is the coreloss component of resistance & X_m is the magnetizing reactance of each phase of (T_1 & T_2). $\bar{I}_{01}, \bar{I}_{02}$ and $\bar{I}_{03}$ are shown in fig. 1. There are no corresponding currents in the star-connected secondaries of T_1 & T_2.



$\overline{Z}_a$ = impedance of the auxiliary transformer / ph referred to ℓv.

Induced emfs are represented by sources.

Fig.2

A current $\dfrac{E\angle 0°}{\overline{Z}_a + 2\overline{Z}}$ flows through the R-phase secondaries of T_1 & T_2. Define $\bar{I}_R = \dfrac{E\angle 0°}{\overline{Z}_a + 2\overline{Z}}$. $\bar{I}_R$ is shown in fig.1.

Similarly currents $\bar{I}_Y = \dfrac{E\angle -120°}{\overline{Z}_a + 2\overline{Z}}$ and $\bar{I}_B = \dfrac{E\angle 120°}{\overline{Z}_a + 2\overline{Z}}$ flow through the other secondary phases of T_2 & T_3. $\bar{I}_Y, \& \bar{I}_B$ are also shown in fig.1.

E is so chosen that $\bar{I}_R, \bar{I}_Y, \& \bar{I}_B$ have a magnitude of $\left(\dfrac{300\times 10^3}{\sqrt{3}\ 420}\right)$A..

(Rated ℓv line or phase current of T_1 and T_2)

(b) Using the amp-turn balance requirement of transformers, and dot convention, hv currents $\bar{I}_{Rh}, \bar{I}_{Yh}, \& \bar{I}_{Bh}$ corresponding to $\bar{I}_R, \bar{I}_Y, \& \bar{I}_B$ are shown in fig.1. The magnitude of these hv currents is $\left(\frac{420}{\sqrt{3}\ 6600}\right)$ times the magnitude of $\bar{I}_R, \bar{I}_Y, \& \bar{I}_B$, and each hv current is in phase with the corresponding ℓv current.

(c). Thus in T_1 & T_2 each hv carries the no load current as well as the rated hv load current, while each ℓv carries the rated ℓv load current. This is precisely what they carry when they are separately loaded using actual loads.

Full load conditions are thus simulated for each transformer and temperature rise ~ time can be studied. Losses can be measured and efficiency as well as voltage regulation can also be found.

Temperature rise of a transformer from given numerical data:

1. The given 200 kVA transformer is assumed to be a single-phase one.
2. At full load and upf, output = 200 × 1 = 200 kW.

Losses = $200\left(\frac{1-0.98}{0.98}\right)$ kW = 4082 W

= $W_c + W_{cu}$. (W_c : corelosses

W_{cu}: copper losses).

Given that $W_{cu} = 3\ W_c$,

W_c = 1020.5 W and W_{cu} = 3061.5W.

With 20% overload, both the hv and ℓv currents increase by 1.2 times, and copper losses now become (3061.5) ×1.2^2= 4408.6 W. core losses remain unchanged. Total losses now become (4408.6+1020.5) = 5429.1 W.

Steady state temperature rise (as given by temperature rise of oil)

$$= 45 \times \frac{5429.1}{4082} = 59.85°.$$

With 20% over load (at upf), output = 200×1.2 =240 kW.

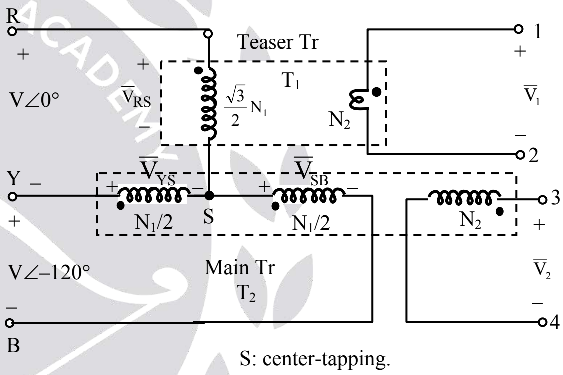
Input = (240+5.429) = 245.429 kW.

$$\text{Efficiency} = \frac{240}{245.429} = 97.79\%.$$

14.

Sol: 1. 1-phase,scott-connected transformers: circuit diagram and analysis:

Circuit:



S: center-tapping.

$\bar{V}_{BR}$, with '+' at B, will automatically be V∠120°

Fig.1.

Analysis: Let the transformers T_1 & T_2 be ideal. (no losses & no leakage flux). Using KVL, we have,

$$\bar{V}_{RS} - \bar{V}_{YS} = V\angle 0° \ \ldots\ldots\ (1)$$

$$\bar{V}_{YS} + \bar{V}_{SB} = V\angle -120° \ \ldots\ldots\ (2)$$

$$\bar{V}_{YS} = \bar{V}_{SB} \ \ldots\ldots\ (3) \text{ (transformer property)}$$

$$\therefore\ \bar{V}_{YS} = \frac{V}{2}\angle -120°$$

$$\bar{V}_{RS} = V\angle 0° + \frac{V}{2}\angle -120° \ \ldots\ldots\ (4)$$

$\bar{V}_{RS}$ is shown in the phasor diagram of fig.2.

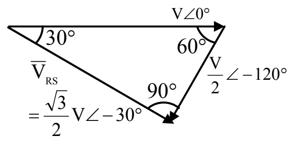


Fig.2

$$\therefore\ \bar{V}_1 = \frac{N_2}{\left(\frac{\sqrt{3}}{2}\right)N_1}\frac{\sqrt{3}}{2}V\angle-30° = \frac{N_2}{N_1}V\angle-30°$$

Applying transformer properties to the main transformer, we have $\bar{V}_2 = \frac{N_2}{N_1}V\angle-120°$

$\bar{V}_1$ & $\bar{V}_2$ **constitute a balanced, 4-wire 2-phase supply.**

In the problem, loads are connected on the 2-phase side and supply given on the 3-phase side. It is assumed that the loads are at upf. The circuit diagram of fig.1 is repeated in fig.2, with the loads added, and given numerical values substituted.

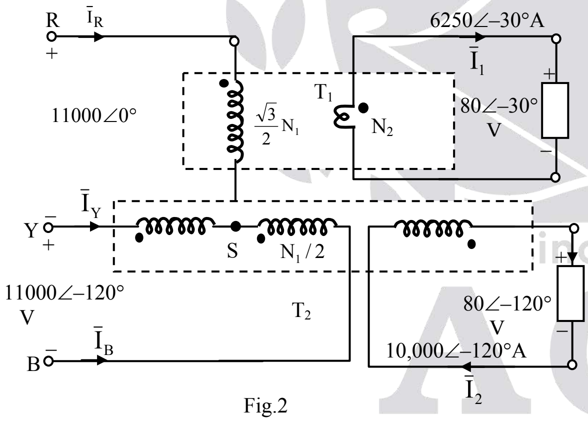


Fig.2

V = 11000 volts = 3-phase supply line voltage.

Voltage applied to the furnaces

$$= \frac{N_2}{N_1}V = 80V.$$

$$\therefore \frac{N_2}{N_1} = \frac{80}{11000}$$

Load on transformer 1 = 500 kW at upf.

Hence $\bar{I}_1 = \frac{500\times10^3}{80}\angle-30°$ = 6250 ∠–30° A.

Similarly, $\bar{I}_2 = 10{,}000\angle-120°$ A.

Current $\bar{I}_R$ (using transformer property & dot convention):

$$= 6250\times\frac{N_2}{\frac{\sqrt{3}}{2}N_1}\angle-30°$$

$$= \frac{2}{\sqrt{3}}6250\times\frac{80}{11000}\angle-30°$$

$$= 52.49\angle-30°\text{ A.}$$

Currents $\bar{I}_Y$ & $\bar{I}_B$:

$$\bar{I}_Y\frac{N_1}{2} - \bar{I}_B\frac{N_1}{2} = \bar{I}_2N_2$$

[Note that $\bar{I}_Y$ & $(-\bar{I}_B)$ are the currents which enter their respective windings at dots. $\bar{I}_2$ leaves its winding at dot].

$\therefore$ $[\bar{I}_2, \bar{I}_Y, \& -\bar{I}_B]$ must be in phase.

$$\bar{I}_Y - \bar{I}_B = \bar{I}_2 2\left(\frac{N_2}{N_1}\right)$$

$$= (10{,}000\angle-120°)\times2\times\frac{80}{11000}$$

$$= \frac{1600}{11}\angle-120° = 145.46\angle-120°.$$

By KCL, $\bar{I}_R + \bar{I}_Y + \bar{I}_B = 0$.

$\Rightarrow$ $\bar{I}_Y + \bar{I}_B = -\bar{I}_R = -52.49\angle-30°$.

$\therefore$ $\bar{I}_Y = 72.73\angle-120° - 26.25\angle-30°$

$= 77.3\ \angle-139°$

Thus

$\bar{I}_R = 52.49\angle-30°A$, $\bar{I}_Y = 77.3\angle-139°A$,

and $\bar{I}_B = 78.03\angle81°A$.

($\bar{I}_R + \bar{I}_Y + \bar{I}_B$ must be zero)

15.

Sol: 1. In this problem, resistance and leakage reactance of the "primary" are given to be significantly larger than the corresponding values of the "secondary". Hence primary is taken to be the hv winding and secondary the ℓv winding.

2. Resistances and leakage reactances:

Rated phase voltage of primary= $\frac{11000}{\sqrt{3}}$ V

(Primaries connected in star, and line voltage rating = 11 kV).

Rated phase voltage of secondary = 3300 V (secondaries connected in delta, and line voltage rating = 3300V).

Turns ratio of each phase [ℓv turns/ph)/(hv turns/ph)] = $\frac{3300\sqrt{3}}{11000}$

$\therefore$ hv resistance/ph ref ℓv = $\left(0.3\times\sqrt{3}\right)^2\times 0.375$

= 0.10125 Ω

Similrly, hv reactance/ph ref ℓv = 0.27× 9.5

= 2.565 Ω

Total resistance and reactance/ph ref ℓv are 0.19625 Ω and 4.565 Ω respectively.

3. Circuit:

Shorting the secondary terminals implies a balanced operation. Hence to calculate currents, it is sufficient if we consider one phase of the 3-phase Y/Δ transformer. The circuit is given in fig.1.

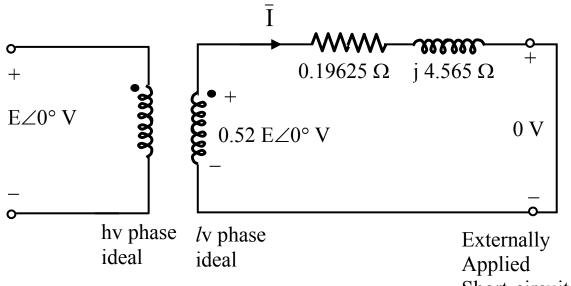


Fig.1

4. Calculation of hv applied voltage & power input:

It is given that I in fig.1

$$= \frac{1000\times10^3}{3\times3300} = \frac{10^4}{99}\text{A}$$

$$\text{Also, } I = \frac{0.52E}{\sqrt{\left(0.1965^2+4.565^2\right)}} = 0.113\,E$$

Hence E, the hv applied voltage/ph

$$= \frac{10^4}{99\times0.202} = 887.6 \text{ V.}$$

Applied line voltage on hv (primary side)

$\sqrt{3}$ 887.6 = 1.53 kV

Power input under these conditions

= $3(I^2 r_{eq})$ (core losses are neglected Under this reduced voltage operation).

$$= \frac{3\times10^8\times0.19625}{99^2} = 6007 \text{ W.}$$

16.

Sol: From the given data:

1. Load current:

$$\sqrt{3}\ V_L I_L \cos\theta = \sqrt{3},\ (33000)\ \ I_L(0.8)$$

$$= 1500\times10^3.$$

$\therefore I_L$, the line current on the load side = 32.8 A.

2. Turns ratio:

Phase voltage on ℓv = 11,000 V. (ℓv is Δ-connected).

Phase voltage on hv $= \frac{33,000}{\sqrt{3}}$ V (hv is star connected).

$$\frac{\text{hv turns/ph}}{\ell\text{v turns/ph}} = \frac{N_{hv}}{N_{\ell v}} = \frac{33,000}{\left(11,000\sqrt{3}\right)} = \sqrt{3} = a.$$

3. resistances and reactances of hv phase ref ℓv phase:

$r_{\ell v} = \ell$v resistance/ph = 0.5 Ω

$\Rightarrow r'_{\ell v} = a^2 r_{\ell v} = 1.5\ \Omega$.

$x_{\ell v} = \ell$v reactance/ph=6.5 Ω

$\Rightarrow x'_{\ell v} = a^2 x_{\ell v} = 19.5\ \Omega$.

4. Line impedances:

It is assumed that transmission lines are between the star-connected hv side & the load. Hence each line impedance ref hv = (10+j6) Ω.

5. Equivalent circuit/ph:

This is shown in fig.1. It is assumed that tappings are provided on the hv side (which is common). The specified supply and load voltages are used.

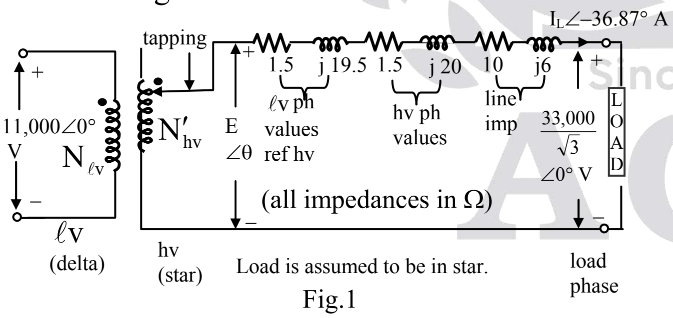


Fig.1

6. Analysis:

Applying KVL on hv side,

$$(13 + j45.5)\,(32.8\angle-36.87°) + \frac{33,000}{\sqrt{3}}\angle 0° = E\angle\theta \quad \ldots\ldots (1)$$

Using eq.1, we can find both E & θ. In this problem, only E is required.

We get E = 20310.85 V.

7. Determination of tapping:

We have $\frac{N_{hv}}{N_{\ell v}} = \sqrt{3}$ and

$$\frac{N'_{hv}}{N_{\ell v}} = \frac{20310.85}{11,000} = 1.846.$$

$$\therefore \frac{N'_{hv}}{N_{hv}} = \frac{1.8464}{\sqrt{3}} = 1.066$$

If N_{hv} = 100 turns, $N'_{hv} = 106.6$ turns. The tapping must increase the hv turns by 6.6%.

Note: When tapping is changed, circuit parameters will be changed. This is not taken into account here.

17.

Sol: 1. Problem specifies that load is connected to the ℓv terminals. Side to which load is connected is conventionally called secondary. Hence in this problem ℓv is the secondary.

2. The approximate equivalent circuit ref hv will be used. From the given data,

2.1. $R_{chv} = \frac{(11000)^2}{1100} = 110\ k\Omega$

Core loss component of resistance ref hv.

2.2. Full load current ref hv

$$= \frac{110\times10^3}{11000} = 10\,A.$$

2.3 $Z_{eqhv} = \frac{500}{10} = 50\,\Omega.$

$10^2\ r_{eqhv}$ = 1000 W ⇒ r_{eqhv} = 10 Ω.

$x_{eqhv} = \sqrt{z^2_{eqhv} - r^2_{eqhv}} = \sqrt{2400}$ = 49 Ω.

2.4. Actual load current = 250 ∠ –36.87° A (ref ℓv, assuming the phase angle of the load voltage as zero).

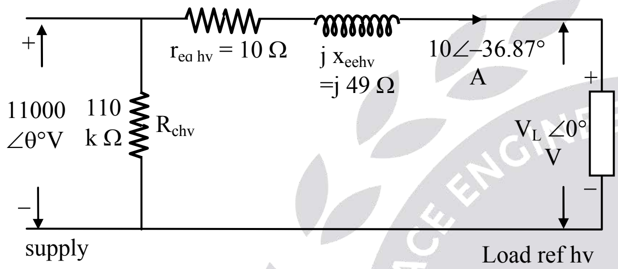
Load current ref hv

$$= 250 \times \left(\frac{440}{11000}\right) = 10\,A \text{ (in magnitude)}.$$

As a phasor, load current ref hv

= 10∠–36.87°A.

3. The equivalent circuit ref hv is shown in fig.1



The load voltage magnitude V_L is unknown.
Its phase angle is assumed as zero.
The supply voltage (on the hv side) magnitude is given. Its phase angle θ is unknown.

Fig.1.

4. **Calculation of V_l and efficiency:**

Applying KVL in fig.1,

$V_L\angle 0° + (10\angle -36.87°)\,(10 + j49) = 11000\angle\theta$ ……(1)

This equation involving complex quantities can be solved to find the unknowns V_L & θ.

$V_{L,}$ the load voltage ref hv, is obtained as 10,626.03 V. Actual load voltage (on ℓv) will be (440 / 11000) (10626.03) = 425 V.

Power output = 425 × 250 × 0.8 = 85 kW.

Copper loss in transformer = 10^2 (10) = 1000 W.

Core loss = 1100 W

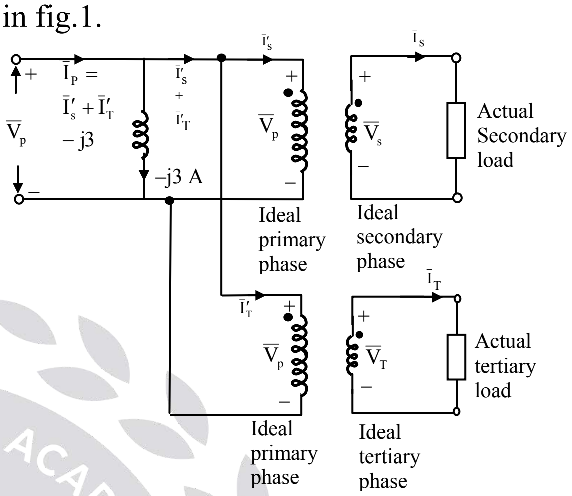
Total loss = 2100 W ⇒ Input = 87.1 kW

⇒ Efficiency = 97.6%.

18.

Sol: 1. Equivalent circuit per phase:

An equivalent circuit per phase of the star/star/mesh 3-phase transformer is shown in fig.1.



Problem specifies no losses Hence core loss component of resistance R_c is assumed ∞. Winding resistances r_p, r_s & r_T are assumed zero. Problem does not state anything about leakage, but leakage reactances are not given. Hence x_p, x_s & x_T are assumed zero.

Fig.1

2. Calculation of parameters from the given data:

2.1. Secondary:

(a). Secondary is star-connected. Hence phase voltage $V_s = \frac{1000}{\sqrt{3}}$V. $\bar{V}_s$ is assumed to be $\frac{1000}{\sqrt{3}}\angle 0°$. (phase angle zero is arbitrarily selected). Polarity of $\bar{V}_s$ in fig.1. is arbitratily chosen. Polarity of $\bar{V}_P$ can also be arbitrarily chosen. But if it is chosen as shown in fig.1, it must be in phase with $\bar{V}_s$ as per dot convention.

$$\therefore \bar{V}_p = \frac{11000}{\sqrt{3}}\angle 0°\text{ V.}$$

(b). $\frac{1000}{\sqrt{3}} I_s = \frac{600\times10^3}{3} \Rightarrow I_s = 200\sqrt{3}$ A .

If we choose to write $\bar{I}_s = 200\sqrt{3}\angle 36.87°$ A, its reference direction shown in figure is **not arbitrary**. It must be a current being delivered by $\bar{V}_s$, as in fig. (1).

From transformer properities, $\bar{I}'_s$, (with ref. direction as shown) $= \bar{I}_s \frac{1000}{11000}$

.

2.2. Tertiary:

Tertiary is delta-connected (as is usual).

$\therefore$ Tertiary phase voltage V_T = 400 V. If we choose to write $\bar{V}_T = 400\angle 0°$, then using the dot convention, its polarity in the figure must be as shown.

$$400 I_T \cos\theta = \frac{150}{3} = 50\,\text{kW}$$

$$\Rightarrow I_T = \frac{125}{\cos\theta}\text{A.}$$

Let $\bar{I}_T = \frac{125}{\cos\theta}\angle\theta$ A. where θ is unknown

Its ref direction is chosen in the figure as for $\bar{I}_s$.

$$\bar{I}'_T = \bar{I}_T\left(\frac{400\sqrt{3}}{11{,}000}\right) = \frac{50\sqrt{3}}{11\cos\theta}\angle\theta.$$

Its ref. direction must also be as shown in the figure (since $\bar{I}'_T$ & $\bar{I}_T$ are to be in phase).

2.3. KCL:

Now, using KCL, $\bar{I}_p = -j3 + \bar{I}'_S + \bar{I}'_T \Rightarrow$

$$\bar{I}_p = 3\angle -90° + \frac{200\sqrt{3}}{11}\angle -36.87° + \frac{50\sqrt{3}}{11\cos\theta}\angle\theta$$

$$= \frac{\sqrt{3}}{11}\left[210 - j\left\{\frac{33}{\sqrt{3}} + 120 - 50\tan\theta\right\}\right] \ldots (1)$$

3. Calculation of I_P & I_T :

It is given that the primary power factor (cosϕ where $\bar{I}_p = I_P\angle -\phi$) is 0.82.

$\therefore$ ϕ = 34.92°.

$$\text{From eq.(1), } \tan\phi = \frac{\frac{33}{\sqrt{3}} + 120 - 50\tan\theta}{210}$$

But tan ϕ = tan 34.92° = 0.698.

Solving, tan θ = – 0.1506 ⇒ θ = –8.564° ⇒ cos θ = 0.989.

I_p is found to be 38.93 A, and I_T = 126.4 A.

[Note: If only I_p is required, it can be found as follows: secondary output /ph $\frac{600\times0.8}{3} = 160$ kW

Tertiary output/ph $= \frac{150}{3} = 50$ kW .

Since there are no losses, primary input/ph = 210 kW.

Primary power factor = 0.82(lag).

$$\therefore \frac{11}{\sqrt{3}} I_p(0.82) = 210.$$

$$I_p = \frac{210\sqrt{3}}{0.82\times11} = 40.3\,\text{A}$$

However, to find $\bar{I}_T$, we need to use the equivalent circuit].

19.

Sol: From the given data,

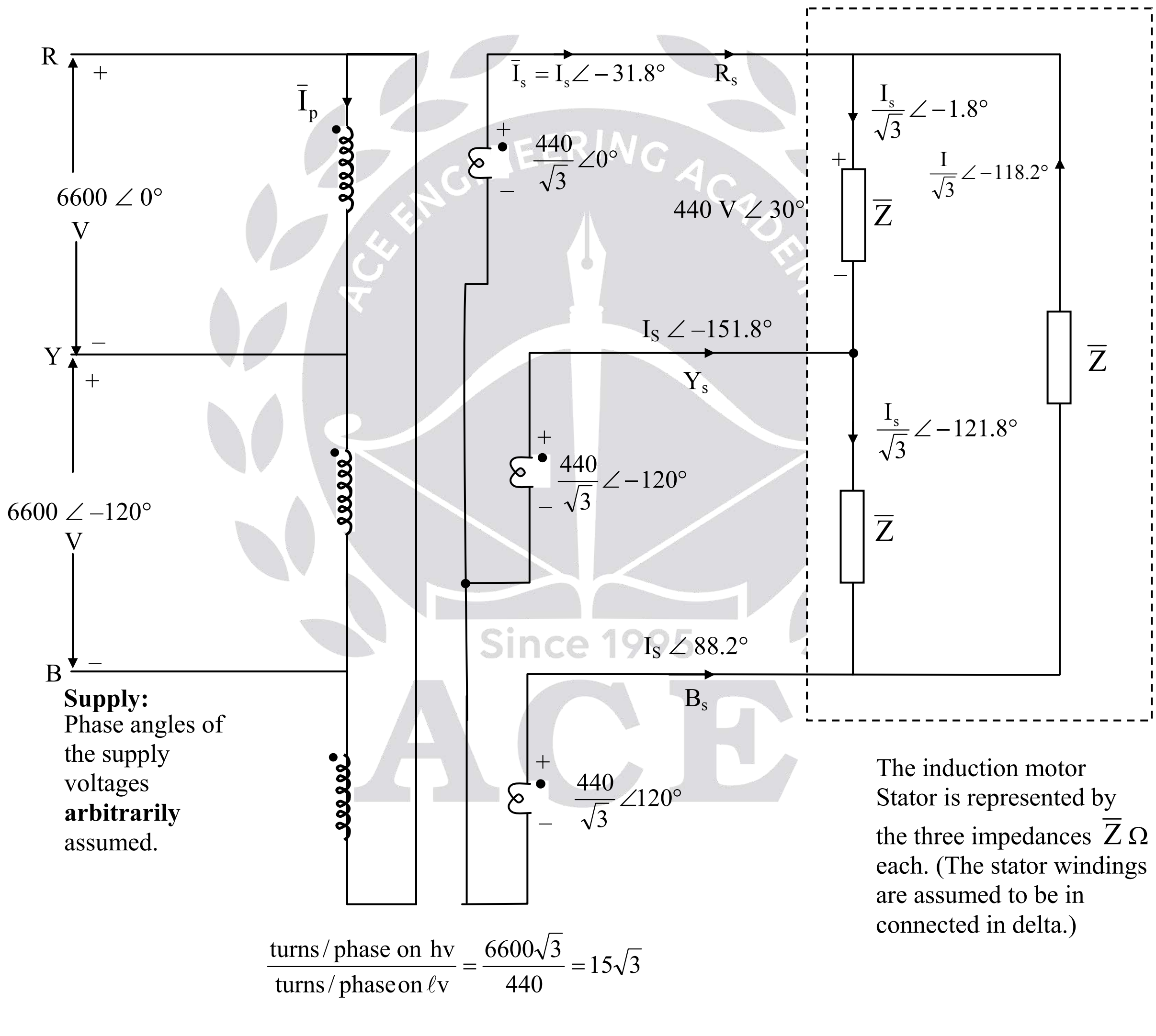
1. 3-phase input to the induction motor = 3-phase output of the transformer = (50 ×746)/(0.9) W.

This is also equal to $\sqrt{3}\ V_L I_S \cos\theta$

$= \sqrt{3}\ 440\ I_s\ (0.85)$ W.

Here V_L & I_S are line values. θ is the phase angle between phase voltage & phase current. Since cos θ is given as 0.85 (lagging assume) θ = 31.8°, Therefore I_S = 64 A.

2. The problem asks for currents. Since the currents are ac, their phase angles should also form part of the answer. For clarity, a complete 3-phase circuit is shown in fig.1.



$$\frac{\text{turns/phase on hv}}{\text{turns/phase on } \ell\text{v}} = \frac{6600\sqrt{3}}{440} = 15\sqrt{3}$$

Fig.1

3. Any hv side phase current can now be readily written using transformer properities.

With the directions shown for $\bar{I}_p$ & $\bar{I}_s$ in fig.1, $\bar{I}_p$ & $\bar{I}_s$ must be in phase.

$\therefore \bar{I}_p = \frac{64}{(15\sqrt{3})}\angle -31.8°$

$= \mathbf{2.46 \angle{-31.8°}\ A}$

$\bar{I}_s$(from fig.1) $= \mathbf{64\angle -31.8°\ A}$

2. DC Machines

Solutions for Objective Practice Questions

01. Ans: 1609 (Range: 1600 to 1610)

Sol: Given data:

P = 8, A = 8 (∵ lap wound)

No. of conductors, Z = 60 × 22

$\frac{\text{Pole arc}}{\text{pole pitch}} = 0.64$ m

Bore diameter (D) = 0.6 m

Length of the pole shoe (l) = 0.3 m

Flux density (B) = 0.25 Wb/m^2

E_g = 400 V

Speed N = ?

Pole pitch $= \frac{2\pi r}{P} = \frac{\pi D}{P} = \frac{\pi \times 0.6}{8}$

Pole arc = 0.64 × pole pitch

Area of pole shoe A = pole arc × l

$= 0.64 \times \frac{\pi \times 0.6}{8} \times 0.3$

= 0.0452 m^2

Generated emf (E_g) $= \frac{\phi Z N_p}{60A}$

$E_g = \frac{BAZNP}{60A}$

$400 = \frac{0.25 \times 0.0452 \times 60 \times 22 \times N \times 8}{60 \times 8}$

⇒ N = 1609 rpm

02. Ans: 6.9 (Range: 6 to 7)

Sol: Given data:

V_t = 250 V, ϕ = constant

R_a = 0.1 Ω

P_1 = 100 kW and P_2 = 150 kW

Case (i):

$P_1 = V_t I_{a1}$

100 k = 250 × I_{a1}

⇒ $I_{a1} = 0.4 \times 10^3$ A

$E_{g1} = V_t + I_{a1} \times R_a$

= 250 + 400 × 0.1

= 290 V

Case (ii):

$P_2 = V_t I_{a2}$

$150 \times 10^3 = 250 \times I_{a2}$

⇒ I_{a2} = 600 A

$E_{g2} = V_t + I_{a2} R_a$

= 250 + 600 × 0.1

= 310 V

From emf equation of generator, $E_g \propto N$

$\Rightarrow \frac{N_2}{N_1} = \frac{E_{g2}}{E_{g1}} = \frac{310}{290}$

% Increase in speed $= \frac{N_2 - N_1}{N_1} \times 100$

$= \left(\frac{N_2}{N_1} - 1\right) \times 100$

$$= \left(\frac{310}{290} - 1\right) \times 100$$

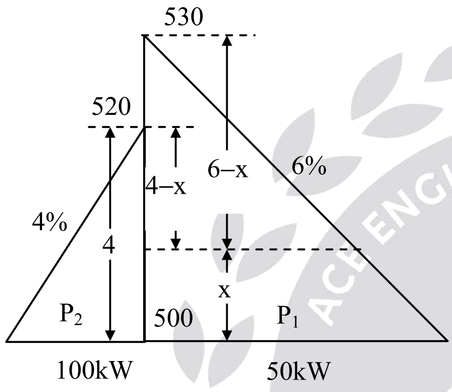
$$= 6.9\%$$

03. Ans: (a)

Sol: Given data: Load current = 250 A

Generator (A): 50 kW, 500 V, % drop = 6%

Generator (B): 100 kW, 500 V, % drop = 4%



The no-load voltage of generator (A)

$$= 500 + \left(\frac{6 \times 500}{100}\right)$$

$$= 530 \text{ V}$$

$$\text{Generator (B)} = 500 + \left(\frac{4 \times 500}{100}\right)$$

$$= 520 \text{ V}$$

$$\frac{P_1}{50k} = \frac{6 - x}{6}$$

$$\Rightarrow P_1 = \frac{50 \times 10^3}{6}(6 - x)$$

$$\frac{P_2}{100k} = \frac{4 - x}{4}$$

$$\Rightarrow P_2 = \frac{100 \times 10^3}{4}(4 - x)$$

Total load power,

$$250 \times 500 = \frac{50 \times 10^3}{6}(6 - x) + \frac{100 \times 10^3}{4}(4 - x)$$

$$\Rightarrow 125 = \frac{50}{6}(6 - x) + \frac{100}{4}(4 - x)$$

$$\Rightarrow \quad 5 = \frac{(6 - x)}{3} + (4 - x)$$

$$x = \frac{3}{4}$$

Load shared by generator (A),

$$P_1 = \frac{50 \times 10^3}{6}\left(6 - \frac{3}{4}\right)$$

$$= 43.75 \text{ kW}$$

$$\therefore \text{ Current I} = \frac{43.75}{500} = 87.5 \text{ A}$$

Load shared by generator (B),

$$P_1 = \frac{100 \times 10^3}{6}\left(4 - \frac{3}{4}\right)$$

$$= 81.25 \text{ kW}$$

$$\therefore \text{ Current I} = \frac{81.25}{500} = 162.5 \text{ A}$$

04. Ans: (d)

Sol: Terminal voltage = 500 + x% of 500

$$= 500 + \frac{3}{4}\text{ \% of } 500$$

$$= 503.75 \text{ V}$$

05. Ans: (b)

Sol: $$\omega_m = \frac{V_t}{\sqrt{K_a C T_e}} - \frac{r_a + r_s}{K_a C}$$

Speed is directly proportional to applied voltage.

06. Ans: 100 Ω

Sol: Given data:

$V_t = 200$ V, $R_f = 100\ \Omega$ and $\phi \propto \dfrac{I_f}{1+0.5I_f}$

$N_0 = 1000$ rpm and N_1=1500 rpm

R_e = ?

We know that $\phi \propto \dfrac{1}{\text{speed}(N)}$

$$\frac{\phi_0}{\phi_1} = \frac{N_1}{N_0}$$

$$\Rightarrow \frac{\phi_0}{\phi_1} = \frac{1500}{1000} = 1.5$$

Field current $I_{f0} = \dfrac{V_t}{R_f} = \dfrac{200}{100} = 2A$

$$\phi \propto \frac{I_f}{1+0.5I_f}$$

$$\frac{\phi_0}{\phi_1} = \left(\frac{I_{f0}}{I_{f1}}\right)\left(\frac{1+0.5I_{f1}}{1+0.5I_{f0}}\right)$$

$$1.5 = \left(\frac{2}{I_{f1}}\right)\left(\frac{1+0.5I_{f1}}{1+0.5\times 2}\right)$$

$1.5I_{f1} = 1 + 0.5I_{f1}$

$\therefore\ I_{f1} = 1$ A

Field current $I_f \propto \dfrac{1}{R_f}$

$$\frac{I_{f0}}{I_{f1}} = \frac{R_f + R_e}{R_f}$$

$\Rightarrow R_f + R_e = 2\ R_f$

$\Rightarrow R_e = 100\ \Omega$

07. Ans: 32. 95 Nm

Sol: Given data: 500 V, 60 hp, 600 rpm

$R_a = 0.2\ \Omega$ and $R_{sh} = 250\ \Omega$

Losses = $\left(\dfrac{1}{\eta} - 1\right)$ output power

$= \left(\dfrac{1}{0.9} - 1\right) \times 60 \times 746$

= 4973.33 watt

Input power = $\dfrac{\text{Output power}}{\text{efficiency}} = \dfrac{60\times 746}{0.9}$

= 49.7333.33 W

Source current $I_s = \dfrac{49733.3}{500} = 99.46$ A

Field current $I_f = \dfrac{500}{250} = 2A$

Armature current $I_a = 99.46 - 2 = 97.46$ A

Shunt copper los, $I_f^2 R_{sh} = 4 \times 250$

= 1000 W

Armature copper loss, $I_a^2 R_a = (97.46)^2 \times 0.2$

= 1900 W

Loss torque ∝ (Friction and windage loss + core loss)

∴ Loss power (P_l) = 4973 – 1000 – 1900

= 2073 W

Loss torque (τ) = $\dfrac{60 \times P_\ell}{2\pi \times N}$

$= \dfrac{60 \times 2073}{2\pi \times 600}$

= 32.99 Nm

08. Ans: 166.67 Ω

Sol: Speed ∝ field resistance

$$\frac{N_1}{N_2} = \frac{R_{sh}}{R_{sh} + R_e}$$

$$\frac{600}{1000} = \frac{250}{250 + R_e}$$

$\Rightarrow R_e = 166.67\ \Omega$

09. 83.26%

Sol: Loss torque ∝ speed?

Loss torque = $\frac{1000}{600}\times 32.99$

= 54.98 Nm/rad

Power = $\frac{2\pi NT}{60} = \frac{2\pi\times 1000}{60}\times 54.98$

= 5757.49 watt

Armature copper loss = $(I_a)^2R_a$

= $(97.46)^2 \times 0.2$

= 1900 watt

Now, field current $I_f = \frac{V}{R_{sh}+R_e}$

$= \frac{500}{250+166.67} = 1.2$ A

Field copper loss = $I_f^2 R_{sh\ (total)}$

= $(1.2)^2 \times 416.67$

= 600 watt

Total power loss in the machine

= 5757 + 1900 + 600

= 8257 watt

Input power = [97.46 + 1.2] × 500

= 49330 W

$\%\eta = \frac{\text{Input power} - \text{losses}}{\text{Input power}}\times 100$

$= \frac{49330-8257}{49330}\times 100 = 83.26\%$

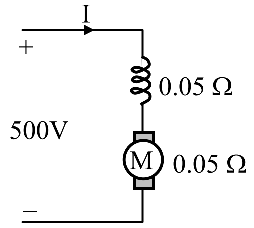
10. Ans: -0.062 Ω (update key)

Sol: Given data: 500 V DC, R_a=0.05, R_{se} = 0.05

(i) 1800 Nm, 800 rpm, 90%

(ii) 900 Nm, 1200 rpm, 80%

Case (i):



Shaft torque = 1800 Nm/rad

Speed = $800\times\frac{2\pi}{60}$ rad/sec

Output = $1800\times\frac{800\times 2\pi}{60}$ watt

= 48000 π

Input power = $\frac{48000\pi}{0.9}$ = 167551.6 watt

Total losses = 167551.6 – 150796.4

= 16755.15 watt

Input current I = $\frac{167551.6}{500}$ = 335.1 A

$E_b = V - I(R_a + R_{se})$

= 500 – 335.1(0.1)

= 466.49 V

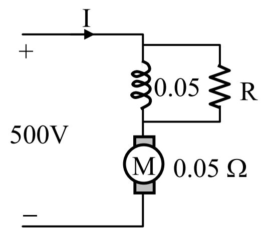
Copper losses = $(335.1)^2 \times 0.1$

= 11229.2 watt

Other losses = 5526 watt

Loss torque = $\left(\frac{5526}{\frac{1800\times 2\pi}{60}}\right)$ ………… (1)

Case (ii)



Shaft torque = 900 Nm/rad

Speed = $1200\times\frac{2\pi}{60}$ rad/sec

Output = $900\times1200\times\frac{2\pi}{60}$

= 900 × 40π

= 36000π watt

Input power = $\frac{36000\pi}{0.8}$ = 141371.7 watt

New total loss = 141371.7 – (36000×π)

= 28274.33 watt

I = $\frac{141371.7}{500}$ = 282.7

New copper loss

$$=(282.7)^2\left[\frac{0.05\times R}{0.05+R}+0.05\right]$$

Other losses (W_l)

$$= 28274.3-(282.7)^2\left[\frac{0.05\times R}{0.05+R}+0.05\right]$$

Loss torque = $\frac{W_\ell}{\left(\frac{1200\times2\pi}{60}\right)}$ Nm/rad

……..(2)

Given, loss torque unchanged.

From (1) and (2)

$$\frac{5526}{\left(1800\times\frac{2\pi}{60}\right)}=\frac{W_\ell}{\left(1200\times\frac{2\pi}{60}\right)}$$

$3W_l = 2 \times 5526$

$W_l = 3684$

$$28274.3-(282.7)^2\left[\frac{0.05R}{0.05+R}+0.05\right]=3684$$

$$24590=(282.7)^2\left[\frac{0.05R}{0.05+R}+0.05\right]$$

0.05 + R = 0.194 R

R = – 0.062 Ω

11. Ans: (a)

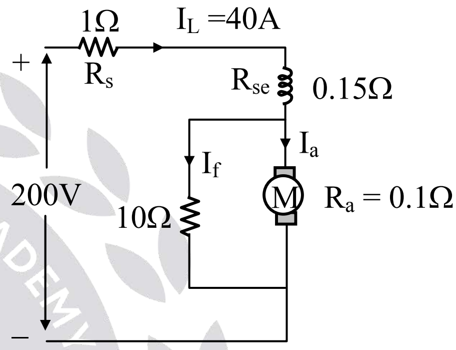
Sol: Given data: N_1 = 1500rpm I_L = V0A

Before modification:

$E_{b1} = V - I_L(R_a + R_{se})$

= 200 – 40 (0.1+0.15)

=190 V



After modification, shown in figure:

$I_f = \frac{V_{sh}}{10}$

Where V_{sh} = 200 – I_L (R_s +R_{se})

= 200– 40 (0.1+0.15)

= 154V

Therefore, I_f = 15.4 A

Now $E_{b_2} = V - I_aR_a - I_L(R_s + R_e)$

= 200 – (40 –15.4)0.1 –40(1.15)

= 151.54V

We know that,

$$\frac{E_{b_1}}{E_{b_2}}=\frac{N_1}{N_2}$$

$$\Rightarrow N_2=\frac{151.54\times1500}{190}$$

=1196.3 rpm

12. Ans: 3

Sol: Given data:

$V_t = 250V, I_{a_1} = 700A, I_{a_2} = 350A,$

$r_a = 0.05\ \Omega$

We know that, $\alpha^n = \frac{r_a}{R_1}$

$\Rightarrow$ Where, $\alpha = \frac{I_{a_2}}{I_{a_1}} = \frac{350}{700}$

$$R_1 = \frac{V_t}{I_{a_1}} = \frac{250}{700}$$

$$\left(\frac{350}{700}\right)^n = \left(\frac{0.05\times 700}{250}\right)$$

Take logarithm on both sides,

$n \log_{10}^{0.5} = \log_{10}^{0.14}$

$n = 2.83 \approx 3$

The number of resistance elements, n = 3

13(a). Ans: 532.85 rpm

Sol: $V_t = 250V$, $N_r = 500rpm$, $R_a = 0.13\Omega$ and $I_a = 60A$

In motring mode,

$E_b = V - I_aR_a = 250 - 60\ (0.13) = 242.2V$

Full load torque $= \frac{E_aI_a}{\omega_r}$

$$= \frac{E_bI_a \times 60}{2\pi N_r}$$

$$= \frac{242.2\times 60\times 60}{2\pi\times 500}$$

$= 277.5$ Nm

In regenerative braking mode,

$E_g = V + I_aR_a = 250 + 60(0.13) = 257.8V$

Given, $\tau_b = \tau_{F\ell}$

$$\Rightarrow\ 277.5 = \frac{(E_gI_a)\times 60}{2\pi N_r}$$

$$\Rightarrow\ N_r = \frac{257.8\times 60\times 60}{277.5\times 2\pi}$$

$= 532.28$ rpm

13(b). Ans: 2.6 Ω

Sol: Plugging current limited to 3pu

$$I_a = \frac{V_1 + E_b}{R_a + R_{ext}}$$

$$3\times 60 = \frac{250 + 242.2}{0.13 + R_{ext}}$$

$$\Rightarrow R_{ext} = 2.604\Omega$$

13(c). Ans: – 177 rpm

Sol: $\tau_{br} = \tau_{F.L}, \tau \alpha I_a$

$\therefore I_{br} = I_{max} = 60A$

$$I_{br} = \frac{V_t + E_b^1}{R_a + R_{ext}}$$

$$60 = \frac{250 + E_b^1}{(0.13 + 2.604)}$$

$$\Rightarrow E_b^1 = -85.96V$$

$$\frac{E_b}{E_b^1} = \frac{N_0}{N^1}$$

$$\Rightarrow N^1 = \frac{-85.96\times 500}{242.2} = -177.95rpm$$

13(d). Ans: –129 V

Sol: Rated torque and half the rated speed i.e 250rpm

$E_b \propto$ speed

$$\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2}$$

$$\Rightarrow E_{b_2} = \frac{250}{500} \times 242.2$$

$$= 121.1V$$

$$E_{b2} = V - I_a R_a$$

$$\Rightarrow V = 121.1 + 60(0.13)$$

$$= 128.9V$$

To run the motor in reverse direction, the polarity of supply voltage must be change i.e –129V

14. Ans: (c)

Sol: In region (1) , Power (+ve) = $T_e \times$ Speed

In region (3) , Power (+ve) = $-T_e \times -$ Speed

Therefore, region (1) and (3) comes under motering mode.

In region (2), Power (–ve) = $T_e \times$ (– Speed)

In region (4), Power (–ve) = $-T_e \times$ Speed

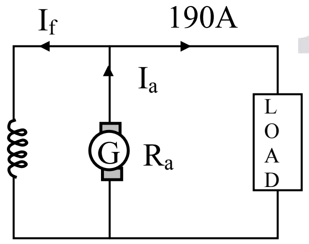
Therefore, region (2) and (4) comes under regenerating mode.

15. Ans: (b)

Sol: Given data, 250V, I_L = 190A, R_{sh} = 125Ω and

Stray loss = constant loss = 800W

At η = 90 %:



Losses in machine

$$= \left(\frac{1}{\eta} - 1\right) \times \text{Out put power}$$

$$= \left(\frac{1}{0.9} - 1\right) \times 190 \times 250 = 5277.7 \text{ Watt}$$

Stray loss +Shunt Copper loss+Armature Copper loss = 5277.7

$$\text{Shunt copper loss} = \frac{V^2}{R_{sh}} = \frac{250^2}{125} = 500W$$

∴ Armature copper loss,

$$\left(I_2^2 R_a\right) = 5277.7 - 800 - 500$$

$$I_a^2 R_a = 3977.7$$

Where, $I_a = I_L + I_f$

$$= 190 + \left(\frac{250}{125}\right) = 192A$$

$$\therefore R_a = \frac{3977.7}{192^2} = 0.1079\Omega$$

16. Ans: (a)

Sol: At maximum effeiciency,

Variables losses = Constant losses

$I_a^2 R_a$ = Stray loss+shunt copper loss

= 800+500

$$I_a^2 = \frac{1300}{0.107} \Rightarrow I_a = 110.2A$$

Solutions for Conventional Practice Questions

01.

Sol: Supply voltage, V = 230V, R_a= 0.5Ω, R_f= 230Ω

(i) Shunt motor at no-load:

N_1=1000rpm,

Input current, I_L=3A

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{230} = 1A$$

For motor, $I_{a1} = I_L - I_{sh} = 3 - 1 = 2A$

Back emf, $E_{b1} = V - I_{a1}.R_a$

$= 230 - (2\times0.5) = 229V$

Shunt motor at full-load:

Full load current, $I_L = 23A$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{230} = 1A$$

For motor, $I_{a2} = I_L - I_{sh} = 23 - 1 = 22A$

Back emf, $E_{b2} = V - I_{a2}.R_a$

$= 230 - (22\times0.5) = 219V$

We know, motor speed, $N \propto \frac{E_b}{\phi}$

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$\therefore$ Full load speed,

$$N_2 = 1000 \times \frac{219}{229} \times \frac{\phi_1}{0.98\phi_1}$$

$= 975.84$ rpm (Ans.)

(ii) Find full load torque

We know power = Torque × speed

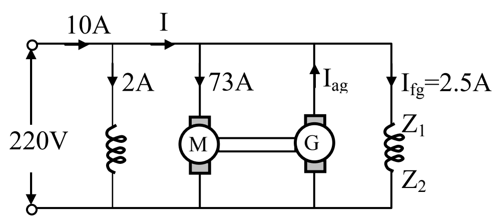
$$\Rightarrow \quad P = T \times \frac{2\pi N}{60}$$

$$\Rightarrow \quad 5000 = T \times \left(\frac{2\pi\times975.84}{60}\right)$$

Full-load torque, T = 48.93 N-m

02.

Sol: Given data:



$V_t = 220V$, $I_{fg} = 2.5A$

$I_{fa} = 2A$, $I_{am} = 73A$

$R_{ag} = R_{am} = 0.05\Omega$

$I_L = 10A$

$I_{ag} = I_{am} + I_{fg} + I_{fa} - I_L$

$= 73 + 2 + 2.5 - 10 = 67.5$

$\therefore$ Armature circuit loss in generator

$= (67.5)^2 \times 0.05 = 227.81W$

Armature circuit loss in motor $= (73^2 \times 0.05)$

$= 266.45W$

Power drawn from the supply (Excluding the field loss in two machines) $= V_tI$

$I = I_L - I_{fg} - I_{fm}$

$= 10 - 2.5 - 2 = 5.5A$

$P_{loss} = 220 \times 5.5 = 1210W$

$\therefore$ No-load rotational loss in both the machines

$$W_0 = V_tI - r_a\left(\left(I_{ag}^2 + I_{am}^2\right)\right)$$

$= 220 \times 5.5 - 0.05\,[(67.5)^2 + (73)^2]$

$= 715.735W$

$\therefore$ No-load rotational loss for each machine

$$= \frac{W_0}{2} = 357.86 \text{ W}$$

For generator, output $= V_tI_{ag}$

$= 220 \times 67.5 = 14850$

$$\text{Total losses, } W_g = \frac{W_g}{2} + V_tI_{f2} + I_g^2r_a$$

$W_g = 357.86 + 220 \times 2.5 + 227.815$

$= 1135.675W$

$$\therefore \eta_g = \left[1 - \frac{\text{loss}}{\text{losses} + \text{output}}\right]\times100$$

$$= \left[1 - \frac{1135.67}{1135.67 + 14850}\right]\times100 = 92.89\%$$

For motor, input = $V_t(I_{am} + I_{fm})$

$= 220(73+2) = 16500W$

Total losses, $W_m = \frac{W_0}{2} + I_{am}^2 r_a + V_t I_{fg}$

$= 357.86 + 266.45 + 220 \times 2$

$= 1064.31$

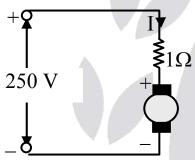
$\eta_m = \left[1 - \frac{\text{losses}}{\text{Input}}\right]$

$= \left(1 - \frac{1064.31}{16500}\right) = 93.371\%$

03.

Sol: Given data: V = 250 V, P = 4, Z = 180,

$\phi = 3.75$ mWb/Amp, $R_a = 1\ \Omega$, $\tau_L = 10^{-4}N^2$



$\phi = 3.75 \times I \times 10^{-3}$ Wb

$E = \frac{\phi ZNP}{60\,A} = \frac{3.75 \times I \times 10^{-3} \times 180 \times N \times 4}{60 \times 4}$

$= 0.01125\ NI$ ………. (1)

From circuit

$250 = I + E$

$= I + 0.01125\ NI$

$\tau = \frac{PZ}{2\pi A} \times \phi I = 10^{-4}\ N^2$

$\Rightarrow \frac{180}{2\pi}\left(3.75 \times I \times 10^{-3}\right) I = 10^{-4}\ N^2$

$\Rightarrow 0.10742 I^2 = 10^{-4}\ N^2$

$\Rightarrow N = 32.77 \times I$

From (1)

$250 = I + 0.01125[32.77]I^2$

$\Rightarrow 0.3687 I^2 + I - 250 = 0$

$\therefore I = 24.71$ A

We know that $N = 32.77 \times I$

$= 32.77 \times 24.71$

$= 809.746$ rpm

04.

Sol: Given,

$r_a = 0.04\ \Omega$, $r_f = 110\Omega$, $V_f = 230V$

$V_t = 230V$

Core and Mechanical loss (P_c) = 960W

Machine = separately excited generator

Field copper losses ($P_{cu,f}$) = $\frac{V_f^2}{r_f} = \frac{(230)^2}{110}$

($P_{cu,f}$) = 480.91W

(a) In a dc separately excited generator, Constant losses are field copper losses and mechanical losses.

Variable losses are armature copper losses.

Constant losses = $P_{cu,f} + P_C$

= 480.91+960W

= 1440.91W

At maximum efficiency,

Constant losses = variable losses

$1440.91 = I_a^2 r_a$

$I_a^2\ (0.04) = 1440.91$

$I_a = 189.8A$

(b) Power output at max efficiency is

$P_0 = V_t I_L$

$P_0 = 230 \times 189.8$ [$I_L = I_a$ for a separately excited generator]

$P_0 = 43653.22W$

Efficiency $\eta = \frac{\text{Power output}}{\text{Power output} + \text{Losses}}$

$$= \frac{43653.22}{43653.22+1440.91+1440.91}$$

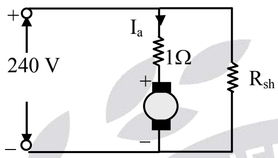
$\eta = 93.8\%$

05.

Sol: Given, $E_b = 230$ V, $V_t = 240$ V and $I_a = 40$ A

(i) Since, $E_b < V_t$ the machine will work as a DC shunt motor.

(ii) From KVL,



$E_b = V - I_aR_a$

$$\Rightarrow R_a = \frac{E_b - V}{I_a}$$

$$= \frac{240-230}{40}$$

$= 0.25\ \Omega$

(iii) $P = \omega_m \times T_{em}$

$$\Rightarrow E_bI_a = \frac{2\pi N}{60} \times T_{em}$$

$$\Rightarrow T_{em} = \frac{230\times40\times60}{2\times\pi\times1200}$$

$= 73.181$ N-m

(iv) If the load is thrown off, $E_b = 240$ V.

We know that $E_b \propto N$

$$\therefore \frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1}$$

$$\Rightarrow N_2 = \frac{E_{b2}\times N_1}{E_{b1}}$$

$$= \frac{240\times1200}{230}$$

$= 1252.17$ rpm

3. Synchronous Machines

Solutions for Objective Practice Questions

01. Ans: (a)

Sol: The direction of rotation of conductor is opposite to direction of rotation of rotor. So by applying Flemings right hand rule at conductor '1' we can get the direction of current as ⊗.

02. Ans: (c)

Sol: As the two alternators are mechanically coupled, both rotors should run with same speed. $\Rightarrow Ns_1 = Ns_2$

$$\Rightarrow \frac{120f_1}{p_1} = \frac{120f_2}{p_2}$$

$$\Rightarrow \frac{f_1}{f_2} = \frac{p_1}{p_2}$$

$$\Rightarrow \frac{p_1}{p_2} = \frac{50}{60} = \frac{5}{6} = \frac{10}{12}$$

$\Rightarrow p_1:p_2 = 10:12$

Every individual magnet should contains two poles, such that number of poles of any magnet always even number.

G_1: p = 10, f = 50 Hz

$\Rightarrow N_s = 600$ rpm **(or)**

G_2: p = 12, f = 60 Hz

$\Rightarrow N_s = 600$ rpm

03. Ans: (c)

Sol: m = 3 slots/pole/phase

$$\text{Slot angle } \gamma = \frac{P\times180}{s} = 20°$$

$$K_d = \frac{\sin n\frac{m\gamma}{2}}{m\sin\frac{n\gamma}{2}}$$

$$K_{d3} = \frac{\sin\frac{3\times3\times20^o}{2}}{3\times\sin\frac{3\times20^o}{2}} = 0.67$$

04. Ans: (b)

Sol: Total Number of conductor = 6 × 180
= 1080

$$f = \frac{NP}{120} = \frac{300\times20}{120} = 50\text{Hz}$$

Number of turns = $\frac{1080}{2} = 540$

N_{ph} (Number of turns (series) (Phase))

$$= \frac{540}{3} = 180$$

Slot angle, $\gamma = \frac{180\times P}{S} = \frac{180\times20}{180} = 20$

and slots/pole/phase, $m = \frac{180}{3\times20} = 3$

Then, breadth factor $K_b = \frac{\sin m\frac{\gamma}{2}}{m\sin\frac{\gamma}{2}}$

$$= \frac{\sin\frac{3\times20}{2}}{3\sin10} = \frac{\sin30^o}{3\sin10^o} = 0.95$$

Hence $E_{Ph} = 4.44\ k_b f N_{ph}\phi$

$= 4.44\times0.95\times50\times180\times25\times10^{-3}$

$= 949.05\text{V} \approx 960\text{ V}$

05. Ans: (d)

Sol: For a uniformly distributed 1-phase alternator the distribution factor

$$(K_{du}) = \frac{\sin(\frac{m\gamma}{2})}{(\frac{m\gamma}{2})\times\frac{\pi}{180}}$$

Where phase spread $m\gamma = 180^0$ for 1-ϕ alternator

$$\therefore\ K_{du} = \frac{\sin 90}{\frac{180}{2}\times\frac{\pi}{180}} = \frac{2}{\pi}$$

The total induced emf E

= No of turns × Emf in each turn × k_p × K_{du}

= T × 2 × k_p × K_{du}

For fullpitched winding $K_p = 1$.

$$\therefore\ E = 2T\times1\times\frac{2}{\pi} = 1.273T\text{ volts}$$

06. Ans: (b)

Sol: $\frac{s}{p} = \frac{48}{4} = 12;$

m = slots / pole / phase = $\frac{48}{3\times4} = 4$

Slot angle $\gamma = \frac{180°}{(s/p)} = \frac{180}{12} = 15°;$

Phase spread $m\gamma = 15\times4 = 60°$

Winding factor ⇒ $K_w = K_p.K_d$ ………. (1)

α = 1 slot pitch = 1 × 15° = 15°

$$K_d = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m.\sin\left(\frac{\gamma}{2}\right)} = \frac{\sin\left(\frac{60°}{2}\right)}{4.\sin\frac{15°}{2}} = \frac{1}{8\text{som}7.5°}$$

$$K_p = \cos\frac{\alpha}{2} = \cos\left(\frac{15°}{2}\right)$$

= cos (7.5°)

∴ From eq (1),

$$K_w = \cos(7.5°)\times\frac{1}{8}\times\frac{1}{\sin(7.5°)}$$

$$= \frac{1}{8}\cot(7.5°)$$

07. Ans: (b)

Sol: emf/conductor = 2V

emf / turn = 4V

Total turns = NT

Total turns / phase $= \frac{NT}{3}$

For 3 – ϕ system mγ = 60°

$$K_d = \frac{\text{Sin}\left(\frac{m\gamma}{2}\right)}{\frac{m\gamma}{2}\times\frac{\pi}{180}} = \frac{\sin\left(\frac{60}{2}\right)}{\frac{60}{2}\times\frac{\pi}{180}} = \frac{3}{\pi}$$

Total induced Emf 'E'

= No.of turns × Emf in each turn per phase

$$= K_d \times 4 \times \frac{NT}{3}$$

$$E = \frac{NT}{3}\times 4\times\frac{3}{\pi}$$

$$E = \frac{4}{\pi}\times NT$$

08. Ans: (c) (update key)

Sol: 4 pole, 50 Hz, synchronous generator, 48 slots.

For double layer winding No. of coils

= No. of slots = 48

Total number of turns = 48 × 10 = 480

For 3-phase winding

Turns/phase $= \frac{480}{3} = 160$

$$K_p = \cos\left(\frac{\alpha}{2}\right) = \cos\left(\frac{36}{2}\right) = 0.951$$

$$K_d = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m\sin\left(\frac{\gamma}{2}\right)}$$

$$\gamma = \frac{4\times 180}{48} = 15^0,$$

$$\therefore K_d = \frac{\sin\left(\frac{60}{2}\right)}{4\sin\left(\frac{15}{2}\right)} = 0.9576.$$

$$E_{ph} = 4.44 K_p K_d \phi f T_{ph}$$

$$E_{ph} = 4.44\times0.951\times0.9576\times0.025\times50\times160$$

$$E_{ph} = 808.68\text{ V}$$

$$E_{L\text{-}L} = 1400.67\text{ V}$$

09. Ans: (c)

Sol: $E_{ph} \propto k_d T_{ph.}$

$$\frac{E_{ph(3-\phi)}}{E_{ph(2-\phi)}} = \frac{K_{d(3-\phi)}.T_{ph(3-\phi)}}{K_{d(2-\phi)}.T_{ph(2-\phi)}}$$

$$K_{d(2-\phi)} = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m\sin\left(\frac{\gamma}{2}\right)}$$

$$= \frac{\sin\left(\frac{90}{2}\right)}{6\sin\left(\frac{15}{2}\right)} = 0.903 \quad \left[\because m = \frac{48}{2\times4} = 6\right]$$

$$T_{ph(2-\phi)} = \frac{480}{2} = 240$$

$$\therefore \frac{E_{ph(3-\phi)}}{E_{ph(2-\phi)}} = \frac{0.9576}{0.903}\times\frac{160}{240}$$

$$= 0.707$$

$$E_{ph(2-\phi)} = \frac{808.68}{0.707}$$

$$= 1143.85$$

$$E_{L-L(2-\phi)} = \sqrt{2}E_{ph(2-\phi)}$$

$$= 1617.65\text{V}.$$

(Or)

Method – 2

For 2 – phase connection

$$T_{ph} = \frac{480}{2} = 240$$

$K_p = 0.95;\ \gamma = 15^0$

$$M = (\text{slot / pole / phase}) = \frac{48}{4\times2} = 6$$

$$K_d = \frac{\sin(90/2)}{6\sin(15/2)} = 0.9027$$

$E_{ph} = 4.44 \times 0.9027 \times 0.951 \times 0.025 \times 50\times 240$

$= 1143.55$ V

$E_{L-L}\ (2-\phi) = \sqrt{2} \times E_{Ph}$

$= \sqrt{2} \times 1143.55$

$= 1617.22$ V

10. Ans: (a)

Sol: To eliminate n^{th} harmonic the winding could be short pitched by $(180^0/n)$. As the winding is short pitched by 36^0 fifth harmonic is eliminated.

11. Ans: (1616)

Sol: EMF inductor 1 - ϕ connection

$$\frac{E_{3-\phi}}{E_{1-\phi}} = \frac{Kd_{3-\phi}\times Tp_{n_3}}{Kd_{3-\phi}\times Tp_{n_1}} = 0.5$$

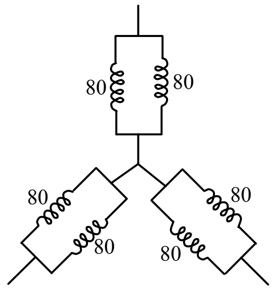
$$E_{1-\phi} = \frac{E_{3-\phi}}{0.5} = \frac{808.68}{0.5} = 1617.36$$

12. Ans: (404 V, 700 V)

Sol: If turns are connected in two parallel paths then

Turns/ph = 160

$$\text{Turns / Ph / Path} = \frac{160}{2} = 80$$



$E_{ph} = 4.44\times0.951\times0.957\times0.025\times50\times80$

$= 404$ V

$E_L = \sqrt{3} \times E_{ph} = 700$ V

13. Ans: (571 V, 808 V)

Sol: If the turns are connected among two parallel paths for two phase connection

$$E_{Phase} = \text{Turns/Ph} = \frac{480}{2} = 240$$

$$\text{Turns/Phase/Path} = \frac{240}{2} = 120$$

$E_{Phase} = 4.44\times0.957\times0.951\times0.025\times50\times120$

$= 571.77$ V

$E_{L-L} = \sqrt{2} \times E_{Phase}$

$= \sqrt{2} \times 571.77$

$E_{L-L} = 808.611$ V

14. Ans: (b)

Sol: Main field is produced by stator so it's stationary w.r.t stator.

For production of torque two fields (Main field & armature field) must be stationary w.r.t. each other. So rotor (armature) is rotating at N_s. But as per torque production principle two fields must be stationary w.r.t each other. So the armature field will rotate in opposite direction to rotor to make. It speed zero w.r.t stator flux.

15. Ans: (d)

Sol: Field winding is an rotor, so main field so produced will rotate at 'N_s' w.r.t stator.

Field winding is rotating, field so produced due to this also rotates in the direction of rotor.

Field produced is stationary w.r.t. rotor.

16. Ans: (a)

Sol: In figure (a), rotor field axis is in leading postion w.r.t stator fileld axis at some load angle, therefore the machine is operating as Alternator.

In figure (b), rotor field axis is in lagging postion w.r.t stator fileld axis at some load angle, therefore the machine is operating as synchronous motor.

In figure (c), rotor field axis is aligned with stator field axis with zero load angle, therefore the machine is operating either as Alternator or as synchronous motor.

17. Ans: (b)

Sol: When state or disconnected from the supply $I_a = 0$, $\phi_a = 0$

Without armature flux, the air gap flux

$\phi_r = \phi_m \pm \phi_a$ =25mwb

With armature flux, the air gap flux

$\phi_r = \phi_m \pm \phi_a$ = 20mwb

So the armature flux is causing demagnetizing effect in motor. Hence the motor is operating with Leading power factor.

18. Ans: (b)

Sol: BD is the field current required to compensate drop due to leakage reactance.

19. Ans: (a)

Sol: Voltage regulation in descending order is

EMF method > Saturated Synchronous impedance method >ASA > ZPF > MMF

20. Ans: (a)

Sol: load angle δ

$$\tan\psi = \frac{V\sin\phi + I_a X_q}{V\cos\phi + I_a R_a}$$

$$= \frac{(0.6)+1(0.5)}{(0.8)+0} = \frac{1.1}{0.8}$$

$\Rightarrow \psi = 53.97^o$

$\delta = \psi - \phi = 53.97 - 36.86^o = 17.11^o$

21. Ans: (b)

Sol: $I_q = I_a\cos\psi$ =1cos(53.97) = 0.588

$I_d = I_a\sin\psi$ = 1.sin(53.97) = 0.808

$E = V\cos\delta + I_qR_a + I_dX_d$

= 1 cos(17.1) + 0.588(0) + 0.808(0.8)

= 1.603pu

22. Ans: (b)

Sol: P.F = UPF $\quad \because \phi = 0$

X_d = 1.2 PU, X_q = 1.0 PU, R_a = 0

V = 1PU , kVA = 1PU, I_a = 1PU

$$\tan\psi = \frac{V\sin\phi + I_a X_q}{V\cos\phi + I_a R_a} = \frac{1\times 0 + 1\times 1}{1\times 1 + 1\times 0}$$

$\therefore \Psi = 45$

$\delta = \Psi - \phi = 45 - 0 = 45^o$

23. Ans: (a)

Sol: Given, P = 2.5 MW, $\cos\phi = 0.8$,

$V_L = 6.6$ kV and $R_a = 0$.

$$X_d = \frac{V_{max}}{I_{min}} = \frac{96}{10} = 9.6\Omega$$

$$X_q = \frac{V_{min}}{I_{max}} = \frac{90}{15} = 6\Omega$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{6.6\times10^3}{\sqrt{3}} = 3810V$$

$$I_L = \frac{P}{\sqrt{3}V_L\cos\phi} = \frac{2.5\times10^6}{\sqrt{3}\times6.6\times10^3\times0.8}$$

$I_L = 273.36A = I_{ph}$

$$\tan\psi = \frac{V\sin\phi + I_aX_q}{V\cos\phi + I_aR_a}$$

$$= \frac{3810\times0.6 + 273.36\times6}{3810\times0.8 + 273.36\times0}$$

$\tan\psi = 1.288$

$\psi = 52.175°$

$\delta = \psi - \phi = 52.175° - 36.86° = 15.32°$.

24. Ans: (c)

Sol: Condition for zero voltage regulation is

$$\cos(\theta+\phi) = \frac{-I_a Z_s}{2V}$$

$$I_a = \frac{P}{\sqrt{3}\times V_L} = \frac{10\times10^3}{\sqrt{3}\times415} = 13.912$$

$Z = (0.4 + j5) = 5.015\angle85.42$

$$V_{Ph} = \frac{415}{\sqrt{3}} = 239.60$$

$$\cos(\theta+\phi) = \frac{-13.912\times5.015}{2\times239.60}$$

$\theta + \phi = 98.39 \Rightarrow \phi = 12.970$

P.f = 0.974 lead

25. Ans: (b)

Sol: Regulation will be maximum when

$\phi = \theta$

$\phi = 85.62$

P.f = $\cos\phi = \cos(85.42)$

$= 0.08$ Lag

26. Ans: (29%)

Sol: Maximum possible regulation at rated condition is

$$E_0^2 = (V\cos\phi + I_aR_a)^2 + (V\sin\phi \pm I_aX_s)^2$$

$I_a = 13.912$

$$E_0 = \sqrt{(239.06\times0.08 + 13.912\times0.4)^2 + (239.06\times0.996 + 13.912\times5)^2}$$

$E_0 = 309.38$ V

$$\%\text{ Regulation} = \frac{E_0 - V}{V}\times100$$

$$= \frac{309.38 - 239.06}{239.06}\times100$$

$= 29.41\%$

27. Ans: – 6.97%

Sol: Regulation at 0.9 p.f lead at half rated condition is when $I_{a_2} = \frac{I_{a_1}}{2} = 6.95$

$$E = \sqrt{(239.06\times0.8 + 6.9562\times0.4)^2 + (239.06\times0.6 - 6.956\times5)^2}$$

E = 222.38 V

$$\%\text{ Regulation} = \frac{E_0 - V}{V}\times100$$

$$= \frac{222.38 - 239.06}{239.06}\times100$$

$= -6.97\%$

28. Ans: 75

Sol: **Given data,** $V_L = 200\sqrt{3}$, S = 3 kVA, X_s = 30 Ω and R_a = 0 Ω.

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{200 \times \sqrt{3}}{\sqrt{3}} = 200\,V$

$S = 3V_{ph}I_{ph} = 3000$

$\Rightarrow I_{ph} = I_a = \frac{1000}{200} = 5\,A$

Internal angle, $\theta = \tan^{-1}\left(\frac{X_s}{R_a}\right) = 90°$

At maximum voltage regulation, θ = ϕ.

Therefore, ϕ = 90° and cosϕ = 0.

Excitation voltage is

$$E_0^2 = (V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_s)^2$$

$$E_0 = \sqrt{(200 \times 0 + 5 \times 0)^2 + (200 \times 1 + 5 \times 30)^2}$$

E_0 = 350 V

$$\%\ \text{Regulation} = \frac{E_0 - V}{V} \times 100$$

$$= \frac{350 - 200}{200} \times 100 = 75\ \%$$

29. Ans: –14.56

Sol: Given data: 25 kVA, 400V, Δ -connected

$$\therefore I_L = \frac{25 \times 1000}{\sqrt{3} \times 400} = 36.08\ A$$

$$\Rightarrow I_{ph} = \frac{36.08}{\sqrt{3}} = 20.83\ A$$

I_{sc} = 20.83A when I_f = 5A

$V_{oc(line)}$ = 360V when I_f = 5A

$$X_s = \left.\frac{V_{oc}}{I_{sc}}\right|_{I_f = \text{given}}$$

$$= \frac{360(\text{phase voltage})}{20.83(\text{phase current})} = 17.28\Omega$$

For a given leading pf load [cosϕ = 0.8 lead]

$$\Rightarrow E_0 = \sqrt{(V\cos\phi + I_ar_a)^2 + (V\sin\phi - I_aX_s)^2}$$

$$= \sqrt{[400 \times 0.8]^2 + [400 \times 0.6 - 20.83 \times 17.28]^2}$$

= 341. volts/ph

$$\text{Voltage Regulation} = \frac{|E| - |V|}{|V|} \times 100$$

$$= \frac{341 - 400}{400} \times 100$$

$$= -14.56\%$$

30. Ans: (a)

Sol: That synchrozing current will produce synchronizing power. Which will demagnetize the M/C M_2 and Magnetize the M/C M_1

31. Ans: (a)

Sol: Excitation of 'M_1' is increased, its nothing but magnetizing the M_1.

So, synchronizing power will come into picture, it will magnetize the M/C M_2 means alternator operating under lead p.f and demagnetize the M/C M_1 means alternator operating under lagging p.f.

32. Ans: (b)

Sol: **Effect of change in steam input (Excitation is kept const):**

- Effect of change in steam input causes only change in its active power sharing but no change in its reactive power sharing. Because the synchronizing power is only the active power.
- If the steam input of machine 1 increases

Machine 1	Machine2
$kVAR_1$ =	$kVAR_2$
$kW_1\uparrow$	$kW_2\downarrow$
$kVA_1\uparrow$	$kVA_2\downarrow$
$I_{a1}\uparrow$	$I_{a2}\downarrow$
$p.f_1\uparrow$	$p.f_2\downarrow$

Active power sharing is depends on the Steam input and also depends on the turbine characteristics.

33. Ans: (b)

Sol: Excitation of machine 1 is increased (Steam input is kept constant):

- Effect of change in excitation causes only change in it's reactive power sharing but no charge in it's active power sharing, because the synchronizing power is only the reactive power.
- If the excitation of machine 1 increases

Machine 1	Machine 2
kW_1 =	kW_2
$kVAR_1\uparrow$	$kVAR_2\downarrow$
$kVA_1\uparrow$	$kVA_2\downarrow$
$I_{a1}\uparrow$	$I_{a2}\downarrow$
$P.f_1\downarrow$	$P.f_2\uparrow$

34. Ans: (d)

Sol: At perfect synchronization means both systems has all the characteristics similar at that point. No unstability factor so there is no – need for production of synchronizing power.

35. Ans: (c)

Sol: For any change in field current there will be a change in reactive power of the machine so there will be change in p.f of the machine.

36. Ans: (a)

Sol: To increase the load share of the alternator, steam input of the machine to be increase by keeping field excitation constant.

39. Ans: (d)

Sol: Rate of flickering = beat frequency

$= f - f^l$

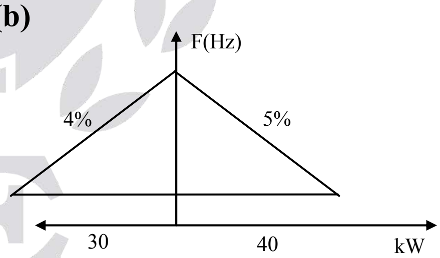
$= 50.2 - 50$

$= 0.2\text{Hz}$

$\Rightarrow$ 0.2 Flickers/sec = 0.2×60 = 12 filckers/min

40. Ans: (b)

Sol:



Without over loading any one machine. So here 300 kW is maximum capacity of machine 1.

→ For M/C 2 maximum load. It can bear is

$$\frac{P}{400} = \frac{4}{5}$$

$P_1 = 320$ kW

Total load = $P_1 + P_2 = 300 + 320 \le 620$ kW

41. Ans: (a)

Sol: M/C's are working at UPF now. For increased 'I_f' from V, inverted V curves. We can find that there will be change in p.f of alternator 'A' from lead to lag.

Alternator and lagging p.f is over-excited. So it will deliver lagging VAR to the system.

43. Ans: (c)

Sol: For synchronizing an alternator, the speed of alternator need not be same as already existing alternator.

44. Ans: (a)

Sol: Synchronizing current per phase

$$= \frac{|\bar{E}_1 - \bar{E}_2|}{Z_{s1} + Z_{s2}} \text{ given } Z_{s1} = Z_{s2}$$

$\bar{E}_1$ and $\bar{E}_2$ must be of phase quantities.

$$\therefore \; I_{sy} = \frac{\left|\frac{3300}{\sqrt{3}} - \frac{3200}{\sqrt{3}}\right|}{2\times 1.7}$$

$I_{sy} = 16.98$A.

45.

Sol:

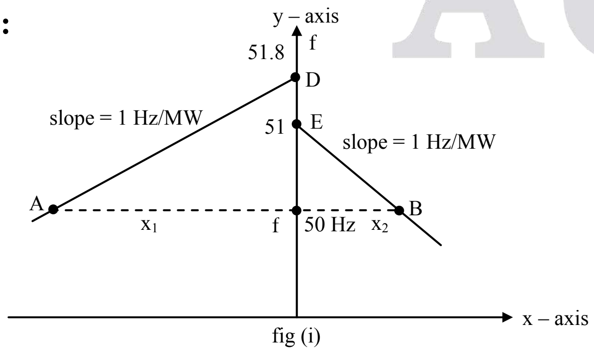


fig (i)

$y = -mx + c$

(a) $f = -1\times x_1 + 51.8 = -1\times x_2 + 51$

$x_1 - x_2 = 0.8$ …………. (1)

$x_1 + x_2 = 2.8$ ………. (2)

From equation (1) & (2)

$2x_1 = 3.6$

$x_1 = 1.8$ MW

$x_2 = 1$ MW

set frequency (f) $= -x_1 + 51.8$

$= -1.8 + 51.8$

$= 50$Hz

(b) If load is increased to 1 MW

$x_1 + x_2 = 3.8$ MW …… (3)

$x_1 - x_2 = 0.8$ MW …… (4)

From equation (3) & (4)

$2x_1 = 4.6$

$x_1 = 2.3$ MW

$x_2 = 1.5$ MW

$f = -x_1 + 51.8$

$= -2.3 + 51.8 = 49.5$ Hz

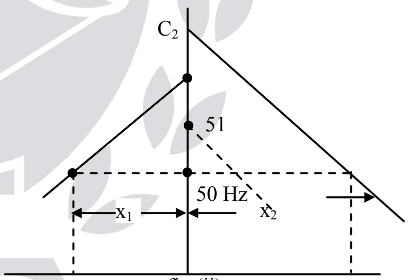


fig (ii)

(c) as in part(b)

total load $= x_1 + x_2^1 = 3.8$ ……. (1)

at f = 50 Hz

load shared by machine(1)

$f = -1 \times x_1 + 51.8 = 50$

$-x_1 + 51.8 = 50 \Rightarrow x_1 = 1.8$ MW

$\therefore \; x_2 = 3.8 - x_1 = 3.8 - 1.8 = 2.0$ MW

for machine (2)

$f = -x_2 + c_2 = 50$

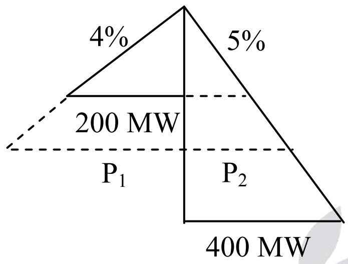
$-20 + c_2 = 50$

$c_2 = 70$

46.

Sol: (i) Given data: G_1: 200 MW, 4%

G_2 : 400 MW, 5%



$$\Rightarrow \frac{P_1}{200} = \frac{x}{4} \Rightarrow P_1 = 50x$$

$$\Rightarrow \frac{P_2}{400} = \frac{x}{5} \Rightarrow P_2 = 80x$$

But, total load = $P_1 + P_2 = 600$ MW….. (1)

From (1) $\Rightarrow$ $50x + 80x = 600$

$$\Rightarrow \quad x = \frac{600}{130} = 4.615$$

Given, no-load frequency = 50 Hz

present system frequency

$\Rightarrow f = 50 - (50 \times x\,\%)$

$$= 50 - 50 \times \frac{4.615}{100} = 47.69 \approx 47.7\text{Hz}$$

(ii) Load shared by M/C I is ___ and M/C 2 is _____.

From above solution we got

x = 4.615

$P_1 = 50\,x = 50 \times 4.615 = 230.75$ MW

$P_2 = 80\,x = 80 \times 4.615 = 369.2$ MW

Here 'P_1' violates the unit.

(iii) Maximum load the set can supply without overloading any Machine is _____.

From above solution 'P_1' violated the limit so take 'P_1' value as reference

$P_1 = 200$ MW

From % Regugraph find P_2

$$\frac{P_2}{400} = \frac{4}{5}$$

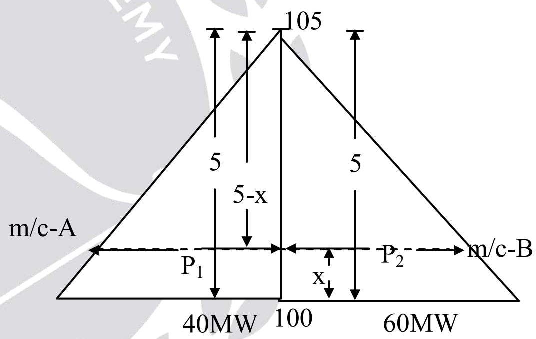
$P_2 = 320$ MW

Total load = $P_1 + P_2 = 320 + 200$

= 520 MW set can supply.

47. Ans: (c)

Sol: Let power factor is unity, M/C-A =40 MW and M/C-B = 60 MW



$$\frac{P_2}{60} = \frac{5-x}{5} \Rightarrow P_2 = 12(5-x)$$

$$\frac{P_1}{40} = \frac{5-x}{5} \Rightarrow P_1 = 8(5-x)$$

$P_1 + P_2 = 80$

$\Rightarrow 8(5-x) + 12(5-x) = 80$

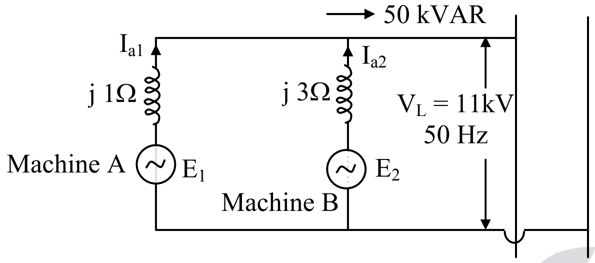
$\Rightarrow x = 1$

$\therefore P_1 = 8(5-1) = 32\text{MW}$

$P_2 = 12(5-1) = 48\text{MW}$

48. Ans: 0.74

Sol: Two parallel connected 3-ϕ, 50 Hz, 11kV, star-connected synchronous machines A & B are operating as synchronous condensers.



The total reactive power supplied to the grid = 50 MVAR

$3VI_{a1}\sin\phi_1 + 3VI_{a2}\sin\phi_2 = 50$ MVAR

$3VI_{a1}\ \sin 90 + 3VI_{a2}\sin 90 = 50$ ($\because$ only reactive power pf = $\cos\phi = 0 \Rightarrow \phi = 90^o$)

$6VI_a = 50 \times 10^6$ ($\because I_{a1} = I_{a2} = I_a$)

$$I_a = \frac{50\times10^6}{6\times\frac{11\times10^3}{\sqrt{3}}} = 1312.16 \text{ A}$$

$\therefore\ E_1 = V\angle 0 - I_{a1}\angle 90 \times X_{s1}\angle 90$

$= \frac{11\times10^3}{\sqrt{3}}\angle 0\ - 1312.16\angle 90 \times 1\angle 90$

$= 6350.8\angle 0 - 1312.16\angle 180$

$= 7662.96$ V

$E_2 = V\angle 0 - I_{a2}\angle 90 \times X_{s2}\angle 90$

$= 6350.8\angle 0 - 1312.16\angle 90 \times 3\angle 90$

$= 6350.8\angle 0 - 3936.48\angle 180$

$= 10,287.28$ V

$\therefore$ The ratio of excitation current of machine A to machine B is same as the ratio of the excitation emfs

i.e., $\frac{E_1}{E_2} = \frac{7662.96}{10,287.28} = 0.7448$

49. Ans: (b)

Sol: $V_L = 11$kV

$$V_{ph} = \frac{111\text{kV}}{\sqrt{3}} = 6350.8 = 6351 \text{ V}$$

at 100A, UPF, $E = V\angle 0 + I_a\angle \pm \phi . Z_s\angle\theta$

$= 6350\angle 0 + 100\angle 0 \times 10\angle 90^o$

$= 6429.1\ \angle 8.94^o$

$\therefore\ \delta = 8.94^o$

Excitation increased by 25%

$\Rightarrow E^1 = 1.25E$

$= 6429.1\times1.25 = 8036.3$ V

$\because$ Turbine input kept constant

$$P^1 = P = \frac{E^1V}{X_s}\sin\delta^1 = \frac{EV}{X_s}\sin\delta$$

$$\frac{8036.3}{10}\sin\delta^1 = \frac{6350}{10}\sin(8.94) = 7.14^o$$

50. Ans: (a)

Sol: $I_a{}^1 = \frac{E^1\angle\delta^1 - V\angle 0}{Z_s\angle\theta}$

$= \frac{8036.3\angle 7.14 - 6350\angle 0}{10\angle 90}$

$= 190.6\angle{-58.4^o}$

$I_a{}^1 = 190.4$ A

51. Ans: (0.523 lag)

Sol: p.f = cos(58.4) = 0.523 lag

52. Ans: (d)

Sol: 'X' is in % P.U = 25%; $V_{ph} \le \frac{6600}{\sqrt{3}} \le 3810$

'X' in Ω is = 0.25 × Z_b = $0.25\times\frac{(KV)^2}{MVA_b}$

$$= 0.25\times\frac{(6.6)^2}{(1.2)} = 9.07$$

$E = V + j\, I_a X_s \rightarrow$ In alternator

By substituting the values

$$I = \frac{P}{\sqrt{3}\,V} = \frac{1200\times 10^3}{\sqrt{3}\times 6600} = 104.97$$

$E = 3810 + 104.97\angle{-36.86} \times 9.07\angle 90$

$E = 4447\angle 9.867$

The current (I_a) at which the p.f is unity ($\because R_0 = 0$)

$$E = \sqrt{(V\cos\phi + I_a R_a)^2 + (V\sin\phi \pm I_a X_s)^2}$$

$$4447 = \sqrt{(63810\times 1 + 0)^2 + (3810\times 0 + 9.07)^2}$$

$I_a = 252.716$ A

53. Ans: (5360.9V)

Sol: $E = V + j\, I_a X_s$

$$V_{Ph} = 3810 = \frac{6.6\times 10^3}{\sqrt{3}};\ I_a = \frac{P}{\sqrt{3}\times V} = \frac{1000\times 10^3}{\sqrt{3}\times 6.6\times 10^3}$$

$= 87.47$ A

$E_{Ph} = 3810 + 82.47\angle{+36.86} \times 20\angle 90$

$E_{Ph} = 3095.17\angle 26.88$

$E_L = \sqrt{3}\, E_{Ph} = 5360.99$ V

54. Ans: (26.88°)

Sol: Power angle (or) $\delta = 26.88^0$

55. Ans: (b)

Sol: $P = \frac{EV}{X_S}\sin\delta$

$$\Rightarrow 0.5 = \frac{1.3\times 1}{0.8}\sin\delta$$

$\Rightarrow \delta = 17.92^0$

$E = V + j\, I_a X_s$

$$I_a = \frac{E\angle\delta - V\angle 0}{X_s\angle 90}$$

$$= \frac{1.3\angle 17.92 - 1\angle 0}{0.8\angle 90}$$

$= 0.581\angle{-30.639^0}$

56. Ans: (a)

Sol: From above solution Answer is 0.581

57. Ans: (0.860 lag)

Sol: From above solution power factor is

p.f = $\cos\phi = \cos(30.639) = 0.860$ lag

58. Ans: (0.296 PU)

Sol: Reactive power (Q) = $\frac{V}{X_s}[E\cos\delta - V]$

$$= \frac{1}{0.8}[1.3\times\cos(17.92) - 1]$$

$= 0.296$ P.U

59. Ans: (2.05 PU)

Sol: The current at which maximum power output is ______

Under maximum output conditions $\delta = \theta$

Here $\theta = 90$ ($\because R_a = 0$)

$$I = \frac{E\angle\delta - V\angle 0}{Z_s\angle\theta}$$

$$I_a = \frac{1.3\angle 90 - 1}{0.8\angle 90} = 2.05\angle 37.56^0$$

$= 2.05$ PU

60. Ans: (0.792 lead)

Sol: Power factor at maximum power output is

p.f = $\cos(37.56) = 0.792$ lead

61. Ans: (–1.25 PU)

Sol: reactive power at maximum

$$Q=\frac{V}{X_s}\left[E\cos\delta-V\right]$$

Substitute $\delta = \theta = 90$

$$Q=\frac{1}{0.8}\left[1.3\cos(90)-1\right]$$

$$=-1.25\,P.U$$

62. Ans: 32.4 to 34.0

Sol: A non – salient pole synchronous generator

$X_s = 0.8$ pu, P = 1.0 pu, UPF

V = 1.1pu, $R_a = 0$

$P = V\,I_a\cos\phi \Rightarrow 1 = 1.11\times I_a\times 1$

$\Rightarrow I_a = 0.9$ pu

∴ The voltage behind the synchronous reactance i.e $E = V + I_a Z_s$

$= 1.11\angle 0 + 0.9\angle 0\times 0.8\angle 90°$

$= 1.11 + j\,0.72$

$= 1.323\angle 32.969°$

63. Ans: 0.1088

Sol: $E_f = 1.3$pu, $X_s = 1.1$pu, P =0.6pu, V=1.0pu

$$P=\frac{EV}{X_s}\sin\delta \Rightarrow 0.6=\frac{1.3\times 1}{1.1}\sin\delta$$

$\Rightarrow \delta = 30.53°$

$$Q=\frac{V}{X_s}\left[E\cos\delta-V\right]$$

$$=\frac{1}{1.1}\left[(1.3)\cos 30.53-1\right]=0.1088\,pu$$

64. Ans: (a)

Sol: Motor input $=\sqrt{3}\,V_L I_L\cos\phi$

$=\sqrt{3}\times 480\times 50\times 1 = 41569.2$ W

given motor is loss less

Electrical power converted to mechanical power = Motor input –output

= 41569.2 – 0 = 41569.2 W

$$N_s=\frac{120f}{P}=\frac{120\times 60}{4}=1800\text{rpm}$$

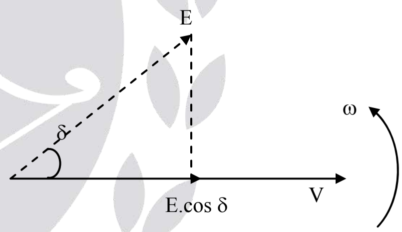
$$T=\frac{P}{\omega}=\frac{41569.2}{2\pi\times\frac{1800}{60}}=220.53\,N-m$$

65. Ans: (a)

Sol: From phasor diagram, 'E' leads the 'V', hence called "Generator".

Here, E cos δ > V called over excited generator.

An under excited generator always operators at "laging power factor".



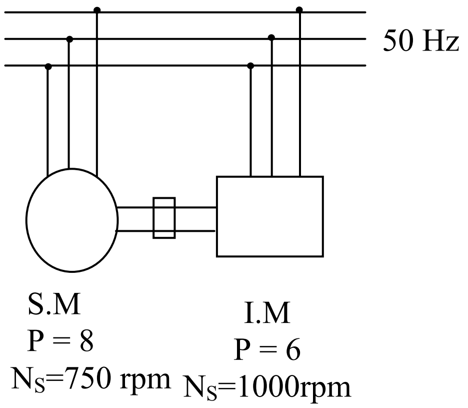
66. Ans: (a)

Sol: We know that, synchronous motor always rotates only at synchronous speed but induction motors can rotate at more or less than the synchronous speed.

∴Consider speed of Induction motor, $N_r = 750$ rpm.

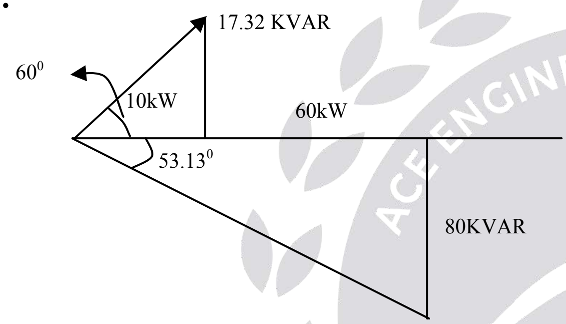
$$\text{slip}=\frac{N_s-N_r}{N_s}=\frac{1000-750}{1000}=\frac{1}{4}$$

$$f_r = sf = \frac{1}{4}\times 50 = 12.5\text{ Hz}$$



67. Ans: (b)

Sol:



Total kW of load = kV × cosϕ

$P_1 = 100 \times 0.6 = 60$ kW

kVAR Requirement of load

= P × tanϕ = 60 × tan 53.13 = 80 kVAR

KW requirement of synchronous motor

$(P_2) = 10$ kW

Operating p.f of load = 0.5 leads

Phase angleϕ = $\cos^{-1}(0.5) = 60$

$Q = P\tan\phi = 10 \times 10^3 \times \tan 60 = 17.32$ kVAR

(KVAR supplied by synchronous motor)

Total load $P_1 + P_2 = 70$ kW

Total KVAR requirement = 80 – 17.32

= 62.68 kVAR

Overall power factor

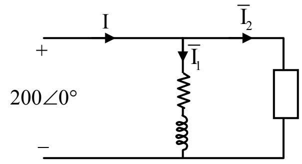
$$\tan\phi = \frac{Q}{P} = \frac{62.68}{70} = 0.895$$

ϕ = 41.842

p.f = cos ϕ = 0.74 lag

68. Ans: 24 A

Sol:



$$\bar{I}_1 = \frac{200\angle 0}{4 + j3}$$

$= 40\angle{-36.87°}$

$= 40\cos(36.87) - j40\sin 36.87$

$= 32 - j24$ A

Assume that the motor draws a current j24 A, then overall pf = 1, therefore answer is 24 A

69. Ans: (b)

Sol: $V_1 = 400V$ $E = 400V$

$$V_{ph} = \frac{400}{\sqrt{3}} = 230.9V,$$

$$E_{ph} = \frac{400}{\sqrt{3}} = 230.9V$$

$$P_{in} = \frac{EV}{X_s}\sin\delta$$

$$\frac{5\times 10^3}{3} = \frac{230.9 \times 230.9}{10}\sin\delta$$

$\Rightarrow \delta = 18.21°$

70. Ans: (c)

Sol: From the armature current $7.3\angle{-9.1^o}$

9.1^o is the angle difference between V and I.

$\therefore \cos\phi = \cos(-9.1^o)$

PF = 0.987 Lag

71. Ans: (d)

Sol: $I_a = \dfrac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$

$= \dfrac{230.9\angle 0 - 2309\angle 18.21}{10\angle 90} = 7.3\angle\text{-}9.1^o$

$I_a = 7.3^a$

72. Ans: (a)

Sol: $E_{ph} = \dfrac{2500}{\sqrt{3}} = 1443.37V$

$V_{ph} = \dfrac{2000}{\sqrt{3}} = 1154.7V$

$Z_s = 0.2 + j2.2 = 2.2\angle 84.8^o \Rightarrow \theta = 84.8^o$

$P_{in} = \dfrac{V^2}{Z_s}\cos\theta - \dfrac{EV}{Z_s}\cos(\theta+\delta)$

$\dfrac{800\times10^3}{3} = \dfrac{(1154.7)^2}{2.2\angle 84.8^o}\cos(84.8) - \dfrac{(1154.7\times1443.37)}{2.2\angle 84.8^o}\cos(84.8+\delta)$

$I_a = \dfrac{V\angle 0 - E\angle\delta}{Z_s\angle\theta}$

$= \dfrac{1154.7\angle 0 - 1443.37\angle 21.43}{2.2\angle 84.8^o}$

$= 254.59\angle 24.9^o$

73. Ans: (b)

Sol: PF = cos (24.9) = 0.907 lead

74. Ans: (760.9 kW)

Sol: Mechanical power developed

$P = E_a I_a^*$

$P = \dfrac{EV}{Z_S}\cos(\theta-\delta) - \dfrac{E^2}{Z_S}\cos\theta$

$P = \dfrac{\frac{2500}{\sqrt{3}}\times\frac{2000}{\sqrt{3}}}{2.209}\cos(84.80-21.51) - \dfrac{\left(\frac{2500}{\sqrt{3}}\right)^2}{2.209}\cos(84.80)$

$P_{phase} = 253.364$ kW

$P_{3-\phi} = 760.94$ kW (Or)

$P_{mech} = P - 3\,I_a^2\,R_a$

$= 800\times10^3 - (3\times254^2\times0.2)$

$P_{mech} = 761$ kW

75. Ans: (4.84 Nm)

Sol: (In question poles and frequency not given let take P = 4, F = 50)

$N_s = 1500$

$T = P/\omega = \dfrac{760.94\times60}{2\pi\times1500} = 4.84$ Nm

76. Ans: (b)

Sol: $V_L = 230V$

$\Rightarrow V_{ph} = \dfrac{230}{\sqrt{3}} = 132.8V$

$Z_s = 0.6 + j3 = 3.06\angle 78.69^o$

$\theta = 78.69^o$

at $I_a = 10A$, UPF ,

$E = V\angle 0 - I_a\angle\pm\phi\, Z_s\angle\theta$

$= 132.8\angle 0 - 10\angle 0\; 3.06\angle 78.69$

$= 130.29\angle -13.31^o$

$\because$ Excitation is kept constant E =130.29,

V = constant

Load on the motor is ↑, δ↑, I_a↑ to 40A (given)

$|I_a Z_s| = \overline{V}(0) - \overline{E}\angle-\delta$

$= \sqrt{V^2 + E^2 - 2VE\cos\delta}$

40×3.06

$= \sqrt{132.8^2 + 130.29^2 - 2\times132.8\times130.29\cos\delta}$

$\delta = 55.4^o$

$I_a = \dfrac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$

$I_a = \dfrac{132.8\angle 0 - 130.29\angle -55.4}{3.06\angle 78.69^o}$

$I_a = 40\angle -17.3$

PF = cos (17.3) =0.954 lag

77. Ans: (c)

Sol: $P_{Mech} = P_{in}$ – Copper loss

$= \sqrt{3}\, V_L I_L \cos\phi - 3I_a^2 R_a$

$= (\sqrt{3} \times 230 \times 40 \times 0.953) - (3 \times 40^2 \times 0.6)$

= 12.035 kW

$T = \dfrac{P_{mech}}{\omega} = \dfrac{12.035\times 10^3}{2\pi\times\dfrac{1000}{60}} = 78.34\ N-m$

78. Ans: (b)

Sol: $V_{ph} = \dfrac{6.6}{\sqrt{3}} = 3810.5V$

$P_{in} = \sqrt{3}\, V_L I_L \cos\phi \Rightarrow I_L$

$= \dfrac{1000\times 10^3}{\sqrt{3}\times 6.6\times 10^3\times 0.8} = 109.3A = I_{ph}$

$E = V\angle 0 - (I_a \angle \pm \phi\ z \angle\theta)$

$= 3810.5\ \angle 0 - 109.3\ \angle 36.86 \times 12\angle 90^o$

$= 4715.5\angle -12.85^o$

Excitation is constant, V is constant

$P = \dfrac{EV}{X_s}\sin\delta$

$= \dfrac{1500\times 10^3}{3}$

$= \dfrac{4715.5\times 3810.5}{12}\sin\delta$

$\Rightarrow \delta = 19.5^o$

79. Ans: (a)

Sol: $I_a = \dfrac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$

$= \dfrac{3810.5\angle 0 - 4715.5\angle -19.5}{12\angle 90}$

$= 141.4\angle 21.95$

PF = cos (21.95°)

= 0.92 lead

80. Ans: (*)

Sol: Data given

$V_{ph} = \dfrac{400}{\sqrt{3}} = 230.94$ V, 100 kVA,

$R_a = 0.13\ \Omega$ and

$X_s = 1.3\ \Omega$

$I_{line} = I_{phase} = \dfrac{100\times 10^3}{\sqrt{3}\times 400}$

= 144.33 A

Stray losses = 4000 W and power input =75 kW

Total cu losses = $3 \times 144.33^2 \times 0.13$

= 8125 W

Total losses = Stray losses + Cu losses

= 4000 + 8125

= 12125 W

$\%\ \eta = \dfrac{\text{input} - \text{losses}}{\text{input}}\times 100$

$= \dfrac{75000 - 12125}{75000}\times 100$

= 83.83%

Solutions for Conventional Practice Questions

01.

Sol: Given data,

$P = 6, 3\phi, f = 50$ Hz,

$m = 3 \ (s/p = 3\times3 = 9)$

4 conductors per slot, (double layer)

$\beta = 150°,\ \ \phi/\text{pole} = 0.2$ Wb

$E_{r.m.s/phase} = \sqrt{E_1^2 + E_3^2 + E_5^2}$

$\beta = 150°$

$\Rightarrow \alpha = 30°$

Pitch factor: $k_p = \cos\dfrac{\alpha}{2} = \cos 15° = 0.965$

Distribution factor:

Slot angle $\gamma = \dfrac{180}{S/P} = \dfrac{180}{9} = 20°$

$$k_d = \frac{\sin m\frac{\gamma}{2}}{m\sin\frac{\gamma}{2}} = \frac{\sin\frac{3\times20^{\circ}}{2}}{3\sin\frac{20°}{2}} = 0.9597$$

Turns/phase:

Slots/pole /phase (m) = 3

$\Rightarrow$ slots/pole = 9

$\Rightarrow$ slots = 9 × 6 = 54

Total conductors = 54 × 4 = 216

Number of turns $= \dfrac{216}{2}$

$= 108$

Turns/phase $= \dfrac{108}{3} = 36$

$E_1 = 4.44 \times k_p \times k_d \times f \times \phi_1 \times T/_{phase}$

$= 4.44 \times 0.965 \times 0.9597 \times 50 \times 0.2 \times 36$

$= 1480.3$V

Harmonic voltages:

3rd harmonic:

$K_{p3} = \cos\dfrac{n\alpha}{2} = \cos\dfrac{3\times30°}{2} = 0.707$

$$K_{d3} = \frac{\sin\frac{mn\gamma}{2}}{m\sin\frac{n\gamma}{3}} = \frac{\sin\frac{3\times3\times20}{2}}{3\sin\frac{3\times20}{2}} = 0.67$$

$\phi_3 = \dfrac{0.2\times\phi_1}{3} = 0.013$

$f_3 = 3 \times 50 = 150$ Hz

T/ph = 36

$E_3 = 4.44\ k_{p3}\ k_{d3}\ f_3\ \phi_3$ T/ph

$= 4.44 \times 0.707 \times 0.67 \times 150 \times 0.013 \times 36$

$= 147.6$ V

5th harmonic:

$K_{p5} = \cos\dfrac{5\times30}{2} = 0.258$

$$K_{d5} = \frac{\sin\frac{3\times5\times20}{2}}{3\sin\frac{5\times20}{2}} = \frac{0.5}{2.298} = 0.217$$

$\phi_5 = \dfrac{0.1\times\phi_1}{5} = 4$ mWb

$f_5 = 5 \times 50 = 250$ Hz

T/ph = 36

$E_5 = 4.44 \times k_{p5} \times k_{d5} \times f_5 \times \phi_5 \times T/_{phase}$

$= 4.44 \times 0.258 \times 0.217 \times 250 \times 4\times10^{-3} \times 36$

$= 8.94$ V

$E = \sqrt{1480.3^2 + 147.6^2 + 8.94^2} = 1487$V

02.

Sol: $V_L = 11$kV

$\Rightarrow V_{ph} = \dfrac{11\times10^3}{\sqrt{3}} = 6351$ volts

$Z_s = R_a + jx_s = 2 + j\,10$

$\Rightarrow Z_s = \sqrt{2^2 + 10^2}$

$= 10.198\ \Omega/\text{ph}$ and $\theta = 78.69°$

At 2MVA:

$$I_L = \frac{MVA}{\sqrt{3}V_L} = \frac{2\times10^6}{\sqrt{3}\times11\times10^3}$$

$= 104.97A = I_{ph}$

Regulation at 0.8 lag P.F

$$E = \sqrt{(v\cos\phi + I_a r_a)^2 + (V\sin\phi + I_a X_s)^2}$$

$$= \sqrt{(6351\times0.8 + 104.97\times2)^2 + (6351\times0.6 + 104.97\times10)^2}$$

$= 7184$ V

$$\text{Regulation} = \frac{E-V}{V}\times100$$

$$= \frac{7184-6351}{6351}\times100$$

$= 13.12\%$

Regulation at 0.9 p.f lead:

$$E = \sqrt{(V\cos\phi + I_a r_a)^2 + (V\sin\phi - I_a X_s)^2}$$

$$= \sqrt{(6351\times0.8 + 104.97\times2)^2 + (6351\times0.6) - 104.97\times10)^2}$$

$= 5697$ V

$$\text{Regulation} = \frac{E-V}{V}\times100$$

$$= \frac{5697-6351}{6351}\times100$$

$= -6\ \%$

iii) At UPF:

$$E = \sqrt{(V\cos\phi + I_a r_a)^2 + (V\sin\phi - I_a X_s)^2}$$

$$E = \sqrt{(6351 + 104.97\times2)^2 + (0 - 104.97\times10^2)}$$

$= 6644.38$V

$$\text{Regulation} = \frac{E-V}{V}\times100$$

$$= \frac{6644.38-6351}{6351}\times100$$

$= 4.62\%$

iv) $\cos(\theta + \phi) = \dfrac{-I_a Z_s}{2V}$

$$\cos(78.69 + \phi) = \frac{-104.97\times10.19}{2\times6351}$$

$\Rightarrow \phi = 16.14°$

$\therefore$ p.f $\cos\phi = 0.96$ lead

v) At rated condition

$$I_L = \frac{MVA}{\sqrt{3}\times V_L} = \frac{3\times10^6}{\sqrt{3}\times11\times10^3}$$

$= 157.4A = I_{ph}$

Maximum regulation possible at

$\phi = \theta = 78.69°$

$$E = \sqrt{(V\cos\phi + I_a r_a)^2 + (V\sin\phi) + I_a X_s)^2}$$

$$E = \sqrt{(6351\times0.196 + 157.4\times2)^2 + (6351\times0.98 + 157.4\times10)^2}$$

$= 7952.4$ V

$$\text{Regulation} = \frac{E-V}{V}\times100$$

$$= \frac{7952.4-6351}{6351}\times100$$

$= 25.21\%$

03.

Sol: $V_L = 400$ V

$$\Rightarrow V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231\ \text{Volts}$$

$$I_L = \frac{kVA}{\sqrt{3}\times V_L} = \frac{10\times10^3}{\sqrt{3}\times400} = 14.43A = I_{ph}$$

i) $P = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{Xq}-\frac{1}{X_d}\right)\sin 2\delta$

$\tan\Psi = \frac{V\sin\phi \pm I_a X_q}{V\cos\phi + I_a R_a}$

$= \frac{231\times 0.6 + 14.43\times 6}{231\times 0.8 + 14.43\times 0}$

$= 1.21$

$\Rightarrow \Psi = 50.6°$

For lagging power factor

$\psi = \delta + \phi$

$\Rightarrow \delta = \psi - \phi$

$= 50.6 - \cos^{-1}(0.8)$

$= 13.75°$

Direct axis current, $I_d = I_a \sin\psi$

$= 14.43 \sin(50.6)$

$= 11.15$ A

Quadrate axis current $I_q = I_a \cos\psi$

$= 14.43 \cos(50.6)$

$= 9.15$A

$E = V\cos\delta + I_q R_a \pm I_d X_d$

$= 231\times\cos(13.75) + 9.15\times 0 + 11.15\times 8$

$= 313.58$ volt

i) $P = \frac{313.58\times 231}{8}\sin(13.75) +$

$\frac{(231)^2}{2}\left(\frac{1}{6}-\frac{1}{8}\right)\sin(2\times 13.75)$

$= 2152.16 + 513.82$

Power for 3-ϕ = $3\times 2152 + 3\times 513$

$= 6456 + 1539$

Electro magnetic power = 6456 watt

Reluctance power = 1539 watt

ii) Maximum power developed can be obtained as

$P_{max} = \frac{dP}{d\delta} = 0$

$P_{max} = \frac{EV}{X_d}\cos\delta + \frac{V^2}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)2\cos 2\delta$

$= 0$

$\Rightarrow \frac{EV}{X_d}\cos\delta = V^2\left(\frac{1}{X_d}-\frac{1}{X_q}\right)\cos 2\delta$

$\frac{313.58}{2}\cos(\delta) = 231\times\left(\frac{1}{8}-\frac{1}{6}\right)\cos 2\delta$

$\frac{\cos 2\delta}{\cos\delta} = -4.07$

$\frac{2\cos^2\delta - 1}{\cos\delta} = -4.07$

$\Rightarrow 2\cos^2\delta + 4.07\cos\delta - 1 = 0$

$\Rightarrow \cos\delta = 0.22$

$\Rightarrow \delta = 77.29°$

$P_{max} = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\sin 2\delta$

$= \frac{313.58\times 231}{8}\sin 77.29° +$

$\frac{(231)^2}{2}\left(\frac{1}{6}-\frac{1}{8}\right)\times\sin(2\times 77.29)$

P = 8832 + 477

P = 9309

Power for 3ϕ is P = 3 × 9309

= 27.927 kW

iii) When excitation fails, $E = 0 \Rightarrow P_{em} = 0$

$\therefore P_{rel} = \frac{V^2}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\sin 2\delta$

$(P_{rel})_{max} = \frac{dP_{rel}}{d\delta} = 0$

$$\Rightarrow V^2\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\cos 2\delta = 0$$

$\Rightarrow \cos 2\delta = 0$

$\Rightarrow \quad \delta = 45°$

$$P_{rel} = \frac{(231)^2}{2}\left(\frac{1}{6}-\frac{1}{8}\right) \Rightarrow 111.6 \text{ watt}$$

For 3 ϕ: $3 \times 1111.6 \Rightarrow 3335$W

$$I_q = \frac{V\sin\delta}{X_q} = \frac{231\times\sin 45}{6} = 27.22 \text{ A}$$

$$I_d = \frac{V\cos\delta}{X_d} = \frac{231\times\cos 45}{8} = 20.41 \text{ A}$$

$$I_a = \sqrt{I_d^{\,2}+I_q^2} = 34.02\text{A}$$

Power factor: $\quad I_d = I_a \sin\phi$

$20.41 = 34.02 \sin\phi$

$\Rightarrow \quad \psi = 36.86°$

$\psi = \phi \pm \delta$ (+ lag, – lead)

$36.86 = \phi - \delta$

$36.86 + 45 = \phi$

$\phi = 81.8°$

$\cos\phi = 0.14$ lead

04.

Sol: Given data:

Number of poles = 12

reactances of $X_d = 5\Omega$, $X_q = 3\Omega$.

Power factor at unity

$s = \sqrt{3}\ V_L I_a$

$20 \times 10^6 = \sqrt{3} \times 11\times 10^3\ I_a$

$$I_a = \frac{20\times10^6}{\sqrt{3}\times11\times10^3} = 1049.72 \text{ A}$$

At unity power factor

$V\sin\delta = I_qX_q$

$I_q = I_a\cos\delta$

$I_d = I_a\sin\delta$

$\therefore V\sin\delta = (I_a\cos\delta)X_q$

$$\tan\delta = \frac{I_aX_q}{V} = \frac{1049.7\times3}{\left(\frac{11\times10^3}{\sqrt{3}}\right)} = 0.49585$$

$\delta = 26.4°$

$I_q = I_a\cos\delta = 1049.72\cos26.4^o = 940.3$

$I_d = I_a\sin\delta = 1049.72\sin26.4^o = 466.7$

(a) Excitation voltage per phase

$E = V\cos\delta + I_dX_d$

$$E = \frac{11\times10^3}{\sqrt{3}}\times\cos26.4^o + 466.7\times5$$

$= 5688 + 2333.5$

$= 8021.5$ V

(b) Active power for 3-phase

$$P = \frac{3VE}{X_d}\sin\delta + \frac{3V^2}{2}\frac{(X_d-X_q)}{X_dX_q}\sin 2\delta$$

$$= \frac{3\times11\times10^3\times8021.5}{\sqrt{3}\times5}\sin 26.4° +$$

$$\frac{3}{2}\left(\frac{11\times10^3}{\sqrt{3}}\right)\left(\frac{5-3}{5\times3}\right)\sin 52.8°$$

$= 13591127 + 6423615$

$= 20$ MW

(c) Synchronizing power per electrical degree

$$P_{syn2} = \frac{dP}{d\delta}\frac{\pi}{180} \text{ watts}$$

$$= \left[\frac{3EV}{X_d}\cos\delta + 3V^2\left(\frac{X_d-X_q}{X_dX_q}\right)\cos2\delta\right]\frac{\pi}{180}$$

$$= \left[\frac{3\times 8021.5\times 6350}{5}\cos 26.4° + 3\times(6350)^2\left(\frac{5-3}{5\times 3}\right)\cos 52.8°\right]\frac{\pi}{180}\ W$$

= 647.975 kW/elec.degree

Synchronous torque

τ_{syn2}

$$= \frac{\text{synchronizing power per elec.degree}}{2\pi n_s}$$

$$\tau_{syn2} = \frac{P_{syn2}}{2\pi n_s} = \frac{P_{syn2}}{2\pi(f/p)}$$

$$= \frac{647.975\times 10^3}{2\pi(50/6)} = 12375\ \text{Nm}$$

(d) Synchronizing per mechanical degree

$$P_{syn} = \left(\frac{dP}{d\delta} - \frac{\pi}{180}\right)P$$

$$= 647.975\times\frac{12}{2} = 3887.8\ \text{kW}$$

Corresponding torque

$$t_{syn} = \frac{P_{syn}}{2\pi n_s} = \frac{P_{syn}}{2\pi\times(f/p)}$$

$$= \frac{3887.8\times 10^3}{2\pi\times 50/6} = 74251\ \text{N-m}$$

(e)

ii) Maximum power developed can be obtained

$$\text{as } P_{max} = \frac{dP}{d\delta} = 0$$

$$P_{max} = \frac{EV}{X_d}\cos\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right) 2\cos 2\delta = 0$$

$$\Rightarrow \frac{EV}{X_d}\cos\delta = V^2\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\cos 2\delta$$

$$\frac{8021.5}{5}\cos(\delta) = \frac{11\times 10^3}{\sqrt{3}}\left(\frac{1}{5} - \frac{1}{3}\right)\cos 2\delta$$

$$\frac{\cos 2\delta}{\cos\delta} = -1.89$$

$$\frac{2\cos^2\delta - 1}{\cos\delta} = -1.89$$

$$\Rightarrow 2\cos^2\delta + 1.89\cos\delta - 1 = 0$$

$$\Rightarrow \cos\delta = 0.37$$

$$\Rightarrow \delta = 68.28°$$

$$P_{max} = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

$$= \frac{8021.5\times 11\times 10^3}{\sqrt{3}\times 5}\sin 68.28° + \frac{(11000)^2}{6}\left(\frac{1}{3} - \frac{1}{5}\right)\times\sin(2\times 68.28)$$

$P = 9.46\times 10^6 + 1.84\times 10^6$

$P = 11.32$ MW

Power for 3ϕ is $P = 3\times 11.32$

$= 33.92$ MW

05.

Sol: Given data:

Two generators with ratings = 300 MW; 500 MW

Droop characteristics of alternator – (1)= 4%

Droop characteristics of alternator – (2)= 5%

at no- load frequency = 50Hz

Total load $P = P_1 + P_2 = 700$ MW

Required data:

(a) calculate system frequency

(b) load shared by machines P_1=? P_2=?

(c) maximum load that can supply without overloading any machine

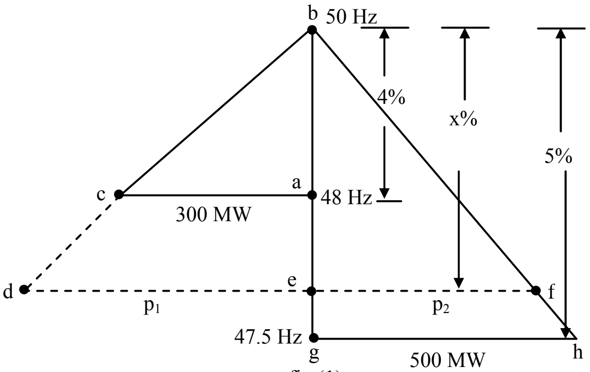


fig (1)

The rated powers are 300 MW and 500 MW.

Its rated frequencies are 48Hz, 47.5Hz, when both are connected in parallel the set must operate with the same frequency as shown dotted line in figure (1).

'P_1' is load shared by machine – 1 and 'P_2' is load shared by machine – 2 for both machines frequency drop is 'x' (say).

Triangle symmetry = Ratio of Base = Ratios of height

By triangle abc & ebd = Ratio of base = Ratios of height

$$= \frac{P_1}{300} = \frac{x}{4} \Rightarrow P_1 = 75x \;\ldots\ldots.\ (1)$$

By symmetrical triangle ebf & gbf

$$= \frac{P_2}{500} = \frac{x}{5} \Rightarrow P_2 = 100x \ldots\ldots\ldots\ (2)$$

But $P_1 + P_2 = 700$ MW(given)

$75x+100x = 700$

$\Rightarrow x = 4$

(a) Set frequency = 50 – x% of (50)

$$= 50 - \frac{4}{100}\times 50 = 48 \text{ Hz}$$

(b) Load shared by machine (1), $P_1 = 75x$

$= 75 \times 4 = 300$ MW

Load shared by machine (2), $P_2 = 100x$

$= 100 \times 4 = 400$ MW

06.

Sol: Given data:

(i) phase angle of load 1, $\phi_1 = \cos^{-1} 0.90$

$= 25.842^\circ$

Load kVAr; $kVAr_1 = P_1 \times \tan\phi_1$

$= 500 \times \tan 25.842$

$= 242.16$

(ii) phase angle of load 2, $\phi_2 = \cos^{-1} 0.8$

$= 36.869^\circ$

Load kVAr, $kVAr_2 = P_2 \times \tan\phi_2$

$= 1000 \times \tan 36.869^\circ$

$= 749.97$

(iii) phase angle of load 3, $\phi_3 = \cos^{-1} 1$

$= 0$

Load kVAr, $kVAr_3 = P_3 \times \tan\phi_3$

$= 0$

(iv) phase angle of load 4, $\phi_4 = \cos^{-1} 0.8$

$= -36.869^\circ$

Load kVAr, $kVAr_4 = P_4 \times \tan\phi_4$

$= 600 \times \tan(-36.869^\circ)$

$= -449.98$

$\therefore$ Total

$kVAr = kVAr_1 + kVAr_2 + kVAr_3 + kVAr_4$

$= 242.16+749.97+0-449.98$

$= 542.15$ kVAr

Total load (active power)

$= 500+1000+800+600 = 2900$ kW

Load supplied by machine-1 = 2000 kW

Reactive power supplied by m/c 1

$= 2000 \times \tan(\cos^{-1} 0.95)$

$= 657.368$ kVAr

Load supplied by machine-2

= 2900 – 2000 = 900 kW

kVAr supplied by machine 2

= 542.15 – 657.368 = −115.218

Phase angle of machine 2

$$\phi_2 = tan^{-1}\left(\frac{kVAr}{kW}\right)$$

$$= \tan^{-1}\left[\frac{115.218}{900}\right] = 7.295^\circ$$

∴ power factor of machine 2 = cos ϕ_2

= cos7.295

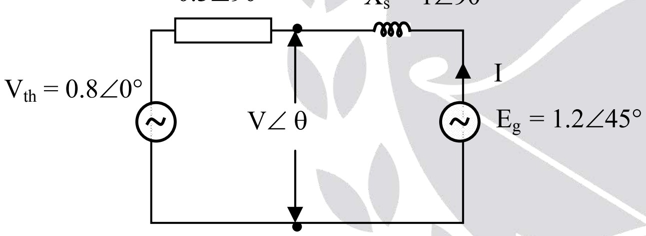
= 0.99 lead

07.

Sol: Given data, $V_{th} = 0.8\angle 0°$, $Z_{th} = 0.3\angle 90°$

$E_g = 1.2\angle 45°$ and $V_s = 1\angle 90°$

(a)



$$I = \frac{E_g - V_{th}}{Z_{th} + X_s} = \frac{1.2\angle 45° - 0.8\angle 0°}{0.3\angle 90° + 1.0\angle 90°}$$

$$= 0.65\angle -3.27°$$

From circuit,

$$V\angle\theta = E_g - IZ_s$$

$$= 1.2\angle 45° - (0.65\angle -3.27)1.0\angle 90°$$

= 0.834 ∠13.57°,

$$P = \frac{E_g V}{X_s}\sin(45° - 13.57°)$$

$$= \frac{1.2 \times 0.834}{1} \times 0.521$$

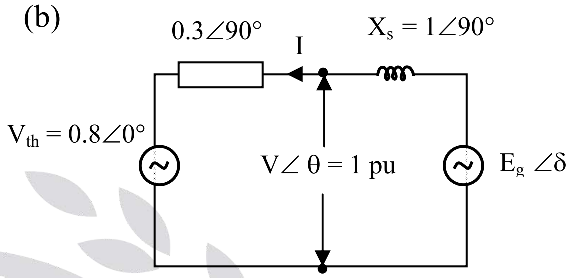
= 0.521 pu

$$Q = \frac{V}{X_s}\left[E_g \cos\delta - V\right]$$

$$= \frac{0.834}{1}\left[1.2\cos(31.43) - 0.834\right]$$

= 0.158 pu

(b)



For same active power transfer,

$$P = \frac{VV_{th}}{Z_{th}}\sin\theta$$

$$0.521 = \frac{1 \times 0.8}{0.3}\sin\theta$$

$\Rightarrow \theta = 11.26°$

$$\therefore I = \frac{V\angle\theta - V_{th}\angle 0°}{0.3\angle 90°} = \frac{1\angle 11.26 - 0.8\angle 0°}{0.3\angle 90°}$$

$$= 0.887\angle -42.7$$

Similarly

$$I = \frac{E_g\angle\delta - 1\angle 11.26}{1\angle 90°}$$

$$\Rightarrow E_g\angle\delta = 1\angle 11.26 + (0.887\angle -42.7)(1\angle 90°)$$

= 1.795 ∠28.13

= 1.795 pu

(c) Reactive power,

$$Q = \frac{V}{X_s}\left[E_g\cos\delta - V\right]$$

$$= \frac{1}{1}\left[1.795\cos(28.13 - 11.26) - 1\right]$$

= 0.717 pu

08.

Sol: Given, $V_L = 415$ V,

$R_a = 0.5\Omega/\text{ph}$, $X_s = 4\Omega/\text{ph}$

$$\Rightarrow \theta = \text{Tan}^{-1}\left(\frac{X_s}{R_a}\right) = 82.87°$$

At $I_a = 20$A, UPF:

$$E/ph = V_{ph} - I_a(R_a + jX_s)$$

$$= \frac{415}{\sqrt{3}} - 20(0.5 + j4) = 243\angle -19.2°$$

Now at $I_a = 50$ A and E/ph = $243\angle -\delta$,

δ = ?:

$$E\angle -\delta = V\angle 0° - I_a Z_s$$

$$I_a Z_s = \sqrt{V^2 + E^2 - 2EV\cos\delta}$$

$$50\times(4.03) = \sqrt{(239.6)^2 + (243)^2 - 2\times 239.6\times 243\cos(\delta)}$$

$\Rightarrow \delta = 49.36°$

$$P_{mech} = \frac{EV}{Z_s}\cos(\theta-\delta) - \frac{E^2}{Z_s}\cos\theta$$

$$= \frac{239.6\times 243}{4.03}\cos(82.87-49.36) - \frac{243^2}{4.03}\cos(82.87)$$

= 10.228 kW per phase

For 3-ϕ, $P_{mech} = 3\times 10.228 = 30.684$ kW

Torque developed, $\frac{P_{mech}}{\omega} = \frac{30.684}{2\pi\times\frac{1000}{60}}$

= 293.02 Nm

(b) **New p.f :**

$$I_a = \frac{V\angle 0° - E\angle -\delta}{Z_s\angle\theta}$$

$$= \frac{239.6 - 243\angle -49.3}{4.03\angle 82.87}$$

$= 50\angle -16.64$

Power factor $\cos\phi = \cos(16.64)$

= 0.958 lag

09.

Sol: Given, V = 500V, $R_a = 0.3\Omega/\text{ph}$

$X_s = 3\Omega/\text{ph}$

E = 600 V and (friction +core) loss = 1kW

P_{out} = 100 Hp = 73550W

Mechanical power developed

= P_{out} + losses

= 73.55 +1

= 74.55 kW

$$P_{mech} = \frac{3EV}{Z_s}\cos(\theta-\delta) - \frac{3E^2}{Z_s}\cos\theta$$

$$74.55\times 10^3 = \frac{600\times 500}{3.01}\cos(84.28-\delta) - \frac{600^2}{3.01}\cos(84.28)$$

374 = 500 cos (84.28 – δ) – 600 cos (84.28)

84.28 – δ = 29.81

$\delta = 54.46°$

Line current,

$$I_{ph} = \frac{V\angle 0° - E\angle -\delta}{Z_s\angle\theta}$$

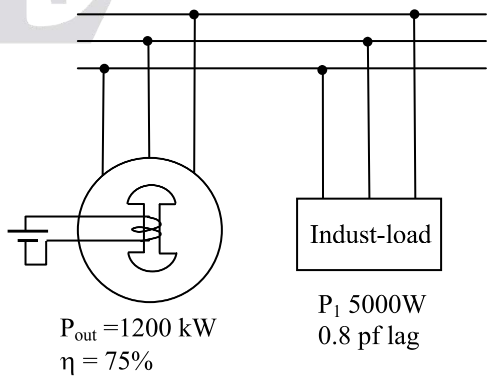
$$= \frac{\frac{500}{\sqrt{3}}\angle 0° - \frac{600}{\sqrt{3}}\angle -54.46}{3.01\angle 84.28}$$

$I_{ph} = I_L = 98.03\angle -11.49$

Power factor = cos (– 11.49) = 0.979 lag

10.

Sol:



Industrial – load 5000 kW

11 kV at 0.8 p.f lag

$$P_{in} = \frac{P_{out}}{\eta} = \frac{1200}{0.75} = 1600 \text{ kW}$$

Active power drawn by the synchronous motor, P_2 = 1600 kW

Active power drawn by Industrial load, P_1 = 5000 kW

Reactive power drawn by Industrial load

$Q_1 = P_1 \tan\phi$

= 5000 × tan (36.86)

= 3748.6 kVAR (lag)

Total active power drawn by the supply is

$P = P_1 + P_2$

= 5000 +1600

= 6600 kW

Total reactive power drawn from the supply is

$= P \tan\phi_2$

$= 6600 \tan[\cos^{-1}(0.9)]$

= 3196.52 kVAr (lag)

Reactive power supplied by the synchronous motor is = 3196.52 – 3748.6

= – 552 (lead)

Rating of synchronous motor,

$$S = \sqrt{P^2 + Q^2}$$

$$= \sqrt{(1600)^2 + (552)^2}$$

= 1692.5 kVA

Power factor of synchronous motor

$$= \frac{kW}{kVA} = \frac{P}{S} = \frac{1600}{1692.5}$$

= 0.94 leading

11.

Sol: 3-ϕ, 7 MVA, 11kV, Y-connected alternator

δ = 40° (load angle) $Z_s = 0 + j12\ \Omega$

[At synchronization E = V and same sequence]

At the time of synchronization floating conduction,

$$V_L = 11\text{kV} \Rightarrow V_{ph} = \frac{11\times10^3}{\sqrt{3}} = 6351\text{V}$$

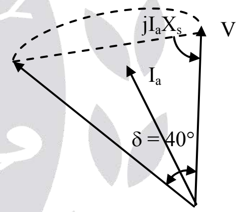
Now stream input is increased, then $\delta\uparrow, P\uparrow, I_a\uparrow$;

$Z_s = 0 + j12\Omega$ and δ = 40°

Under this condition,

Calculate : PF = P =

I_a = Q =



$$I_a = \frac{E\angle\delta - V\angle0^\circ}{Z_s\angle\theta} = \frac{6351\angle40^\circ - 6351\angle0^\circ}{12\angle90^\circ}$$

$I_a = 362.02\ \angle\ 20°$

PF = cosϕ = cos 20° = 0.9396 leading

(∵ E cosδ < V in floating constant)

$$P = \sqrt{3}V_L I_L \cos\phi = \frac{3EV}{X_s}\sin\delta$$

$$= \sqrt{3}\times 11\text{kV} \times 362 \times 0.939$$

P = 6.48 MW

$$Q = \frac{V}{X_s}(E\cos\delta - V)$$

$$= \frac{6391}{12}(6351\times\cos40^\circ - 6351)$$

$= -786.387$ kVAR

$Q_{Total} = 3\times(-786.3) = -2.35$ MVR

∴ Reactive power is absorbed from bus without change in steam input

- How can this alternator made to deliver zero reactive power

  ∴ Steam input is constant P = const = 6.48 MW

- The reactive power can be made zero by increasing the excitation then E increased say (E′) i.e machine has to operate at normal excitation

  $E' \cos \delta' = V$ ……. (1)

- Power is constant → E sin δ = constant

  $E\sin\delta' = E \sin \delta$ …….(2)

  From (1) & (2)

$$\frac{(2)}{(1)} = \frac{E'\sin\delta'}{E'\cos\delta'} = \frac{E\sin\delta}{V} = \frac{6351\sin 40°}{6351} = 0.6427$$

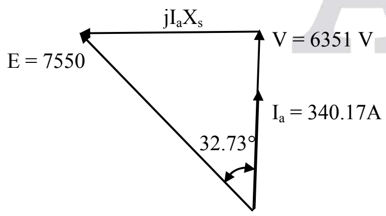
$\tan \delta' = 0.64$

$\Rightarrow \delta' = 32.73°$

$$E'\cos\delta' = V \Rightarrow E' = \frac{6351}{\cos(32.73°)} = 75501$$

$$I'_a = \frac{E'\angle\delta' - V\angle 0°}{Z_s\angle\theta} = \frac{750\angle 32.73 - 6351\angle 0°}{12\angle 90°}$$

$I'_a = 340.17\angle 0°$



12.

Sol: A 6MW, 3-ϕ, 11kV, Y connected

P= 6, f = 50 Hz P.F = 0.9 lead

i.e $\phi = 25.84°$

$X_s = 9\Omega$, $R_s = 0$, $I_{f(rated)} = 50A$

T_d = ?, I_f = ? at rated I_a, 750 rpm & 0.8 pF lead

At rated condition:

$$V_{ph} = \frac{11kV}{\sqrt{3}} = 6351V$$

$$N_s = \frac{120f}{P} = \frac{120\times 50}{6} = 1000 \text{ rpm}$$

$$\omega_s = \frac{2\pi N_s}{60}$$

$$= \frac{2\pi\times 1000}{60} = 104.72 \text{ rad}$$

$$I_L = \frac{P}{\sqrt{3}V_L\cos\phi} = \frac{6\times 10^6}{\sqrt{3}\times 11\times 10^3\times 0.9}$$

$I_L = 349.91A = I_{ph}$

$E = V\angle 0° - I_a\angle\pm\phi\, Z_s\angle\theta$

$= 6351\angle 0° - 349.91\angle 25.64\times 9\angle 90°$

$E = 8227.8\angle -20.15°$

At 750 rpm:

The speed is below rated value. Therefore, $\frac{V}{f}$ control is used.

$$N_s = \frac{120f}{P}$$

$$750 = \frac{120f}{6} \Rightarrow f = 37.5 \text{ Hz}$$

$$\frac{V}{f} = \text{const}$$

$$\therefore \frac{V_2}{V_1} = \frac{f_2}{f_1} \Rightarrow \frac{V_2}{6351} = \frac{37.5}{50}$$

$\Rightarrow$ $V_2 = 4763.25V$

and reactance depends on frequency which is

$X_s = 6.75\ \Omega$

The armature current in rated, i.e $I_a = 349.91A$

p.f = 0.8 lead

Then $E_2 = V_2 \angle 0° - I_a \angle \pm \phi\, Z_s \angle \theta$

$= 4763.25\angle 0° - 349.91\angle 36.86 \times 6.75\angle 90°$

$E_2 = 6462.53\angle -17°$

The field current I_f

$E \propto \phi f$

$$\frac{E_2}{E_1} = \frac{\phi_2}{\phi_1}.\frac{f_2}{f_1} = \frac{I_{f2}}{I_{f1}} \times \frac{f_2}{f_1}$$

$$\frac{6462.53}{8227.8} = \frac{I_{f2}}{50} \times \frac{37.5}{50}$$

$I_{f2} = 52.36$ A

$$\omega_s = \frac{2\pi \times 750}{60} = 78.5336$$

$P_{in} = \sqrt{3} V_L I_L \cos\phi$ [If resistance is neglected, losses are not there then $P_{in} = P_{out}$]

$$P_{in} = \sqrt{3}\left(\sqrt{3} \times 4763.25\right) \times 349.91 \times 0.8 = 4MW$$

$$T = \frac{P}{\omega} = \frac{4M}{78.5338} = 50.929 \text{ kN} - \text{m}$$

13.

Sol: A 3-ϕ, 11 kV, 10 MW, Y-connected, Alternator

$V_L = 11.8$ kV $\Rightarrow V_{ph} = \frac{11 \times 10^3}{\sqrt{3}} = 6351$ V

$Z_s = 0.8 + j8 = 8.04\angle(84.29 = \theta)$

$E_L = 14$ kV $\Rightarrow E_{ph} = \frac{14 \times 10^3}{\sqrt{3}}$

$= 8082.9$ V

$$\Rightarrow P_{max} = \frac{EV}{Z_s} - \frac{V^2}{Z_s}\cos\theta$$

$$= \frac{8082.9 \times 6351}{8.04} - \frac{6351^2}{8.04}\cos 84.29$$

$= 5.885$ MW

(i) $P_{max(Total)} = 3 \times 5.885 = 17.6551$ MW

(ii) $I_a = \frac{E\angle\delta - V\angle 0}{Z_s\angle\theta}$

$$= \frac{8082.9\angle 84.29 - 6351\angle 0}{8.04\angle 84.29}$$

$= 1215.18\angle 40.3°$A

p.f = $\cos 40.3^o = 0.7626$

14.

Sol: $V_1 = 400$V and $E = 480$V

$V_{ph} = \frac{400}{\sqrt{3}} = 230.9V$,

$E_{ph} = \frac{480}{\sqrt{3}} = 277.128V$

$P_{in} = \frac{EV}{X_s}\sin\delta$

$$\frac{10 \times 10^3}{3} = \frac{230.9 \times 277.12}{10}\sin\delta$$

(i) $\delta = 31.39°$

(ii) power factor

$$I_a = \frac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$$

$$= \frac{230.9\angle 0 - 277.12\angle -31.39^o}{10\angle 90}$$

$= 14.14\ \angle 2.24^o$

From the armature current $14.14\ \angle 2.24^o$, 2.24^o is the angle difference between V and I.

$\therefore \cos\phi = \cos(2.24^o) = 0.99$ lead

(iii) $I_a = 14.14$ A

15.

Sol: $V_L = 400\ V \Rightarrow V_{ph} = \frac{400}{\sqrt{3}} = 231\ V$

$Z_s = 0.5 + j4 = 4.031\angle(82.87 = \theta)$

At $I_a = 15$ A, UPF, calculate E

$E = V\angle 0 - I_a\angle\pm\phi\ Z_s\angle\theta$

$= 231\angle 0 - 15\angle 0 \times 4.031\angle 82.87$

$= 231 - 60.465\angle 82.87$

$= 231 - (7.5 + j60)$

$= 223.5 - j60 = 231.41\angle -15°$

⇒ If the load current is increases until line current is increased to 60 A, with the field current is kept constant.

∵ E = 231.41 V = constant

∵ Excitation = constant

$I_aZ_s = V\angle 0 - E\angle -\delta$

$= \sqrt{V^2 + E^2 - 2EV\cos\delta}$

$\Rightarrow 60 \times 4.031 =$

$\sqrt{231^2 + 231.41^2 - 2\times 231\times 231.41\cos\delta}$

$\Rightarrow \delta = 63.07°$

$I_a = \frac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$

$= \frac{231\angle 0 - 231.41\angle -63.07}{4.031\angle 82.87}$

$= \frac{231 - (104.8 - j20.6.31)}{4.031\angle 82.87}$

$= 60\angle -24.33$

∴ Power factor = cos24.33 = 0.911 lag

$P_{mech} = P_{in} -$ Cu losses

$= \sqrt{3}V_L I_L \cos\phi - 3I_a^2 R_a$

$= \sqrt{3}\times 400\times 60\times 0.911 - 3\times 60^2\times 0.5$

= 32469.55 W

$\Rightarrow$ Torque, $T = \frac{P}{\frac{2\pi N}{60}} = \frac{32469.55}{2\pi\times\frac{1000}{60}}$

= 310 N-m

4. Induction Machines

Solutions for Objective Practice Questions

01. Ans: (c)

Sol: General requirement for the production of rotating magnetic fields with three phase winding and three phase currents

(a) The three - phase winding must be physically displaced by 120° electrical in space

(b) The three phase currents allowed to flow through the above three windings must be time displaced by 120° electrical

Option (c) doesn't satisfy condition (a) that is, the three – phase winding are not physically displaced by 120° electrical in space

02. Ans: (d)

Sol: General requirement for the production of rotating magnetic fields with three phase winding and three phase currents

(a) The three - phase winding must be physically displaced by 120° electrical in space

(b) The three phase currents allowed to flow through the above three windings must be time displaced by 120° electrical

Option (d) satisfies both the conditions

03. Ans: (d)

Sol: For motoring, the stator poles and rotor poles must be equal. In the above case, the stator windings are wound for 4 poles, where as the rotor windings are wound for 6 poles. As the stator poles and rotor poles are unequal the torque developed is zero and speed is zero.

04. Ans: (c)

Sol: An inductin motor stator is replaced by a 6-pole stator, then the rotor poles will also be 6 poles, because in squirrel cage rotor, the rotor poles are induced pole. Then, the synchronous speed with 6 poles for 50 Hz supply is 1000 rpm Therefore, the rotor speed will be less than 1000 rpm

05. Ans: (c)

Sol: With the increase in the air gap, the reluctance of the magnetic circuit will be increase; because of this the motor draws more magnetizing current. Hence the power factor decreases.

06. Ans: (b)

Sol:
1. It helps in reduction of magnetic hum, thus keeping the motor quiet,
2. It also helps to avoid “Cogging", i.e. locking tendency of the rotor. The tendency of rotor teeth remaining under the stator teeth due to the direct magnetic attraction between the two,
3. Increase in effective ratio of transformation between stator & rotor,
4. Increased rotor resistance due to comparatively lengthier rotor conductor bars, to improve the starting torque & starting power factor
5. Increased slip for a given torque.

07. Ans: (a)

Sol: Advantages of open slots
1. Easy access of the winding without any problem, i.e the windings are reasonably accessible when individual coils must be replaced or serviced in the field.
2. Access to the former coils is easy, and winding procedure becomes easy.
3. Former coils are the winding coils formed and insulated completely before they are inserted in the slots.

They have less leakage reactance Leakage reactance is less as leakage flux is less , as a result the power transferred to rotor will be more and the maximum torque which depends on this power is also more

08. Ans: 4%

Sol: The frequency of generated emf by the alternator is given as

$$f = \frac{PN_{pm}}{120} = \frac{4\times 1500}{120} = 50\text{Hz}$$

The synchronous speed of Induction motor

$N_s = \frac{120f}{P} = \frac{120\times50}{6} = 1000$ rpm

$\%\ Slip = \frac{N_s - N_r}{N_s}\times100$

$= \frac{1000-960}{1000}\times100 = 4\%$

09. Ans: (a)

Sol: Given data: P = 4, N_r = 1440 rpm and f = 50 Hz

$N_s = \frac{120f}{P} = \frac{120\times50}{4} = 1500$ rpm

$Slip = \frac{N_s - N_r}{N_s} = \frac{1500-1440}{1500} = \frac{6}{150}$

The frequency in the rotor of induction motor is slip frequency (sf).

$\therefore$ Frequency of emf is, $\frac{6}{150}\times50 = 2$ Hz.

10. Ans:(c)

Sol: If the rotor is assumed to run at synchronous speed N_s in the direction of rotating magnetic fields, then there would be no flux cutting action, no emf in the rotor conductors, no currents in the rotor bars and therefore no developed torque. Thus, the rotor of 3-phase induction motor can never attain synchronous speed.

11. Ans:(d)

Sol: For 50 Hz, supply the possible synchronous speeds with different poles.

2 poles $\rightarrow$ 3000 rpm

4 poles $\rightarrow$ 1500 rpm

6 poles $\rightarrow$ 1000 rpm

8 poles $\rightarrow$ 750 rpm

10 poles $\rightarrow$ 600 rpm

12 poles $\rightarrow$ 500 rpm

20 poles $\rightarrow$ 300 rpm

We know that, the rotor of an induction motor always tries to rotate with speed closer to synchronous speed, there fore the synchronous speed closer to 285 rpm for 50 Hz supply is 300 rpm and poles are 20 poles. So its 20 poles induction motor

12. Ans: (d)

Sol: Synchronous speed of field is, $N_s = \frac{120f}{P}$

$\Rightarrow N_s = \frac{120\times50}{6}$

$= 1000$ rpm

When the rotor is rotating in the field direction,

$Slip = \frac{N_s - N_r}{N_s} = \frac{1000-500}{1000} = 0.5$

Rotor frequency sf = 0.5× 50 = 25 Hz.

13. Ans: (d)

Sol: Synchronous speed of field is,

$N_s = \frac{120f}{P}$

$\Rightarrow N_s = \frac{120\times50}{4} = 1500$ rpm

Case (i):

When the rotor is rotating in the field direction,

$$\text{Slip} = \frac{N_s - N_r}{N_s} = \frac{1500-750}{1500} = 0.5$$

Rotor frequency sf = 0.5× 50 = 25 Hz.

Case (ii):

When the rotor is rotating in opposite direction of field.

$$\text{Slip} = \frac{N_s + N_r}{N_s} = \frac{1500+750}{1500} = 1.5$$

Rotor frequency sf = 1.5× 50 = 75 Hz.

14. Ans:(d)

Sol: Synchronous Machine:

Prime mover speed,

$$N_{pm} = \frac{120f}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

The rotor speed of induction motor is fixed at 1500 rpm.

Induction Machine:

For obtaining a frequency of 150 Hz at induction motor rotor terminals the rotating field and rotor must run in opposite directions.

$$150 = \frac{\frac{120\times 50}{P_{in}} + 1500}{\frac{120\times 50}{P_{in}}} \times 50$$

$$\Rightarrow 3 = \frac{6000 + 1500\times P_{in}}{6000}$$

$$\Rightarrow 12000 = 1500\times P_{in}$$

$$\Rightarrow P_{in} = 8$$

For obtaining a frequency of 150 Hz at induction motor rotor terminals the rotating field and rotor must run in same directions.

The induction machine is in generating mode.

$$150 = \frac{1500 - \frac{120\times 50}{P_{in}}}{\frac{120\times 50}{P_{in}}} \times 50$$

$$\Rightarrow 3 = \frac{1500\times P_{in} - 6000}{6000}$$

$$\Rightarrow 24000 = 1500\times P_{in}$$

$$\Rightarrow P_{in} = 16$$

15. Ans: (c)

Sol: We can run with two phases but the motor winding will get heated up, because of over loading the motor with power on two phases and with third phase completely absent.

16. Ans: (c)

Sol: Synchronous speed of field is,

$$N_s = \frac{120f}{P} = \frac{120\times 50}{6}$$

$$= 1000 \text{ rpm}$$

When the rotor is rotating in opposite direction of field.

$$\text{Slip} = \frac{N_s + N_r}{N_s} = \frac{1000+1000}{1000} = 2$$

Slip frequency, sf = 2 × 50

= 100 Hz.

17. Ans: (c)

Sol: If any two leads from slip rings are interchanged in a 3-phase induction motor, the motor will run in a direction opposite to previous one

The direction of rotation in a 3- phase motor depends upon the sequence in which the magnetic poles are created by the respective phase lines. This in turn creates a rotating magnetic field. By interchanging any two phases (lines) the sequence of pole formation is being changed i.e., the direction of the rotating magnetic field is reversed. Hence the direction of rotation of the motor also changes accordingly.

18. Ans: (a)

Sol: P = 4, f = 50 Hz, $R_1 = 0.4\ \Omega$, $I_L = 20$ A and $P_m = 550$ W

Stator copper losses = $3I^2R_1$/phase

$$= 3\times\left(\frac{20}{\sqrt{3}}\right)^2\times 0.4$$

= 160 W

Airgap power $P_r = 4000 - 160$

= 3840 W

Internal torque developed = $\frac{60}{2\pi N_s}P_r$

$$= \frac{60}{2\pi\times 1500}\times 3840$$

= 24.45 Nm

19. Ans: (c)

Sol: Slip frequency sf = 3 Hz

$$\Rightarrow s = \frac{3}{50}$$

Gross mechanical power outut

$P_G = (1-s)P_r$

$$= \left(1-\frac{3}{50}\right)\times 3840 = 3609.6\text{ W}$$

Net mechanical power output,

$P_{net} = 3609.6 - 550 = 3059.6$ W

$$\%\text{ efficiency} = \frac{P_{net}}{P_{input}}\times 100 = \frac{3059.6}{4000}\times 100$$

= 76.49%

20. Ans: 0.154

Sol: I_r/phase = 45 A, s = 3%,

$P_{net} = 40\times 746 = 29.840$ kW

$P_{stator} = 0.05\times$ (input power)

$P_m = 0.015\times 29.840 = 0.4476$ kW

Gross mechanical power output P_G

= 29.840 + 0.4476 = 30.2876 kW

Rotor copper loss = $\frac{s}{1-s}\times P_G$

$$= \frac{0.03}{1-0.03}\times 30.2876$$

$3I_r^2R_2/\text{Phase} = 0.9376$ kW

$$\Rightarrow R_2/\text{Phase} = \frac{0.9367\times 10^3}{3\times 45\times 45} = 0.154\ \Omega$$

21. Ans: 86.97 %

Sol: P = 6, f = 60 Hz, $P_{input} = 48$ kW,

$N_r = 1140$ rpm

$P_s = 1.4$ kW, $P_i = 1.6$ kW, $P_m = 1$ kW

Airgap power (P_r) = $P_{input} - P_s - P_i$

$= 48 - 1.4 - 1.6$

$= 45$ kW

Slip $s = \dfrac{N_s - N}{N_s} = \dfrac{1200-1140}{1200} = 0.05$

Gross mechanical power output,

$P_G = (1 - s)P_r$

$= (1 - 0.05) \times 45$

$= 42.75$ kW

Net mechanical power outut,

$P_{net} = P_G - P_m$

$= 42.75 - 1$

$= 41.75$ kW

% efficiency = $\dfrac{P_{net}}{P_{input}} \times 100$

$= \dfrac{41.75}{48} \times 100 = 86.97\%$

22. Ans: 796.5

Sol: P = 4, f = 50 Hz, P_0 = 48.65 kW,

$P_m = 0.025 \times P_0$ and s = 0.04

Gross mechanical power $P_G = P_0 + P_m$

$= 18.65 + (0.025 \times 18.65)$

$= 19.11625$ kW

Rotor copper losses = $\dfrac{s}{(1-s)} \times P_G$

$= \dfrac{0.04}{1-0.04} \times 19.11625$

$= 0.7965$ kW $= 796.5$ Watt

23 Ans: 46.18

Sol: f = 50 Hz, P = 6, P_r = 40 kW, N_r = 960 rpm, R_2/Phase = 0.25 Ω

I_r/phase = ?

Slip $s = \dfrac{1000-960}{1000} = 0.04$

Rotor copper losses = s × Rotor input

$= 0.04 \times 40 \times 10^3$

$= 1600$ Watt

$3I_r^2 R_2 / \text{Phase} = 1600$

$\Rightarrow I_1/\text{Phase} = \sqrt{\dfrac{1600}{3\times 0.25}} = 46.18$ A

24. Ans: (b)

Sol: $\tau_{em} = 500$ Nm, $V_2 = 0.5 V_1$

$\tau_{em} \propto V^2$

$\Rightarrow \dfrac{\tau_{em1}}{\tau_{em2}} = \left(\dfrac{V_1}{V_2}\right)^2$

$\Rightarrow \tau_{em2} = (0.5)^2 \times 500 = 125$ Nm

25. Ans: (c)

Sol: Given induced emf between the slip ring of an induction motor at stand still (Line voltage), $V_{slirings} = 100$ V

For star connected rotor windings, the induced emf per phase when the rotor is at stantnd still is given by

$E_{20} = \dfrac{V_{sliprings}}{\sqrt{3}} = \dfrac{100}{\sqrt{3}} = 57.7$ V

In general, rotor current, neglecting stator impedaance is

$I_2 = \dfrac{E_{20}}{\sqrt{\left(\dfrac{R_2}{s}\right)^2 + X_{20}^2}}$

For smaller values of slip, s = $\frac{R_2}{s}$ >>>x_{20}

Then the equation for rotor current

$$I_2 = \frac{E_{20}}{\frac{R_2}{s}} = \frac{sE_{20}}{R_2} = \frac{0.04 \times 57.7}{0.4} = 5.77\ A$$

26. Ans: 1.66

Sol: The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000\ rpm$$

Given, the rotor speed of induction motor, at maximum torque

N_{rTmax} = 940 rpm

Therefore, per unit slip at maximum torque,

$$s_{Tmax} = \frac{N_s - N_{rTmax}}{N_s} = \frac{1000 - 940}{1000} = 0.06$$

We have, slip at maximum torque is given by $s_{Tmax} = \frac{R_2}{x_{20}}$

From this,

$$x_{20} = \frac{R_2}{s_{Tmax}} = \frac{0.1}{0.06} = 1.66\ \Omega$$

27. Ans: (a)

Sol: Given rotor resistance per phase R_2 = 0.21 Ω

Stand still rotor reactance per phase X_{20} = 7 Ω

We have slip at maximum torque given by

$$s_{Tmax} = \frac{R_2}{X_{20}} = \frac{0.21}{7} = 0.03$$

The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500\ rpm$$

Rotor speed at maximum torque is given by

$N_{rTmax} = N_s(1 - s)$

$= 1500(1 - 0.03) = 1455$ rpm

28. Ans: (c)

Sol: Synchronous speed, N_s = 1200 rpm, Rotor speed N_{r1} = 1140 rpm

$$\text{Slip } s_1 = \frac{N_{s1} - N_{r1}}{N_{s1}} = \frac{1200 - 1140}{1200} = 0.05$$

Applied voltage v_1 = 215 V

We have $T = k\frac{sv^2}{R_2}$; From sv^2 = constant

$$s_1 v_1^2 = s_2 v_2^2$$

$$s_2 = \frac{s_1 v_1^2}{v_2^2} = \frac{0.05 \times 215^2}{240^2} = 0.04$$

$N_{r2} = N_s(1 - s_2) = 1200(1 - 0.04)$

$= 1152$ rpm

29. Ans: 90 Nm

Sol: T_{max} = 150 N-m

Rotor speed at maximum torque,

N_{rTmax} = 660 rpm

The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750\ rpm$$

Slip at maximum torque,

$$s_{Tmax} = \frac{N_s - N_{rTmax}}{N_s} = \frac{750 - 660}{660} = 0.12$$

Operating slip s = 0.04

We have $\frac{T}{T_{max}} = \frac{2 \times s \times s_{T\max}}{s^2 + s_{T\max}^2}$

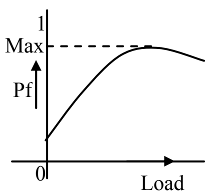
$$= \frac{2 \times 0.12 \times 0.04}{0.04^2 + 0.12^2} = 0.6$$

$$\frac{T}{T_{max}} = 0.6$$

T = 0.6 × 150 = 90 N-m

30. Ans: (d)

Sol: Power factor of an induction motor on no-load is very low because of the high value of magnetizing current. With load the power factor increases because the power component of the current is increased and a stage comes after which as load further increase the over all power factor starts slowly decreasing. Low power factor operation is one of the disadvantages of an induction motor. An induction motor draws a heavy amount of magnetizing current due to presence of air gap between the stator and rotor (unlike a transformer). The reduced the magnetizing current in an induction motor, the air gap is kept as small as possible. It is therefore usual to find the air gap of induction motor smaller than any other type of electrical machine.



31. Ans: 192

Sol: The synchronous speed of the motor is

$$N_s = \frac{120}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Given T_{max} = 200 N-m

Rotor speed at maximum torque,

N_{rTmax} = 1400 rpm

Slip at maximum torque

$$s_{Tmax} = \frac{N_s - N_{rT\max}}{N_s} = \frac{1500 - 1400}{1400}$$

$$= 0.06667$$

Operatin slip s = 0.05

We have $\frac{T}{T_{max}} = \frac{2 \times s \times s_{T\max}}{s^2 + s_{T\max}^2}$

$$= \frac{2 \times 0.06667 \times 0.05}{0.05^2 + 0.06667^2} = 0.96$$

T = 0.96 × 200 = 192 N-m

32. Ans: 0.029

Sol: Given rotor resistance per R_2 = 0.025 Ω

Stand still rotor reactance per phase,

X_{20} = 0.12 Ω

We have slip at maximum torque given by

Let $s_{Tmax} = \frac{R_2 + R_{ext}}{X_{20}}$, for $T_{st} = \frac{3}{4} T_{max}$

$$\frac{T_{st}}{T_{max}} = \frac{2 \times s_{T\max}}{s_{T\max}^2 + 1} = \frac{3}{4}$$

$$s_{T\max}^2 - \frac{8}{3} s_{T\max} + 1 = 0$$

Solving for s_{Tmax} we have s_{Tmax} = 0.45

$$0.45 = \frac{0.025 + R_{ext}}{0.12}$$

$R_{ext} = 0.029\ \Omega$

33. Ans: (b)

Sol: The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Given T_{max} = 520 N-m, slip at maximum torque $s_{Tmax} = 0.2$

Given, $T_{max} \propto s_{Tmax}$

Therefore, $T_{max} = ks_{Tmax}$

$$k = \frac{T_{max}}{s_{T_{max}}} = \frac{520}{0.2} = 2600$$

and also, $T_{fl} \propto s_{fl}$, $T_{fl} = ks_{fl}$

Full load net mechanical power

$P_{net} = 10$ kW

Mechanical losses $P_{ml} = 600$ W = 0.6 kW

$P_{gmd} = P_{net} + P_{ml} = 10 + 0.6 = 10.6$ kW

$$\text{Rotor input, } P_{ri} = \frac{P_{gmd}}{(1 - s_{fl})} = \frac{10.6 \times 10^3}{(1 - s_{fl})}$$

$$T_{fl} = \frac{P_{ri}}{\omega_s} = \frac{60}{2\pi N_s}\frac{10.6 \times 10^3}{(1 - s_{fl})}$$

$$= \frac{60}{2 \times 3.14 \times 1000}\ \frac{10.6 \times 10^3}{(1 - s_{fl})}$$

$$= \frac{101.27}{(1 - s_{fl})} = \frac{101.27}{(1 - s_{fl})} = 2600s_{fl}$$

Solving for s_{fl} , we have $s_{fl} = 0.0405$

$N_{rfl} = N_s(1 - s_{fl}) = 1000(1 - 0.00405)$

$= 959.5$ rpm

34. Ans: (a)

Sol: Given Line voltage (supply),

$V_L = 420$ V

Stator impedance $Z_1 = R_1 + jX_1$

$= 0.07 + j0.3$

From this $R_1 = 0.07\ \Omega$, $x_1 = 0.3$

Standstill rotor impedance referred to stator,

$Z_{20} = R_2 + jX_{20} = 0.08 + j0.37$

From this $R_2^1 = 0.08\ \Omega$ & $X_2^1 = 0.37\ \Omega$

Phase voltage (assuming stator windings are connected in star)

$$V_{1ph} = \frac{420}{\sqrt{3}} = 242.5 \text{ V}$$

$$s_{mm} = \frac{R_2^1}{R_2' + \sqrt{(R_2' + R_{th})^2 + (X_{th} + X_2')^2}}$$

Where

s_{mm} is slip corresponding to maximum internal mechanical power developed. As magnetizing current is neglected there is no need to find out R_{th} and X_{th}, in place we can use, R_1 and X_1, therefore, slip for maximum internal mechanical power developed is

$$s_{mm} = \frac{R_2^1}{R_2' + \sqrt{(R_2' + R_1)^2 + (X_1 + X_2')^2}}$$

$$= \frac{0.08}{0.08 + \sqrt{(0.07 + 0.08)^2 + (0.3 + 0.37)^2}}$$

$= 0.1044$

35. Ans: (a)

Sol: $P_{gmdmax} = 3I_{2mm}^2 R_2^1\left(\frac{1}{s_{mm}} - 1\right)$

$$I'_{2mm} = \frac{V_1}{\sqrt{\left[\left(R_1 + \frac{R'_2}{s_{mm}}\right) + (X_1 + X'_2)^2\right]}}$$

$$= \frac{242.5}{\sqrt{\left(0.07 + \frac{0.08}{0.1044}\right)^2 + (0.3 + 0.37)^2}}$$

= 266.25 A

$$P_{gmdmax} = 3I_{2mm}^2 R_2^1 \left(\frac{1}{s_{mm}} - 1\right)$$

$$= 3 \times 226.25^2 \times 0.08 \left(\frac{1}{0.1044} - 1\right)$$

= 105.38 kW

36. Ans: (c)

Sol: Slip at maximum internal torque developed

$$s_{Tmax} = \frac{R'_2}{\sqrt{R_1^2 + (X_1 + X_2^1)^2}}$$

$$= \frac{0.08}{\sqrt{0.07^2 + (0.3 + 0.37)^2}} = 0.1187$$

37. Ans: (e)

Sol: $$I'_{2T\,max} = \frac{V_1}{\sqrt{\left[\left(R_1 + \frac{R'_2}{s_{T\,max}}\right)^2 + (X_1 + X'_2)^2\right]}}$$

$$= \frac{242.5}{\sqrt{\left(0.07 + \frac{0.08}{0.1187}\right)^2 + (0.3 + 0.37)^2}}$$

= 242.2 A

$$\mathbf{T_{max}} = \frac{180}{2\pi N_s} I'^2_{2T\,max} \frac{R'_2}{s_{T\,max}}$$

$$= \frac{180}{2 \times 3.14 \times 1000} \times 242.2^2 \times \frac{0.08}{0.1187}$$

= 1133 N-m

38. Ans: (c)

Sol: Given data P = 4, I_{BR} = 100 A,

$W_{BR} = 3I_{BR}^2 R_{01}$ = 30 kW

T_{st} = ?

At starting, Rotor input = Rotor copper losses.

$$\tau_{st} = \frac{60}{2\pi N_s}\left(3I_{BR}^2 R_2\right)$$

Here R_2 us rotor resistance refer to primary side of machine

Given $R_1 = R_2 = \frac{R_{01}}{2}$

$$\tau_{st} = \frac{60}{2\pi \times 1500} \times \left(\frac{3I_{BR}^2 R_{01}}{2}\right)$$

$$= \frac{60}{2\pi \times 1500} \times \frac{30 \times 10^3}{2}$$

= 95.49 Nm

39. Ans: (c)

Sol: This method is used in the case of motors, which are built to run normally with a delta connected stator winding. It consists of a two-way switch, which connects the motor in star for starting and then in delta for normal running. When star connected, the applied voltage over each phase is reduced by factor $\frac{1}{\sqrt{3}}$ and hence the torque developed becomes 1/3 of that which would have been developed if motor were directly connected in delta. The line current is reduced to 1/3. Hence during starting period when motor is star connected, it takes 1/3rd as much starting current and develops 1/3 rd as much torque as would have been developed it directly connected in delta.

40. Ans: (c)

Sol: $I_{ac} = 400A; k = 0.7$

$$I_{st,\,supply} = k^2 I_{sc} = 0.7^2 \times 400 = 196A$$

41. Ans: (a)

Sol: $\dfrac{\text{Starting line current with stator winding in star}}{\text{Starting line current with stator winding in delta}} = \dfrac{1}{3}$

Starting line current with stator winding in delta (DOL) = 3×Starting line current with stator winding in star

= 3×50

=150A

42. Ans: (a)

Sol: $N_{set} = \dfrac{120f}{P_1 + P_2} = \dfrac{120 \times 50}{10} = 600$ rpm

43. Ans: 559.3

Sol: Given full load net mechanical power output, P_{net} = 500kW

Stator Input at full load, $P_{si} = \dfrac{P_{net}}{\eta}$

$$= \frac{500}{0.92} = 543.478\text{kW}$$

$$P_{si} = \sqrt{3} V_L I_{fi} \cos\phi$$

$$I_{f\ell} = \frac{P_{si}}{\sqrt{3} V_L \cos\phi}$$

$$= \frac{543.478 \times 10^3}{\sqrt{3} \times 66 \times 10^3 \times 0.85} = 55.93A$$

Short circuit current I_{sc}=10×55.93 A= 559.3A

44. Ans: 60.7%

Sol: Let I_{fl} be the full load current,

$$I_{f\ell} = \frac{70}{Z_{01}}$$

Short circuit current with rated voltage is

$$I_{sc} = \frac{380}{70} I_{f\ell} = 5.431_{f\ell}$$

Starting current drawn from the line

$I_{st,s} = 2 \times I_{fl}$

But we know that,

$$I_{st,s} = k^2 \times I_{sc}; 2 \times I_{f\ell} = k^2 \times 5.43 I_{f\ell}$$

K = 60.7%

45. Ans: (a)

Sol: $T_{st} = \dfrac{1}{4} T_{f\ell}$

$I_{sc} = 4I_{fl}$

we have for auto transformer starting

$$\frac{T_{st}}{T_{f\ell}} = k^2 \left(\frac{I_{sc}}{I_{f\ell}}\right)^2 s_{f\ell}$$

$$\frac{1}{4} = k^2 \times 4^2 \times 0.03$$

K = 72.2%

46. Ans: 2.256

Sol: Given full load net mechanical power output, P_{net} = 12kW

Stator Input at full load,

$$P_{si} = \frac{P_{net}}{\eta} = \frac{12}{0.85} = 14.1176\text{kW}$$

$$P_{si} = \sqrt{3}V_L I_{f\ell} \cos\phi$$

$$I_{f\ell} = \frac{P_{si}}{\sqrt{3}V_L \cos\phi}$$

$$= \frac{14.1176\times10^3}{\sqrt{3}\times440\times0.8} = 23.14\text{A}$$

Short circuit current,

$$I_{sc} = 45\times\frac{440}{220} = 90\text{A}$$

In star delta starter, $I_{st} = \frac{90}{\sqrt{3}} = 52\text{A}$

The ratio of starting to full load current

$$\frac{I_{st}}{I_{f\ell}} = \frac{52}{23.14} = 2.256$$

47. Ans: (d)

Sol: Starting current with rated voltage,

I_{sc} = 300 A

Full load current, I_{fl} = 60 A

The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120\times50}{6} = 1000\text{ rpm}$$

Given, the rotor speed of induction motor at full load $N_{r\,fl}$ = 940 rpm

Therefore, per unit slip at full load,

$$S_{T\max} = \frac{N_s - N_{rf\ell}}{N_s} = \frac{1000-940}{1000} = 0.06$$

Full load torque, T_{fl} = 150 N – m

For DOL starter, we have

$$\frac{T_{st}}{T_{f\ell}} = \left(\frac{I_{sc}}{I_{f\ell}}\right)^2 S_{f\ell} = \left(\frac{300}{60}\right)^2 \times 0.06 = 1.5$$

T_{st} = 1.5×150 = 225 N – m

When star delta starter is used,

$T_{st} = \frac{1}{3}$ times starting torque with

DOL starter = $\frac{1}{3}225 = 75\text{ N}-\text{m}$

$I_{st} = \frac{1}{3}$ time starting current with

DOL starter = $\frac{1}{3}\times300 = 100\text{A}$

49. Ans: (c)

Sol: Application of Capacitor Start IM and Capacitor Start Capacitor Run IM

These motors have high starting torque hence they are used in conveyors, grinder, air conditioners, compressor, etc. They are available up to 6 KW.

Application Permanent Split Capacitor (PSC) Motor:

It finds applications in fans and blowers in heaters and air conditioners. It is also used to drive office machinery.

Applications of Shaded Pole Motor:

Due to their low starting torques and reasonable cost these motors are mostly employed in small instruments, hair dryers, toys, record players, small fans, electric clocks etc. These motors are usually available in a range of 1/300 to 1/20 kW.

50. Ans: (d)

Sol: Phase shift between capacitor current and inductor current is 180 degrees.

51. Ans: (b)

Sol: when an induction motor refuses to start even if voltage is applied to it, this is called as cogging. This happens when the rotor slots and stator slots are same in number or they are integer multiples of each other. Due to this the opposite poles of stator and rotor come opposite to each other and get locked and motor refuses to start. The is particularly observed in squirrel cage induction motor, when started with low voltages

On the other hand when an induction motor runs at a very low speed ($1/7^{th}$ of synchronous speed) even if full rated voltage is applied to it, then it is called at Crawling. This happens due to harmonic induction torques. in which torques due to 7^{th} harmonic overpower the driving Torque(fundamental component torque

52. Ans: (b)

Sol: The synchronous speed of the motor is

$$N_s = \frac{120f}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

Given, the rotor speed of induction motor

$N_r = 1440$ rpm

Therefore, per unit slip,

$$S = \frac{N_s - N_r}{N_s} = \frac{1500-1440}{1500} = 0.04$$

The frequency of induced emf in the rotor winding due to negative sequence component is

$f_{2ns} = (2 - s)f = (2 - 0.04)\times 50 = 98$ Hz

53. Ans: (c)

Sol: Single phasing is a condition in three phase motors and transformers wherein the supply to one of the phases is cut off. Single phasing causes negative phase sequence components in the voltage. Since, motors generally have low impedances for negative phase sequence voltage. The distortion in terms of negative phase sequence current will be substantial. Because of negative sequence component current, negative sequence current torque develops, which reduces the total torque and speed.

Solutions for Conventional Practice Questions

01.

Sol: Given data, 460 V, 100 Hp, 50 Hz, P = 4, s = 0.05

(a) $N_s = \frac{120\times f}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$

$N = N_s(1 - s)$

$= 1500\,(1 - 0.05)$

$= 1425$ rpm

(b) Synchronous speed w.r.t stator = 1500 rpm

(c) Rotor frequency is slip frequency

$= sf$

$= (0.05) \times 50 = 2.5$ Hz

(d) Slip rpm

$$= \frac{120(sf)}{P}$$

$$= \frac{120 \times 2.5}{50} \Rightarrow 75\,\text{rpm}$$

(e) (i) Speed of rotor field w.r.t rotor

= 75 rpm

(ii) w.r.t stator = 1500 rpm

(iii) w.r.t stator rotating field = '0'

Since the relative velocity between stator field and rotor field is zero.

(f) Let us consider primary connection is 'Y' connection

$$K = \frac{N_2/ph}{N_1/ph} = \frac{E_2/ph}{E_1/ph} = \frac{0.5}{1}$$

$$\therefore E_2 = \frac{460/\sqrt{3}}{2}$$

At the operating speed, s = 0.05

$$\therefore sE_2 = 0.05 \times \frac{230}{\sqrt{3}} = 6.63\text{ V}$$

02.

Sol: Given data, consider connection is star connection

$V_{ph} = 460, I_{ph} = 25$ A, $\cos\phi = 0.85$

$P_{sc} = 1$ kW, $P_{rc} = 500$ W, $P_I = 800$ W,

$P_m = 250$ W & stray load loss = 200 W

Input power $= 3V_{ph}I_{ph}\cos\phi$

$= 3 \times 460 \times 25 \times 0.85$

= 29,325 W

(i) Airgap power = Input power – ($P_{sc} + P_I$ + stray load loss)

= 29,325 – 2000

= 27325 W (or) 27.325 kW

(ii) Developed mechanical power = Air gap power – P_{rc}

= 27.325 – 0.5

= 26.825 kW

(iii) shaft power = 26.825 – P_m

= 26.825 – 0.25

= 26.575 kW

= 35. 67 Hp

(iv) $$\eta = \frac{\text{shaft power}}{\text{Input power}} \times 100$$

$$= \frac{26.575}{29.325} \times 100 = 90.62\%$$

03.

Sol: Given data,

Synchronous machine P = 4 & f = 60 Hz

$$\therefore N_s = \frac{120 \times 60}{4} = 1800\,\text{rpm}$$

Induction machine P = 6 & f = 60 Hz

$$N_s = \frac{120 \times 60}{6} \Rightarrow 1200\,\text{rpm}$$

But shaft is rotate with the speed 1800 rpm only.

slip in induction machine $s = \frac{N_s - N}{N_s}$

$$= \frac{1200 - 1800}{1200} = -0.5$$

For induction generator operation slip is negative

(a) Speed of rotor = 1800 rpm

Frequency of the current = sf

$= 0.5 \times 60$

$= 30$ Hz

Power generated by the Induction machine is [i.e air gap power]

$$\text{Air gap power} = \frac{\text{load power loss}}{\text{slip}}$$

$$= \frac{1}{0.5} = 2 \text{ pu}$$

Power taken by the Induction machine is

– 2 p.u

Therefore the synchronous motor has to supply the load power loss and generated power by the induction machine.

$\therefore$ Air gap power + power loss

= 3 p.u

(b) Now slip $= \dfrac{N_s + N}{N_s}$

$$= \frac{3000}{1200} = 2.5$$

Speed of rotor = 1800 rpm

Frequency of the current = sf

$= 2.5 \times 60$

$= 150$ Hz

Power taken by the induction machine is

$$= \frac{\text{load power loss}}{s}$$

$$= \frac{1}{2.5} = 0.4 \text{ p.u}$$

Power taken by the synchronous machine = power loss – power taken by the induction machine

$= 1 - 0.4 = 0.6$ p.u

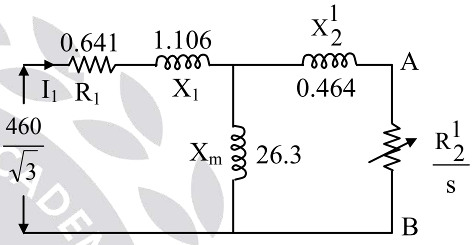
04.

Sol: Given data, $V_L = 460$ V, 25 Hp, 60 Hz, P = 4

$R_1 = 0.641$, $X_1 = 1.106$

$R_2^1 = 0.332, X_2^1 = 0.464$

$X_m = 26.3$



Find Z_{AB} and V_{AB}

$$Z_{AB} = \frac{(R_1 + jX_1)jX_m}{R_1 + j(X_1 + X_m)} + jX_2^1$$

$$= \frac{(0.641 + j(1.106))j(26.3)}{0.641 + j(1.106 + 26.3)} + j0.464$$

$$= \frac{-29.08 + 16.8i}{0.641 + 27.406i} + j0.464$$

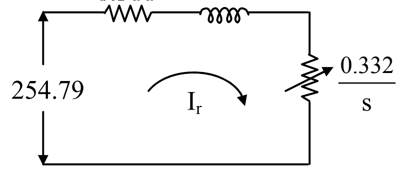
$Z_{AB} = 0.588 + j1.539$

V_{AB} :

$$I_1 = \frac{460/\sqrt{3}}{\sqrt{(0.641)^2 + (1.106 + 26.3)^2}}$$

$= 9.688$A

$V_{AB} = I_1X_m \Rightarrow 9.688 \times 26.3 = 254.79$ V



(a) For slip at maximum torque

$$\frac{0.332}{s} = \sqrt{(0.588)^2 + (1.539)^2}$$

$s_m = 0.202$

Rotor current I_r at slip s_m is

$$I_r = \frac{254.79}{\sqrt{\left(0.588 + \frac{0.332}{s_m}\right)^2 + (1.539)^2}}$$

$= 93.879A$

maximum torque

$$T_{max} = \frac{180}{2\pi N_s} \times I_1^2 \times \frac{R_2^1}{s}$$

$$= \frac{180}{2\pi \times 1800} \times (93.879)^2 \times \frac{0.332}{0.202}$$

$= 230.5$ N-m

Speed $N_r = N_s(1 - s_m)$

$= 1800\,(1 - 0.202)$

$= 1436.4$ rpm

(b) Find rotor current I_r at slip s = 1

$$I_r = \frac{254.79}{\sqrt{(0.588 + 0.332)^2 + (1.539)^2}}$$

$= 142.101$ A

Starting torque

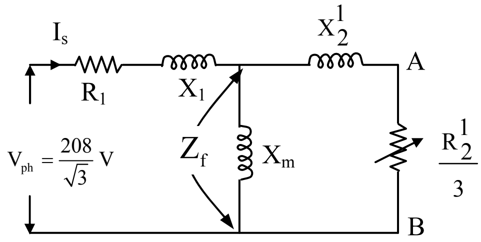
$$T_{st} = \frac{180}{2\pi N_s} I_r^2 R_2$$

$$= \frac{180}{2\pi \times 1800} \times (142.101)^2 \times 0.332$$

$= 106.69$ N-m

05.

Sol:



Induction machine:

Assume connection is star connection

$$V_{ph} = \frac{208}{\sqrt{3}}$$

(a) At 17108 rpm, Induction machine acts as motor

(b) $N_r = N_s\,(1-S)$

$$N_s = \frac{120 \times 60}{4} = 1800\text{rpm}$$

Now $N_r = 1710$ rpm

$$\therefore S = 1 - \frac{1710}{1800} = \frac{90}{1800} = 0.05$$

At s = 0.05

$$R_L = \frac{0.35}{3} = 7\Omega$$

$$Z_f = \frac{j38(7+1.1j)}{j38+7+j1.1} = 6.40 + j2.21\Omega$$

Total impedance of machine is

$= 6.40 + j2.21 + 0.25 + j0.55$

$= 6.65 + j2.76$

$$I_s = \frac{208/\sqrt{3}}{6.65 + j2.76} = 16.7\angle -22.5°$$

(c) Real power $= 3V_{ph}I_{ph}\cos\phi$

$$= 3 \times \frac{208}{\sqrt{3}} \times 16.7 \cos 22.5$$

$= 5558.47$W

Reactive power $= 3V_phI_{ph}\sin\phi$

$$= 3\times\frac{208}{\sqrt{3}}\times 16.7\sin 22.5 = 2302.3\ \text{VAr}$$

(d) Rotor current

$$I_2' = I_s\left[\frac{jX_m}{\frac{R_2'}{s}+jX_2'+jX_m}\right]$$

$$= I_s\left[\frac{j38}{7+j1.1+j38}\right]$$

$$= [16.7\angle{-22.5°}][0.957\angle 10.15]$$

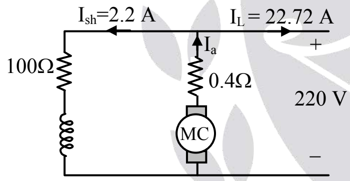
$$I_2' = 15.97\angle{-12.34}$$

Copper loss in the rotor $= 3\left(I_2'\right)^2 R_2'$

$$= 3(15.97)^2 \times 0.35$$

$$= 267.79$$

(e) Assume that machine acts as generator and that 5 kW is output at full load.



$I_L = \frac{5000}{220} = 22.72\ \text{A}$ and

$I_{sh} = \frac{220}{100} = 2.2\ \text{A}$

For rated speed 1750 rpm,

$E_{g1} = 220 + 24.92 \times 0.4 = 229.97$ V

For 1710 rpm

$E_{g2} = \frac{1710}{1750}\times 229.97 = 224.74$

Now armature current $I_a = \frac{224-220}{0.4}$

$= 11.77$ A

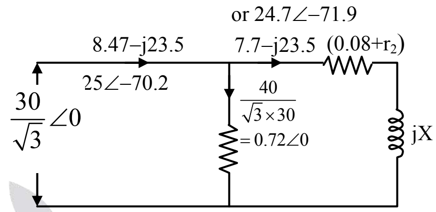
06.

Sol: Given data, $V_L = 30$ V, $I_L = 25$

$\sqrt{3}\,V_L I_L \cos\theta_{sc} = 440$

$\Rightarrow \cos\theta_{sc} = \frac{440}{\sqrt{3}\times 30\times 25} = 0.34$

$\Rightarrow \theta_{sc} = 70.20°$



$R_{dc} = 0.1\Omega$

$\therefore\ R_{ac} = 0.1 \times 1.6$

$= 0.16\ \Omega$

$R_1/\text{ph} = \frac{R_{ac}}{2} = 0.08\ \Omega$

The rotor impedance is

$\frac{30/\sqrt{3}}{24.7} = \sqrt{(0.08+r_2)^2 + x^2}$

$0.49 = (0.08+r_2)^2 + x^2$ ………. (1)

From rotor circuit,

$\tan(71.9) = \frac{x}{0.08+r_2}$

$x = 3.05(0.08+ r_2)$

$x^2 = 9.36(0.08+r_2)^2$ ……….. (2)

From (1) & (2)

$0.49 = \frac{x^2}{9.36} + x^2$

$\Rightarrow$ Reactance/phase = 0.665 Ω

From (1)

Rotor resistance/phase

$= (0.49 - 0.442)^{\frac{1}{2}} - 0.08$

$= 0.1375\ \Omega$

Stator resistance/phase = 0.08 Ω

07.

Sol: Given data, E_2 = 100V, E_j = ± 20V

Now $sE_2 = E_j$

s×100 = 20 (for in phase)

⇒ s = 0.2

Similarly, for opposition s = – 0.2

Now $N_r = N_s(1-s)$

We know that, $N_s = \dfrac{120 \times 50}{4}$

= 1500rpm

N_r = 1500 (1–0.2) = 1200 rpm

And N_r = 1500 (1+0.2) = 1800rpm