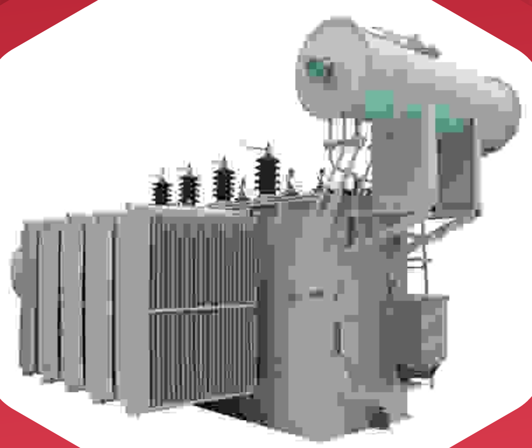
GATE | PSUs

ELECTRICAL ENGINEERING

Electrical Machines

Text Book : Theory with worked out Examples and Practice Questions



HYDERABAD | AHMEDABAD | DELHI | BHOPAL | PUNE | BHUBANESWAR | BANGALORE | LUCKNOW
PATNA | CHENNAI | VISAKHAPATNAM | VIJAYAWADA | TIRUPATHI | KOLKATA

Electrical Machines

(Solutions for Volume-1 Class Room Practice Questions)

1. Transformers

01. Ans: (b)

Sol: Given data: 400/200 V 50 Hz

B_{max} = 1.2 T

800V, 50 Hz linear dimension all double

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

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

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

$$= 7.2 \times 10^{-2} m^2$$

$$\frac{EMF}{TURN} = 4.44 \times 1 \times 7.2 \times 10^{-2} \times 50 = 16\text{ V}$$

03. Ans: (d)

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

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

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

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 $E_2 = M\,\frac{di}{dt}$

$$E_2 = \frac{400}{\pi} \times 10^{-3} \times 10 \times 100\pi \cos(100\pi t)$$

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

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

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)

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

$$= \sqrt{(3.2)^2 - (0.218)^2} = 3.192 \text{ A}$$

$I_{N2} = 4.51$A

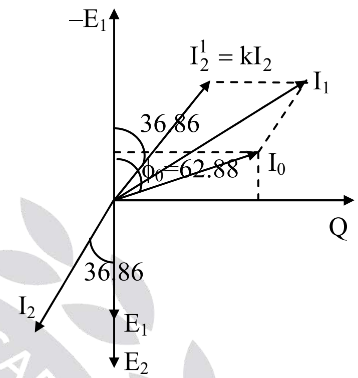
$$I_0 = \sqrt{I_w^2 + I_N^2}$$

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

$$= 4.556 \text{ A}$$

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 $\sin\phi_0 = 0.89$

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

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

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

($\therefore$ $I_2' = KI_2 = 0.1 \times 40 = 4$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(a). Ans: (c)

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

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

$$= 90.76\angle -37.77\text{A}$$

Voltage at the load,

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

$= 453.8\ \angle -0.91$ V

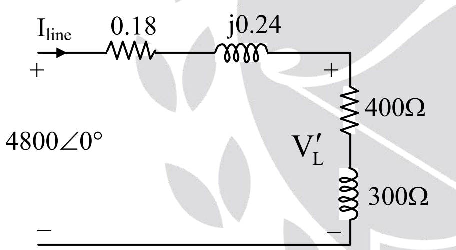
And power loss in tr.line $= (I_{line})^2 \times 0.18$

$= (90.76)^2 \times 0.18$

$= 1482$ W

8(b). Ans: (c)

Sol: The equivalent circuit w.r.t secondary of transformer T_1, and w.r.t primary of transformer T_2 is



$$I_{line} = \frac{4800}{0.3\angle 53.13 + 500\angle 36.96}$$

$$= 9.59\angle -36.86 \text{ A}$$

Power loss in tr. line $= (9.6)^2 \times 0.18$

$= 16.58$ W

And voltage

$$V_L' = (9.59\angle -36.86) \times (500\angle 36.86)$$

$= 4795$V

Now the load voltage $V_L = \frac{V_L'}{10}$ V

$= 479.5$

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

$W_e \propto v^2$

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

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

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

10. Ans: (a)

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

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

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

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

FL cu loss = %R × VA rating

= 0.01 ×20,000 = 200 Watt

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

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

At 90.9A ⇒ Cu loss = 200 W

85A ⇒ Cu loss = ?

Cu loss at

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

Total loss when 14.96 kW o/p

= Iron loss + cu loss at 85A

= 160+174.8

= 334.8 W

Input power = 14.96 kW+334.8W

= 15294.8W

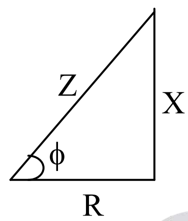
14. Ans: (a)

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

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

$X_2 = 0.2611\ \Omega$

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

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

$Z = 0.281\Omega$

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

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

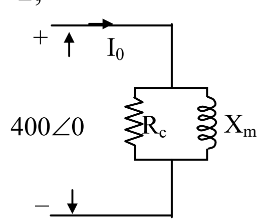
15. Ans: (a)

Sol: Given data:

10 kVA, 400/200 V,

W_0 = 100 watt and M =2H.

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



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

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

$\Rightarrow 2\times\pi\times50\times 4 = 400\pi\Omega$

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

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

$= 0.41$ A

16. Ans: (d)

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

$W_h = W_e = 10$W

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 $W_e \propto f^2$.

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

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

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

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

$W_i + W_{Cu} = 0.0204$ ……..(1)

For 1/2 full load

$$0.98 = \frac{1 \times 1 \times 0.5}{0.5 \times 1 \times 1 + W_i + 0.25 W_{Cu}}$$

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

By solving equation (1) & (2)

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

$$\eta_{3/4} = \frac{0.75 \times 1 \times 1}{0.75 \times 1 \times 1 + 6.8 \times 10^{-3} + (0.75)^2 \times 0.0136}$$

$= 98.1\%$

19. Ans: (a)

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

$$= \sqrt{\frac{6.8 \times 10^{-3}}{0.0136}} = 0.707$$

$$\eta_{max} = \frac{0.707 \times 1 \times 1}{0.707 \times 1 \times 1 + (2 \times 6.8 \times 10^{-3})} \times 100$$

$= 98.1$ %

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 = ?

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

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

$$= \sqrt{\frac{50}{80}} \times 10\,kVA = 7.9\,kVA$$

21. Ans: (c)

Sol: $$\eta_{\substack{max\\0.8pf}} = \frac{7.9 \times 0.8 \times 10^3}{7.9 \times 08 \times 10^3 + (2 \times 50)} \times 100$$

$= 98.44$ %

22(a). Ans: (c)

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

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

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

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

$= 0.024$

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

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

22(b) . Ans: (b)

Sol: The kVA at maximum efficiency is

$E_2 \times I_{2max} = 200 \times 100$

$= 20$ kVA

$$\eta_{\substack{max \\ at\,0.8pf}} = \frac{20 \times 0.8 \times 10^3}{20 \times 0.8 \times 10^3 + 2 \times 240} \times 100 = 97.1\%$$

23. Ans: (c)

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

$$0.98 = \frac{15k \times 0.1}{15k \times 1 + 2W_i}$$

$W_i = 153.06$W

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

kW = kVA $\times\cos\phi$

kW = 20 × 1 = 20 kW

kWh output = 20×12 = 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

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

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

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

$= \dfrac{6377.5}{500\times10^3}\times100$

$= 1.27\ \%$

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

26. Ans: (b)

Sol: Terminal voltage = ?

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

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

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

$= (1.27\times0.283) + (4.317\times0.959)$

% VR = 4.49% = 0 .0449 Pu

Total voltage drop on secondary side

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

$= 0.0449\times400 = 18V$

$V_2 = E_2$ – Voltage drop

$= 400 - 18 = 382V$

27. Ans: (a)

Sol: $R_{02} = R_1' + R_2$

$X_{02} = X_1' + X_2$

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

$R_1' = \left(\dfrac{1}{10}\right)^2\times3.4$

$= 0.034$

$X_1' = k^2X_1$

$= (0.01\times7.2)$

$= 0.072$

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

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

$\%\text{ Reg} = \dfrac{I_2R_{02}\cos\phi_2 \pm I\ X_2\sin\phi_2}{V_2}$

$I_2 = 22.72$ A

$\text{Reg} = \dfrac{22.72\times0.062\times0.8 + 22.72\times0.132\times0.6}{220}$

Reg = 0.0133

% Reg = 1.33% is same on both sides

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

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

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

$= 2\times0.8 + 5\times0.6 = 4.6\%$

$= 0.046$ pu

Voltage drop when with respect to secondary

= p.u. VR × secondary Voltage

$= 0.046\times440 = 20.2V$

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

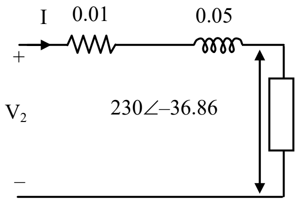
30. Ans: (c)

Sol: $R_{pu} = 0.01$

$X_{pu} = 0.05$

$V_1 = 600V$

$V_2 = 230V, 0.8$ 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

$E_2 = V + Iz$

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

$= 238.85\angle 1.87$

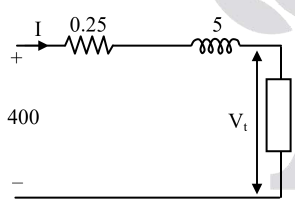
Turns ratio $= \dfrac{E_1}{E_2} = \dfrac{600}{238.85} = 2.5$

31. Ans: (c)

Sol: $P = VI\cos\phi$

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

$\Rightarrow \phi = 38.624$



From given data,

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

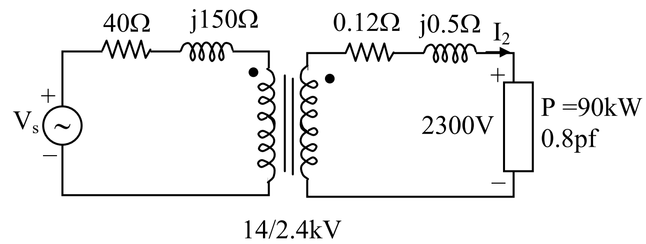
$\Rightarrow V_t = 352.08\angle{-9.81}$

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

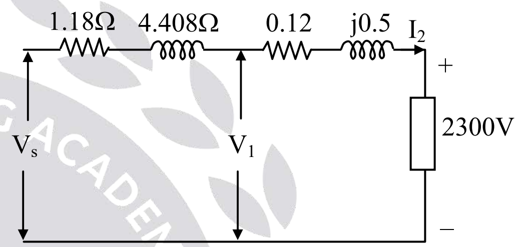
$= 70.4$ V

32. Ans: (*)

Sol:



The equivalent circuit refer to L.V side is



$I_2 = \dfrac{90 \times 10^3}{2300 \times 0.8} = 48.91A$

Where V_1 = voltage applied across the transformer.

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

$= 2300 + 48.91[0.12 \times 0.8 + 0.5 \times 0.6)$

$= 2300 + 19.36$

$V_1 = 2319.36V$

% Regulation$= \dfrac{2319.36 - 2300}{2400} \times 100$

$= 0.807\%$

33. Ans: 96.7%

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

$= (48.91)^2 \times 1.3$

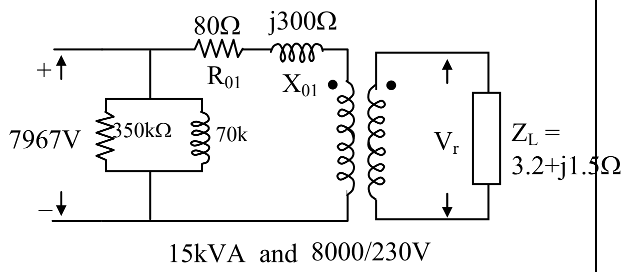
$= 3109.8$ W

$\% \eta = \dfrac{90 \times 10^3}{90 \times 10^3 + 3109.8} \times 100$

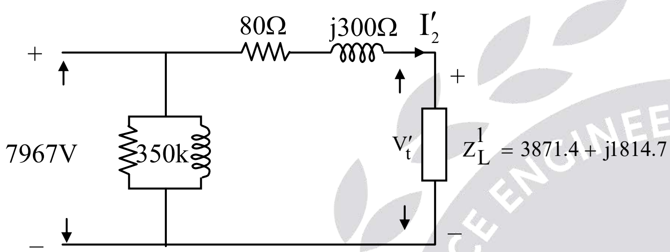
$= 96.67\%$

34. Ans: 218.8

Sol:



Equivalent circuit refer to H.V side is



$Z_L^1 = 4275.6\angle 25.11$

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

$= 310.48\angle 75.06$

$$I_2^1 = \frac{7967}{310.48\angle 75.06 + 4275.6\angle 25.11}$$

$= 1.78\angle -28.15A$

$V_1' = I_2' \times Z_L'$

$= (1.78\angle -28.15) \times (4275.6\angle 25.11)$

$= 7600.6\angle -3.04$

$$\text{Now } V_t = \frac{7600.6 \times 230}{8000}$$

$= 218.52\angle -3.04$

35. Ans: 4.9%

Sol: Voltage regulation = $\dfrac{E_2 - V_t}{E_2} \times 100$

$$= \frac{230 - 218.52}{230} \times 100$$

$= 4.9\%$

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

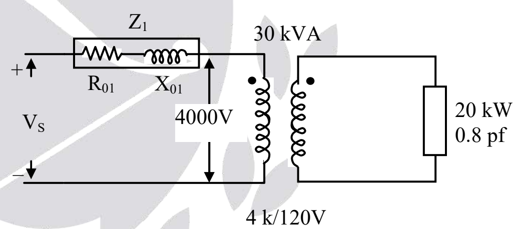
The copper losses for 208.33 A is

$$\left(\frac{208.33}{250}\right)^2 \times 180 = 124.99 \text{ watt}$$

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

$= 98.88\%$

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

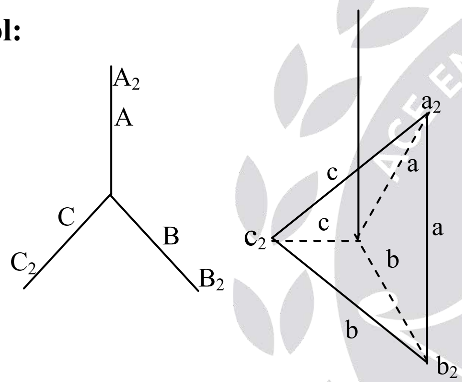
$$V_S = V_2' + I_2'[R_1 \cos\phi + X_1 \sin\phi]$$

$= 4000 + 6.24[3.2 \times 0.8 + 16.98 \times 0.6]$

$= 4079.5$ V

37. Ans: (b)

Sol:

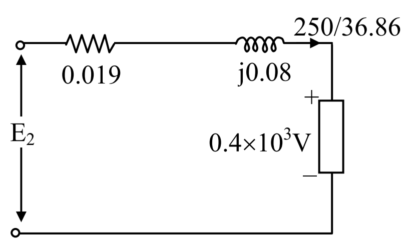


$\therefore$ The Possible Connection is Yd1

38. Ans: (a)

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

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



$$I_2 = \frac{P}{V} = \frac{100 \times 10^3}{0.4 \times 10^3} = 250\angle +36.86$$

$E_2 = 392\angle 2.75$ 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 = $\frac{\text{primary induced voltage}}{\text{secondary induced voltage}}$

secondary induced phase voltage

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

% Reg = % R cosϕ + % X sinϕ

[$\because$ 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

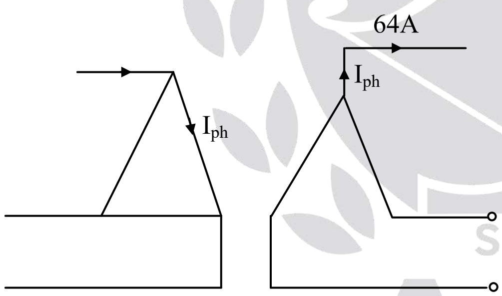
$P_{o/p}$ of induction motor = 36.77 kW

$P_{i/p}$ to induction motor (or) power output of transformer $= \frac{P_{o/p}}{\eta} = \frac{36.77}{0.85} = 40.85\text{kW}$

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

$$= 63.06\ \angle 31.78^o$$

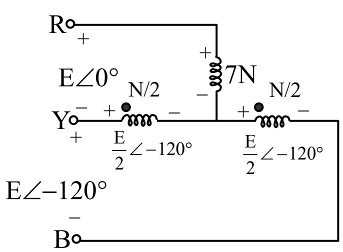
$$\approx 64\text{ A}$$



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

43. Ans: (c)

Sol:



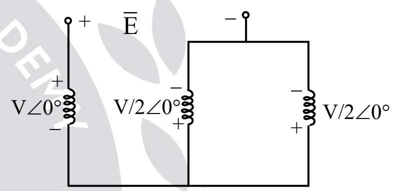
$$E\angle 0° = \bar{V}_{Rs} - \frac{E}{2}\angle -120°$$

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

$$= \frac{\sqrt{3}}{2}E\angle -30°$$

44. Ans: (d)

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



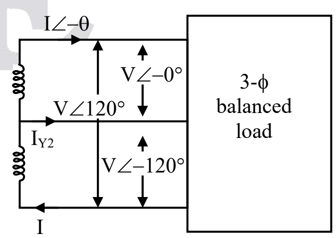
KVL:

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

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

45. Ans: (b)

Sol:



I_{Y2} is −120° lagging w.r.t I∠−θ (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 $\bar{z}_{e2} = 0.04(0.3 + j0.953) = 0.012 + j0.0381$ 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. $\bar{S}_1 = \bar{S}\dfrac{\bar{z}_{e2}}{\bar{z}_{e1} + \bar{z}_{e2}}$

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

$$= 460\angle -36.1°\text{ kVA}$$

$S_2 = (460)(\cos 36.1^{o})$ 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 = $\dfrac{245}{200}$

$= 1.225$ pu

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

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

$= 0.92$ 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 $\dfrac{E_2 - V_2}{E_2} = 0.029546$

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

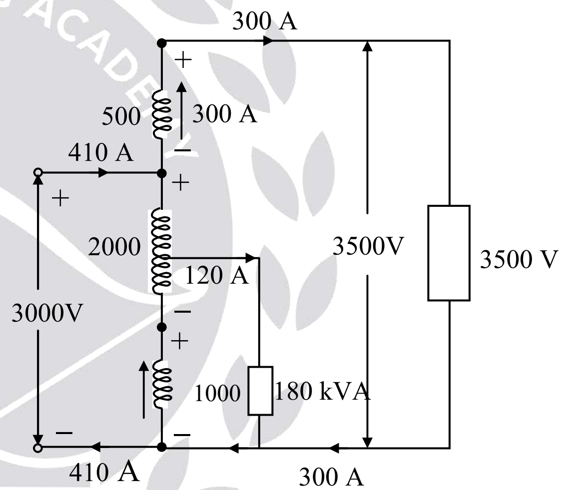
$\therefore$ Rating of AT $= E_{pry} \times I_{pry}$

$= 600 \times 150$

$= 90$ 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

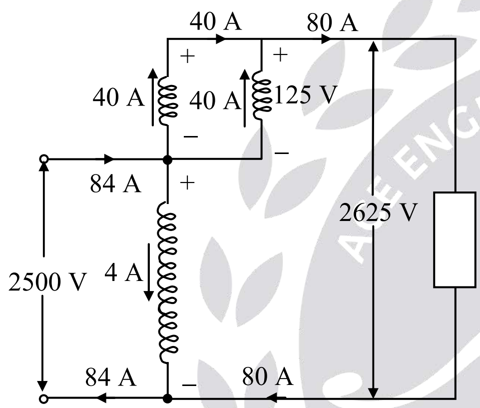
The total current taken from the supply main is $= \frac{1230{,}000}{3000} = 410\text{A}$

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

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

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

$\therefore$ Auto –transformer kVA rating

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

54. Ans: (a)

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

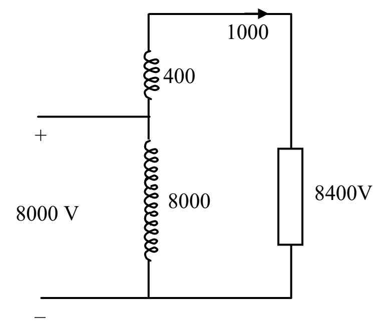
kVA transformed = (1−K) kVA_{AT} and

kVA conducted = 210–10

= 200 kVA.

55. Ans: (d)

Sol:



Current through 480 V winding is

$$I_2 = \frac{480 \times 10^3}{480} = 1000A$$

kVA rating of auto transformer

= 8400 × 1000 = 8.4 MVA

For two winding transformer

$$= 0.978 = \frac{480 \times 10^3 \times 1}{480 \times 10^3 + W}$$

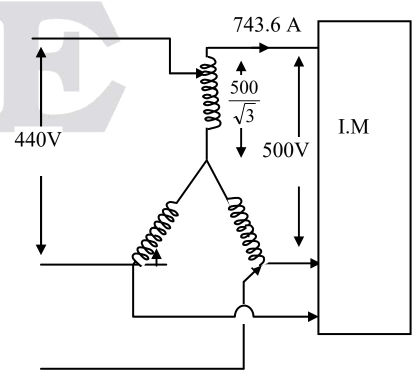
W = 10.79 kW

$$\text{Efficiency} = \frac{8.4 \times 10^6 \times 1}{8.4 \times 10^6 \times 1 + 10.79 \times 10^3} \times 100$$

= 99.87%

56. Ans: (a)

Sol:



$$I_2 = \frac{610 \times 0.745 \times 10^3}{\sqrt{3} \times 500 \times 0.8 \times 0.882}$$

= 743.69A

By equation

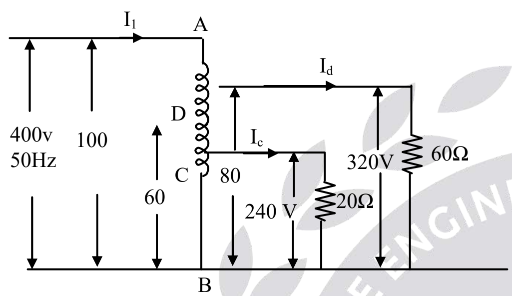
$$\frac{500}{\sqrt{3}} \times 743.6 = \frac{440}{\sqrt{3}} \times I_1$$

$I_1 = 845.11$ A

$I_1 - I_2 = \approx 100$ A

57. Ans: (a)

Sol:



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

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

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

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

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

VA rating fo 20Ω load is $240 \times I_c = 240 \times 12 = 2880VA$

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

$= 320 \times 5.33 = 1705.6$ VA

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

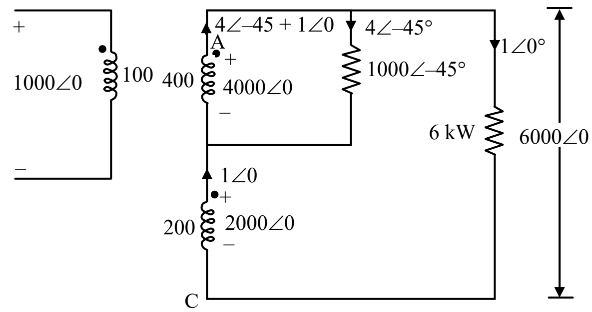
$= \frac{2880 + 1705.6}{400}$

$I_1 = 11.464$ 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 = $400 \times 4.75 \angle -36..55 + 200\angle 0$

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

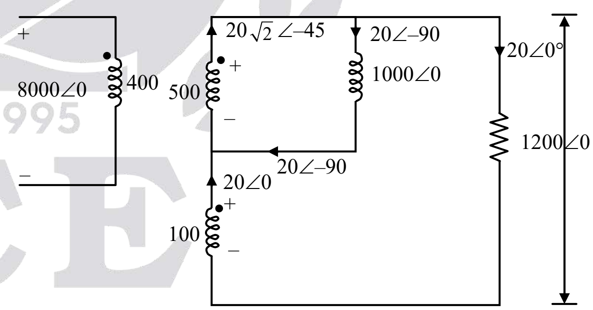
$= 1726.3 - j\,1131.5$

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 = $\dfrac{15620.4\angle -39.8}{400}$

= 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

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

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

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

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

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

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

$I_1 = 14A$

p.f = cos(39.6) = 0.77 lag

61. Ans: (a)

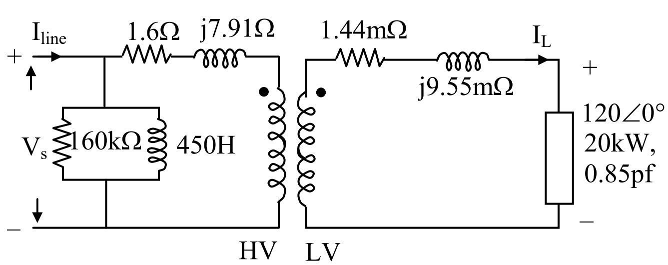
Sol: Given R_1 = 1.6Ω, L_1 = 21mH, R_2 = 1.44mΩ, f = 60Hz, L_2 = 19μH, R_c = 160kΩ,

L_m = 450 H, P = 20 kW, V_2 = 120V and cosϕ = 0.85lag.

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

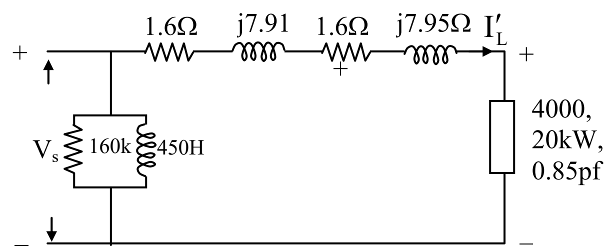
$X_2 = 2\pi fL_2 = 2\times\pi\times60\times19\times10^{-6} = 9.55\ m\Omega$

The equivalent circuit is,



4000/120

Equivalent circuit referred to H.V side.



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

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

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

$= 4000 + 65.12$

$= 4065.12$

$V_s \approx 4066V$

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

Cu losses:

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

$\Rightarrow 5.88\times2\times1.6 = 110.63W$

Core losses:

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

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

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

= 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 $\mu_r = 1000$

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

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

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

$$= 500^2 \times 100 \times 10^{-7}$$

$$= 2.5\text{H}$$

2. DC Machines

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

Sol: Given data:

$P = 8$, $A = 8$ ($\because$ lap wound)

No. of conductors, $Z = 60 \times 22$

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

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 = ?

$$\text{Pole pitch} = \frac{2\pi r}{P} = \frac{\pi D}{P} = \frac{\pi\times0.6}{8}$$

Pole arc = 0.64 × pole pitch

Area of pole shoe A = pole arc × l

$$= 0.64\times\frac{\pi\times0.6}{8}\times0.3$$

$$= 0.0452 \text{ m}^2$$

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

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

$$400 = \frac{0.25\times0.0452\times60\times22\times N\times8}{60\times8}$$

$\Rightarrow$ N = 1609 rpm

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

Sol: Given data:

$V_t = 250$ V, ϕ = constant

$R_a = 0.1\ \Omega$

$P_1 = 100$ kW and $P_2 = 150$ kW

Case (i):

$$P_1 = V_t I_{a1}$$

$100 \text{ k} = 250 \times I_{a1}$

$\Rightarrow I_{a1} = 0.4 \times 10^3$ A

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

$= 250 + 400 \times 0.1$

$= 290$ V

Case (ii):

$$P_2 = V_t I_{a2}$$

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

$\Rightarrow I_{a2} = 600$ A

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

$= 250 + 600 \times 0.1$

$= 310$ V

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

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

$$\%\text{ Increase in speed} = \frac{N_2 - N_1}{N_1}\times100$$

$$= \left(\frac{N_2}{N_1} - 1\right)\times100$$

$$= \left(\frac{310}{290} - 1\right)\times100$$

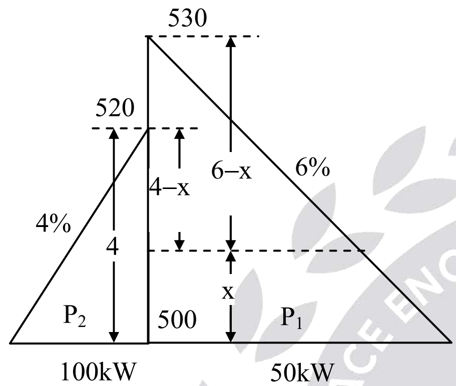
$$= 6.9\%$$

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

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

$= 503.75$ 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 $\phi \propto \frac{I_f}{1+0.5I_f}$

$N_0 = 1000$ rpm and N_1=1500 rpm

R_e = ?

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

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

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

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

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

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

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

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

$\therefore I_{f1} = 1$ A

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

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

$\Rightarrow R_f + R_e = 2\ R_f$

$\Rightarrow R_e = 100\ \Omega$

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

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

= 4973.33 watt

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

= 49.7333.33 W

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

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

Armature current I_a = 99.46 –2 = 97.46 A

Shunt copper los, $I_f^2 R_{sh}$ = 4 × 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)

$\therefore$ Loss power (P_l) = 4973 – 1000 – 1900

= 2073 W

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

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

= 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 = $(I_a)^2 R_a$

= $(97.46)^2 \times 0.2$

= 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

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

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

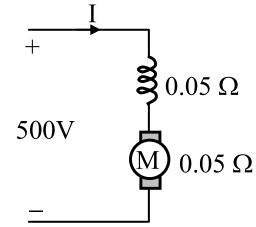
10. Ans: -0.062 Ω (update key)

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

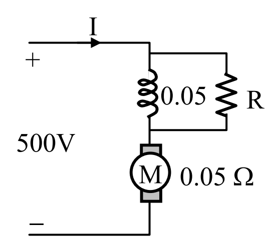
Copper losses = $(335.1)^2 \times 0.1$

= 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 = $900 \times 1200 \times \frac{2\pi}{60}$

$= 900 \times 40\pi$

$= 36000\pi$ 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 = $\frac{W_\ell}{\left(\frac{1200 \times 2\pi}{60}\right)}$ 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)

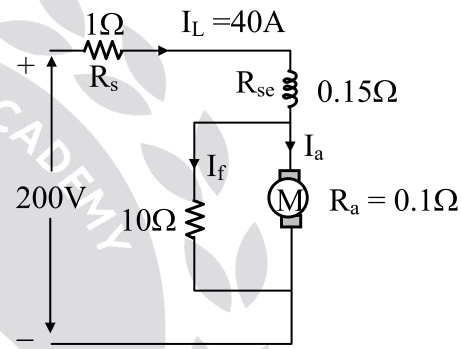
Sol: Given data: N_1 = 1500rpm I_L = V0A

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,

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

$$\Rightarrow N_2 = \frac{151.54 \times 1500}{190}$$

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

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

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

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

$\Rightarrow E_b^1 = -85.96V$

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

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

13(d). Ans: –129 V

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

$E_b \propto$ speed

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

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

$$= 121.1\text{V}$$

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

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

$$= 128.9\text{V}$$

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 × Speed

In region (3) , Power (+ve) = –T_e × – Speed

Therefore, region (1) and (3) comes under motering mode.

In region (2), Power (–ve) = T_e × (– Speed)

In region (4), Power (–ve) = –T_e × Speed

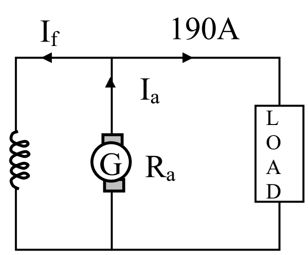
Therefore, region (2) and (4) comes under regenerating mode.

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 Watt

Stray loss +Shunt Copper loss+Armature Copper loss = 5277.7

$$\text{Shunt copper loss} = \frac{V^2}{R_{sh}} = \frac{250^2}{125} = 500\text{W}$$

∴ Armature copper loss,

$$\left(I_2^2 R_a\right) = 5277.7 - 800 - 500$$

$$I_a^2 R_a = 3977.7$$

Where, $I_a = I_L + I_f$

$$= 190 + \left(\frac{250}{125}\right) = 192\text{A}$$

$$\therefore R_a = \frac{3977.7}{192^2} = 0.1079\Omega$$

16. Ans: (a)

Sol: At maximum effeiciency,

Variables losses = Constant losses

$I_a^2 R_a$ = Stray loss+shunt copper loss

= 800+500

$$I_a^2 = \frac{1300}{0.107} \Rightarrow I_a = 110.2\text{A}$$

3. Synchronous Machines

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. $\Rightarrow \quad Ns_1 = Ns_2$

$$\Rightarrow \frac{120f_1}{p_1} = \frac{120f_2}{p_2}$$

$$\Rightarrow \frac{f_1}{f_2} = \frac{p_1}{p_2}$$

$$\Rightarrow \frac{p_1}{p_2} = \frac{50}{60} = \frac{5}{6} = \frac{10}{12}$$

$$\Rightarrow \quad p_1 : p_2 = 10 : 12$$

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

Slot angle $\gamma = \dfrac{P \times 180}{s} = 20°$

$$K_d = \frac{\sin n\frac{m\gamma}{2}}{m \sin \frac{n\gamma}{2}}$$

$$K_{d3} = \frac{\sin\frac{3\times3\times20^\circ}{2}}{3\times\sin\frac{3\times20^\circ}{2}} = 0.67$$

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 $= \dfrac{1080}{2} = 540$

N_{ph} (Number of turns (series) (Phase))

$$= \frac{540}{3} = 180$$

Slot angle, $\gamma = \dfrac{180\times P}{S} = \dfrac{180\times20}{180} = 20$

and slots/pole/phase, $m = \dfrac{180}{3\times20} = 3$

Then, breadth factor $K_b = \dfrac{\sin m\frac{\gamma}{2}}{m\sin\frac{\gamma}{2}}$

$$= \frac{\sin\frac{3\times20}{2}}{3\sin 10} = \frac{\sin 30^\circ}{3\sin 10^\circ} = 0.95$$

Hence $E_{Ph} = 4.44\, k_b f N_{ph} \phi$

$= 4.44\times0.95\times50\times180\times25\times10^{-3}$

$= 949.05\text{V} \approx 960$ 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.

$$\therefore\ E = 2T \times 1 \times \frac{2}{\pi} = 1.273T \text{ volts}$$

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 mγ = 15 × 4 = 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 = $\frac{480}{3} = 160$

$K_p = \cos\left(\frac{\alpha}{2}\right) = \cos\left(\frac{36}{2}\right) = 0.951$

$$K_d = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m\sin\left(\frac{\gamma}{2}\right)}$$

$$\gamma = \frac{4\times180}{48} = 15^0,$$

$$\therefore K_d = \frac{\sin\left(\frac{60}{2}\right)}{4\sin\left(\frac{15}{2}\right)} = 0.9576.$$

$E_{ph} = 4.44 K_p K_d \phi f T_{ph}$

$E_{ph} = 4.44\times0.951\times0.9576\times0.025\times50\times160$

$E_{ph} = 808.68$ V

$E_{L\text{-}L} = 1400.67$ V

09. Ans: (c)

Sol: $E_{ph} \propto k_d T_{ph.}$

$$\frac{E_{ph(3-\phi)}}{E_{ph(2-\phi)}} = \frac{K_{d(3-\phi)}.T_{ph(3-\phi)}}{K_{d(2-\phi)}.T_{ph(2-\phi)}}$$

$$K_{d(2-\phi)} = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m\sin\left(\frac{\gamma}{2}\right)}$$

$$= \frac{\sin\left(\frac{90}{2}\right)}{6\sin\left(\frac{15}{2}\right)} = 0.903$$

$$[\because m = \frac{48}{2\times4} = 6]$$

$$T_{ph(2-\phi)} = \frac{480}{2} = 240$$

$$\therefore \frac{E_{ph(3-\phi)}}{E_{ph(2-\phi)}} = \frac{0.9576}{0.903}\times\frac{160}{240} = 0.707$$

$$E_{ph(2-\phi)} = \frac{808.68}{0.707} = 1143.85$$

$E_{L-L(2-\phi)} = \sqrt{2}E_{ph(2-\phi)}$

$= 1617.65$V.

(Or)

Method – 2

For 2 – phase connection

$$T_{ph} = \frac{480}{2} = 240$$

$K_p = 0.95;\ \gamma = 15^0$

$$M = (\text{slot / pole / phase}) = \frac{48}{4\times2} = 6$$

$$K_d = \frac{\sin(90/2)}{6\sin(15/2)} = 0.9027$$

$E_{ph} = 4.44\times0.9027\times0.951\times0.025\times50\times240$

$= 1143.55$ V

$E_{L-L}\ (2-\phi) = \sqrt{2}\times E_{Ph}$

$= \sqrt{2}\times1143.55$

$= 1617.22$ 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

$$\frac{E_{3-\phi}}{E_{1-\phi}} = \frac{Kd_{3-\phi}\times Tp_{n_3}}{Kd_{3-\phi}\times Tp_{n_1}} = 0.5$$

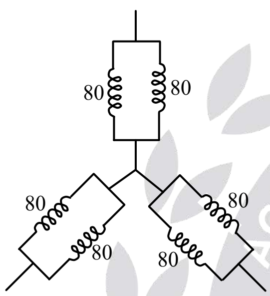
$$E_{1-\phi} = \frac{E_{3-\phi}}{0.5} = \frac{808.68}{0.5} = 1617.36$$

12. Ans: (404 V, 700 V)

Sol: If turns are connected in two parallel paths then

Turns/ph = 160

$$\text{Turns / Ph / Path} = \frac{160}{2} = 80$$



$E_{ph} = 4.44 \times 0.951 \times 0.957 \times 0.025 \times 50 \times 80$

$= 404$ 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} = Turns/Ph = $\frac{480}{2} = 240$

Turns/Phase/Path = $\frac{240}{2} = 120$

$E_{Phase} = 4.44 \times 0.957 \times 0.951 \times 0.025 \times 50 \times 120$

$= 571.77$ 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 $\because \phi = 0$

X_d = 1.2 PU, X_q = 1.0 PU, R_a = 0

V = 1PU , kVA = 1PU, I_a = 1PU

$$\tan\psi = \frac{V\sin\phi + I_a X_q}{V\cos\phi + I_a R_a} = \frac{1\times0+1\times1}{1\times1+1\times0}$$

$\therefore \Psi = 45$

$\delta = \Psi - \phi = 45 - 0 = 45^o$

23. Ans: (a)

Sol: Given, P = 2.5 MW, cosϕ = 0.8, V_L = 6.6 kV and R_a = 0.

$$X_d = \frac{V_{max}}{I_{min}} = \frac{96}{10} = 9.6\Omega$$

$$X_q = \frac{V_{min}}{I_{max}} = \frac{90}{15} = 6\Omega$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{6.6\times10^3}{\sqrt{3}} = 3810V$$

$$I_L = \frac{P}{\sqrt{3}V_L\cos\phi} = \frac{2.5\times10^6}{\sqrt{3}\times6.6\times10^3\times0.8}$$

$I_L = 273.36A = I_{ph}$

$$\tan\psi = \frac{V\sin\phi + I_a X_q}{V\cos\phi + I_a R_a}$$

$$= \frac{3810\times0.6 + 273.36\times6}{3810\times0.8 + 273.36\times0}$$

$\tan\psi = 1.288$

$\psi = 52.175°$

$\delta = \psi - \phi = 52.175° - 36.86° = 15.32°$.

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 ϕ = 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, $X_s = 30\ \Omega$ and $R_a = 0\ \Omega$.

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{200\times\sqrt{3}}{\sqrt{3}} = 200\,V$$

$S = 3V_{ph}I_{ph} = 3000$

$$\Rightarrow I_{ph} = I_a = \frac{1000}{200} = 5\,A$$

$$\text{Internal angle, } \theta = \tan^{-1}\left(\frac{X_s}{R_a}\right) = 90°$$

At maximum voltage regulation, $\theta = \phi$.

Therefore, $\phi = 90°$ and $\cos\phi = 0$.

Excitation voltage is

$$E_0^2 = (V\cos\phi + I_aR_a)^2 + (V\sin\phi + I_aX_s)^2$$

$$E_0 = \sqrt{(200\times0+5\times0)^2 + (200\times1+5\times30)^2}$$

$E_0 = 350$ V

$$\%\ \text{Regulation} = \frac{E_0 - V}{V}\times100$$

$$= \frac{350-200}{200}\times100 = 75\ \%$$

29. Ans: –14.56

Sol: Given data: 25 kVA, 400V, Δ -connected

$$\therefore I_L = \frac{25\times1000}{\sqrt{3}\times400} = 36.08\text{ A}$$

$$\Rightarrow I_{ph} = \frac{36.08}{\sqrt{3}} = 20.83\text{ A}$$

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]

$$\Rightarrow E_0 = \sqrt{(V\cos\phi + I_a r_a)^2 + (V\sin\phi - I_a X_s)^2}$$

$$= \sqrt{[400\times0.8]^2 + [400\times0.6 - 20.83\times17.28]^2}$$

= 341. volts/ph

$$\text{Voltage Regulation} = \frac{|E|-|V|}{|V|}\times100$$

$$= \frac{341-400}{400}\times100$$

$$= -14.56\%$$

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

$= f - f^{l}$

$= 50.2 - 50$

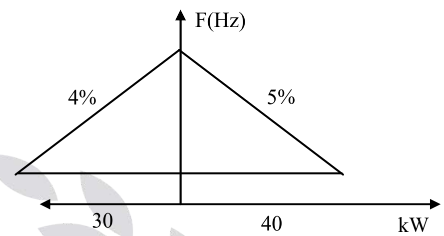
$= 0.2\text{Hz}$

$\Rightarrow$ 0.2 Flickers/sec $= 0.2 \times 60$

= 12 filckers/min

40. Ans: (b)

Sol:



Without over loading any one machine. So here 300 kW is maximum capacity of machine 1.

$\rightarrow$ For M/C 2 maximum load. It can bear is

$$\frac{P}{400} = \frac{4}{5}$$

$P_1 = 320$ kW

Total load $= P_1 + P_2$

$= 300 + 320 \leq 620$ 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

$$= \frac{\left|\overline{E}_1 - \overline{E}_2\right|}{Z_{s1} + Z_{s2}} \text{ given } Z_{s1} = Z_{s2}$$

$\overline{E}_1$ and $\overline{E}_2$ 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:

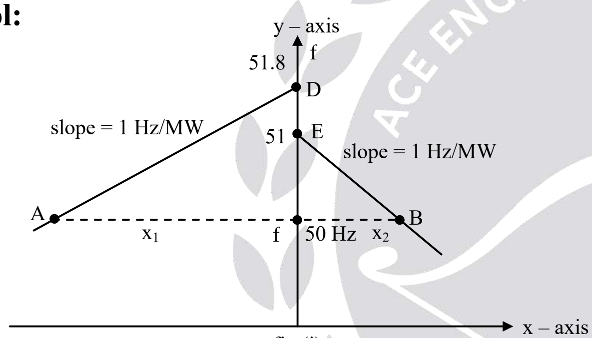


fig (i)

$y = -mx+c$

(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

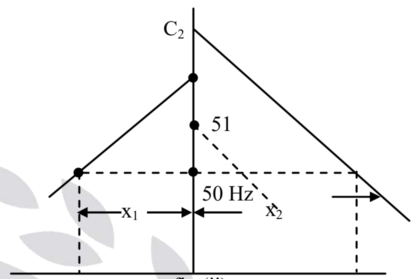


fig (ii)

(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)

$f = -x_2 + c_2 = 50$

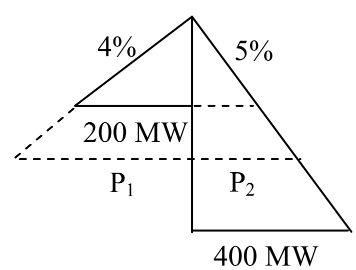
$-20 + c_2 = 50$

$c_2 = 70$

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) ⇒ $50x + 80x = 600$

$\Rightarrow \quad x = \frac{600}{130} = 4.615$

Given, no-load frequency = 50 Hz

present system frequency

⇒ f = 50 – (50 × x %)

$= 50 – 50 \times \frac{4.615}{100} = 47.69 \approx 47.7$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

$\frac{P_2}{400} = \frac{4}{5}$

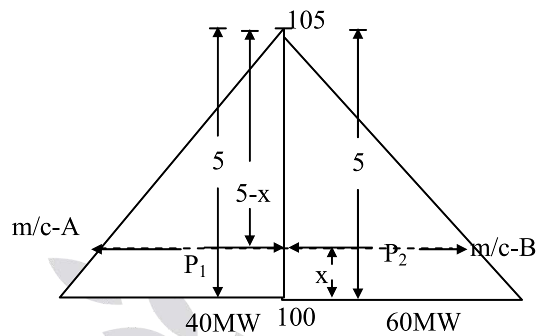
$P_2 = 320$ MW

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



$\frac{P_2}{60} = \frac{5 - x}{5} \Rightarrow P_2 = 12(5 - x)$

$\frac{P_1}{40} = \frac{5 - x}{5} \Rightarrow P_1 = 8(5 - x)$

$P_1 + P_2 = 80$

$\Rightarrow 8(5 - x) + 12(5 - x) = 80$

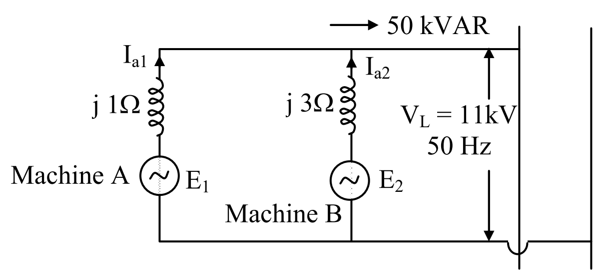
⇒ x = 1

$\therefore P_1 = 8(5 - 1) = 32$MW

$P_2 = 12(5 - 1) = 48$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

$3VI_{a1}$ sin90 + $3VI_{a2}$sin90 = 50 (∵ only reactive power pf = cosϕ = 0 ⇒ ϕ =90°)

$6VI_a = 50 \times 10^6$ (∵ $I_{a1} = I_{a2} = I_a$)

$$I_a = \frac{50\times10^6}{6\times\frac{11\times10^3}{\sqrt{3}}} = 1312.16\text{ A}$$

$\therefore$ $E_1 = V\angle0 - I_{a1}\angle90 \times X_{s1}\angle90$

$$= \frac{11\times10^3}{\sqrt{3}}\angle0 - 1312.16\angle90\times1\angle90$$

$= 6350.8\angle0 - 1312.16\angle180$

$= 7662.96$ V

$E_2 = V\angle0 - I_{a2}\angle90 \times X_{s2}\angle90$

$= 6350.8\angle0 - 1312.16\angle90 \times 3\angle90$

$= 6350.8\angle0 - 3936.48\angle180$

$= 10{,}287.28$ V

∴ 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, $E = V\angle0 + I_a\angle\pm\phi.Z_s\angle\theta$

$= 6350\angle0 + 100\angle0 \times 10\angle90^o$

$= 6429.1\angle8.94^o$

$\therefore \delta = 8.94^o$

Excitation increased by 25%

$\Rightarrow E^1 = 1.25E$

$= 6429.1\times1.25 = 8036.3$ V

∵ 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: $I_a{}^1 = \frac{E^1\angle\delta^1 - V\angle0}{Z_s\angle\theta}$

$$= \frac{8036.3\angle7.14 - 6350\angle0}{10\angle90}$$

$= 190.6\angle-58.4^o$

$I_a{}^1 = 190.4$ 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 = $0.25 \times Z_b = 0.25\times\frac{(KV)^2}{MVA_b}$

$$= 0.25\times\frac{(6.6)^2}{(1.2)} = 9.07$$

$E = V + j\,I_a X_s \to$ In alternator

By substituting the values

$$I = \frac{P}{\sqrt{3}V} = \frac{1200\times10^3}{\sqrt{3}\times6600} = 104.97$$

$E = 3810 + 104.97\angle-36.86 \times 9.07\angle90$

$E = 4447\angle9.867$

The current (I_a) at which the p.f is unity

($\because R_0 = 0$)

$$E = \sqrt{(V\cos\phi + I_aR_a)^2 + (V\sin\phi \pm I_aX_s)^2}$$

$$4447 = \sqrt{(63810\times1+0)^2+(3810\times0+9.07)^2}$$

$I_a = 252.716$ A

53. Ans: (5360.9V)

Sol: $E = V + j\,I_a\,X_s$

$$V_{Ph} = 3810 = \frac{6.6\times10^3}{\sqrt{3}};\ I_a = \frac{P}{\sqrt{3}\times V} = \frac{1000\times10^3}{\sqrt{3}\times6.6\times10^3}$$

= 87.47 A

$E_{Ph} = 3810 + 82.47\angle+36.86 \times 20\angle90$

$E_{Ph} = 3095.17\angle26.88$

$E_L = \sqrt{3}\ E_{Ph} = 5360.99$ V

54. Ans: (26.88°)

Sol: Power angle (or) $\delta = 26.88^0$

55. Ans: (b)

Sol: $P = \frac{EV}{X_S}\sin\delta$

$\Rightarrow 0.5 = \frac{1.3\times1}{0.8}\sin\delta$

$\Rightarrow\ \delta = 17.92^0$

$E = V + j\,I_a\,X_s$

$$I_a = \frac{E\angle\delta - V\angle0}{X_s\angle90}$$

$$= \frac{1.3\angle17.92 - 1\angle0}{0.8\angle90}$$

$= 0.581\angle-30.639^0$

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 $\theta = 90$ ($\because\ R_a = 0$)

$$I = \frac{E\angle\delta - V\angle0}{Z_s\angle\theta}$$

$$I_a = \frac{1.3\angle90-1}{0.8\angle90} = 2.05\angle37.56^0$$

= 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

$$Q = \frac{V}{X_s}[E\cos\delta - V]$$

Substitute $\delta = \theta = 90$

$$Q = \frac{1}{0.8}[1.3\cos(90)-1]$$

$= -1.25$ 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

$\therefore$ 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, $P = 0.6$pu, $V = 1.0$pu

$$P = \frac{EV}{X_s}\sin\delta \Rightarrow 0.6 = \frac{1.3\times 1}{1.1}\sin\delta$$

$$\Rightarrow \delta = 30.53°$$

$$Q = \frac{V}{X_s}\left[E\cos\delta - V\right]$$

$$= \frac{1}{1.1}\left[(1.3)\cos 30.53 - 1\right] = 0.1088\,pu$$

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

$$N_s = \frac{120f}{P} = \frac{120\times 60}{4} = 1800\text{rpm}$$

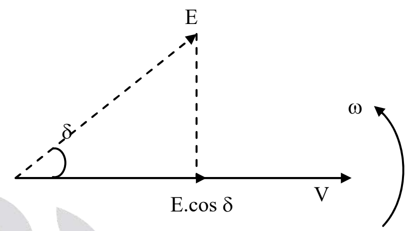
$$T = \frac{P}{\omega} = \frac{41569.2}{2\pi\times\frac{1800}{60}} = 220.53\,\text{N}-\text{m}$$

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".



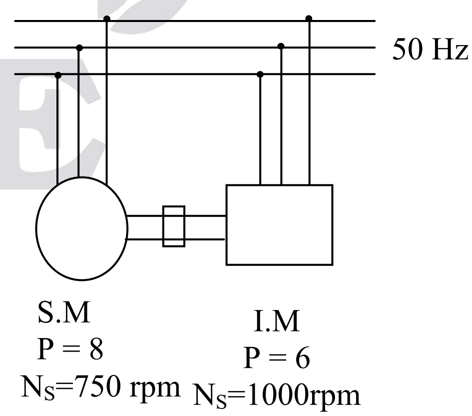
66. Ans: (a)

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.

$\therefore$Consider speed of Induction motor, $N_r = 750$ rpm.

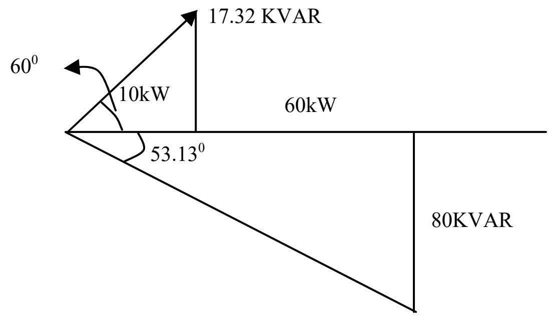
$$\text{slip} = \frac{N_s - N_r}{N_s} = \frac{1000-750}{1000} = \frac{1}{4}$$

$$f_r = sf = \frac{1}{4}\times 50 = 12.5\text{ Hz}$$



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

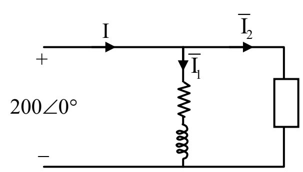
$$\tan\phi = \frac{Q}{P} = \frac{62.68}{70} = 0.895$$

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: $V_1 = 400$V E = 400V

$$V_{ph} = \frac{400}{\sqrt{3}} = 230.9\text{V},$$

$$E_{ph} = \frac{400}{\sqrt{3}} = 230.9\text{V}$$

$$P_{in} = \frac{EV}{X_s}\sin\delta$$

$$\frac{5\times 10^3}{3} = \frac{230.9 \times 230.9}{10}\sin\delta$$

$\Rightarrow \delta = 18.21°$

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: $$I_a = \frac{V\angle 0 - E\angle - \delta}{Z_s\angle\theta}$$

$$= \frac{230.9\angle 0 - 2309\angle 18.21}{10\angle 90} = 7.3\angle\text{-}9.1^o$$

$I_a = 7.3^a$

72. Ans: (a)

Sol: $E_{ph} = \frac{2500}{\sqrt{3}} = 1443.37V$

$V_{ph} = \frac{2000}{\sqrt{3}} = 1154.7V$

$Z_s = 0.2 + j2.2 = 2.2\angle 84.8^o \Rightarrow \theta = 84.8^o$

$P_{in} = \frac{V^2}{Z_s}\cos\theta - \frac{EV}{Z_s}\cos(\theta+\delta)$

$$\frac{800\times10^3}{3} = \frac{(1154.7)^2}{2.2\angle 84.8^o}\cos(84.8) - \frac{(1154.7\times1443.37)}{2.2\angle 84.8^o}\cos(84.8+\delta)$$

$I_a = \frac{V\angle 0 - E\angle\delta}{Z_s\angle\theta}$

$= \frac{1154.7\angle 0 - 1443.37\angle 21.43}{2.2\angle 84.8^o}$

$= 254.59\angle 24.9^o$

73. Ans: (b)

Sol: PF = cos (24.9) = 0.907 lead

74. Ans: (760.9 kW)

Sol: Mechanical power developed

$P = E_a I_a^*$

$$P = \frac{EV}{Z_S}\cos(\theta-\delta) - \frac{E^2}{Z_S}\cos\theta$$

$$P = \frac{\frac{2500}{\sqrt{3}}\times\frac{2000}{\sqrt{3}}}{2.209}\cos(84.80-21.51) - \frac{\left(\frac{2500}{\sqrt{3}}\right)^2}{2.209}\cos(84.80)$$

$P_{phase} = 253.364$ kW

$P_{3-\phi} = 760.94$ kW (Or)

$P_{mech} = P - 3\, I_a^2\, R_a$

$= 800 \times 10^3 - (3 \times 254^2 \times 0.2)$

$P_{mech} = 761$ kW

75. Ans: (4.84 Nm)

Sol: (In question poles and frequency not given let take P = 4, F = 50)

$N_s = 1500$

$T = P/\omega = \frac{760.94\times 60}{2\pi\times 1500} = 4.84$ Nm

76. Ans: (b)

Sol: $V_L = 230V$

$\Rightarrow V_{ph} = \frac{230}{\sqrt{3}} = 132.8V$

$Z_s = 0.6 + j3 = 3.06\angle 78.69^o$

$\theta = 78.69^o$

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

$= \sqrt{132.8^2 + 130.29^2 - 2\times132.8\times130.29\cos\delta}$

$\delta = 55.4^o$

$I_a = \frac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}$

$I_a = \frac{132.8\angle 0 - 130.29\angle -55.4}{3.06\angle 78.69^o}$

$I_a = 40\angle -17.3$

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

$$T = \frac{P_{mech}}{\omega} = \frac{12.035 \times 10^3}{2\pi \times \frac{1000}{60}} = 78.34\,\text{N-m}$$

78. Ans: (b)

Sol: $V_{ph} = \frac{6.6}{\sqrt{3}} = 3810.5\text{V}$

$P_{in} = \sqrt{3}\, V_L I_L \cos\phi \Rightarrow I_L$

$$= \frac{1000 \times 10^3}{\sqrt{3} \times 6.6 \times 10^3 \times 0.8} = 109.3\text{A} = I_{ph}$$

$E = V\angle 0 - (I_a \angle \pm \phi\ z\ \angle\theta)$

$= 3810.5\ \angle 0 - 109.3\ \angle 36.86 \times 12\angle 90^o$

$= 4715.5\angle -12.85^o$

Excitation is constant, V is constant

$$P = \frac{EV}{X_s}\sin\delta = \frac{1500 \times 10^3}{3}$$

$$= \frac{4715.5 \times 3810.5}{12}\sin\delta$$

$\Rightarrow \delta = 19.5^o$

79. Ans: (a)

Sol: $I_a = \frac{V\angle 0 - E\angle -\delta}{Z_s \angle\theta}$

$$= \frac{3810.5\angle 0 - 4715.5\angle -19.5}{12\angle 90}$$

$= 141.4\angle 21.95$

PF = $\cos(21.95^o)$

= 0.92 lead

80. Ans: (*)

Sol: Data given

$V_{ph} = \frac{400}{\sqrt{3}} = 230.94$ V, 100 kVA,

$R_a = 0.13\ \Omega$ and $X_s = 1.3\ \Omega$

$$I_{line} = I_{phase} = \frac{100 \times 10^3}{\sqrt{3} \times 400} = 144.33\text{ A}$$

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

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

$$= \frac{75000 - 12125}{75000} \times 100 = 83.83\%$$

4. Induction Machines

01. 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.

02. Ans: 4%

Sol: The frequency of generated emf by the alternator is given as

$$f = \frac{PN_{pm}}{120} = \frac{4\times1500}{120} = 50Hz$$

The synchronous speed of Induction motor

$$N_s = \frac{120f}{P} = \frac{120\times50}{6} = 1000 \text{ rpm}$$

$$\%\text{ Slip} = \frac{N_s - N_r}{N_s}\times100$$

$$= \frac{1000-960}{1000}\times100 = 4\%$$

03. Ans:(d)

Sol: For 50 Hz, supply the possible synchronous speeds with different poles

2 poles → 3000 rpm

4 poles → 1500 rpm

6 poles → 1000 rpm

8 poles → 750 rpm

10 poles → 600 rpm

12 poles → 500 rpm

20 poles → 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

04. Ans: (d)

Sol: Synchronous speed of field is,

$$N_s = \frac{120f}{P}$$

$$\Rightarrow N_s = \frac{120\times50}{4} = 1500 \text{ rpm}$$

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.

05. Ans: (d)

Sol: Synchronous Machine:

Prime mover speed,

$$N_{pm} = \frac{120f}{P} = \frac{120\times50}{4} = 1500 \text{ rpm}$$

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.

$$150 = \frac{\frac{120\times50}{P_{in}}+1500}{\frac{120\times50}{P_{in}}}\times50$$

$$\Rightarrow 3 = \frac{6000+1500\times P_{in}}{6000}$$

$$\Rightarrow 12000 = 1500\times P_{in}$$

$$\Rightarrow P_{in} = 8$$

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.

$$150 = \frac{1500 - \frac{120\times 50}{P_{in}}}{\frac{120\times 50}{P_{in}}}\times 50$$

$$\Rightarrow 3 = \frac{1500\times P_{in} - 6000}{6000}$$

$\Rightarrow 24000 = 1500\times P_{in}$

$\Rightarrow P_{in} = 16$

06. Ans: (a)

Sol: P = 4, f = 50 Hz, R_1 = 0.4 Ω, 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 = $\frac{60}{2\pi N_s}P_r$

$$= \frac{60}{2\pi\times 1500}\times 3840 = 24.45\text{ Nm}$$

07. 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 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%

08. 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

$$E_{20} = \frac{V_{sliprings}}{\sqrt{3}} = \frac{100}{\sqrt{3}} = 57.7\text{ V}$$

In general, rotor current, neglecting stator impedaance is

$$I_2 = \frac{E_{20}}{\sqrt{\left(\frac{R_2}{s}\right)^2 + X_{20}^2}}$$

For smaller values of slip, s = $\frac{R_2}{s}$ >>>x_{20}

Then the equation for rotor current

$$I_2 = \frac{E_{20}}{\frac{R_2}{s}} = \frac{sE_{20}}{R_2} = \frac{0.04\times 57.7}{0.4} = 5.77\text{ A}$$

09. 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,

$x_{20} = \frac{R_2}{s_{Tmax}} = \frac{0.1}{0.06} = 1.66\ \Omega$

10. Ans: (a)

Sol: Given rotor resistance per phase $R_2 = 0.21\ \Omega$

Stand still rotor reactance per phase $X_{20} = 7\ \Omega$

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

11. 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 $\frac{T}{T_{max}} = \frac{2 \times s \times s_{Tmax}}{s^2 + s_{Tmax}^2}$

$= \frac{2 \times 0.12 \times 0.04}{0.04^2 + 0.12^2} = 0.6$

$\frac{T}{T_{max}} = 0.6$

$T = 0.6 \times 150 = 90$ N-m

12. Ans: 0.029

Sol: Given rotor resistance per $R_2 = 0.025\ \Omega$

Stand still rotor reactance per phase,

$X_{20} = 0.12\ \Omega$

We have slip at maximum torque given by

Let $s_{Tmax} = \frac{R_2 + R_{ext}}{X_{20}}$,

for $T_{st} = \frac{3}{4} T_{max}$

$\frac{T_{st}}{T_{max}} = \frac{2 \times s_{Tmax}}{s_{Tmax}^2 + 1} = \frac{3}{4}$

$s_{Tmax}^2 - \frac{8}{3} s_{Tmax} + 1 = 0$

Solving for s_{Tmax} we have $s_{Tmax} = 0.45$

$$0.45 = \frac{0.025 + R_{ext}}{0.12}$$

$R_{ext} = 0.029\ \Omega$

13. 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

$$\text{Rotor input, } P_{ri} = \frac{P_{gmd}}{(1-s_{fl})} = \frac{10.6 \times 10^3}{(1-s_{fl})}$$

$$T_{fl} = \frac{P_{ri}}{\omega_s} = \frac{60}{2\pi N_s} \frac{10.6 \times 10^3}{(1-s_{fl})}$$

$$= \frac{60}{2 \times 3.14 \times 1000} \frac{10.6 \times 10^3}{(1-s_{fl})}$$

$$= \frac{101.27}{(1-s_{fl})} = \frac{101.27}{(1-s_{fl})} = 2600 s_{fl}$$

Solving for s_{fl} , we have $s_{fl} = 0.0405$

$N_{rfl} = N_s(1 - s_{fl}) = 1000(1 - 0.00405)$

= 959.5 rpm

14. 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 $R_1 = R_2 = \frac{R_{01}}{2}$

$$\tau_{st} = \frac{60}{2\pi \times 1500} \times \left(\frac{3I_{BR}^2 R_{01}}{2}\right)$$

$$= \frac{60}{2\pi \times 1500} \times \frac{30 \times 10^3}{2} = 95.49 \text{ Nm}$$

15. Ans: (c)

Sol: $I_{ac} = 400\text{A}; k = 0.7$

$$I_{st,\,supply} = k^2 I_{sc} = 0.7^2 \times 400 = 196\text{A}$$

16. Ans: (a)

Sol: $\frac{\text{Starting line current with stator winding in star}}{\text{Starting line current with stator winding in delta}} = \frac{1}{3}$

Starting line current with stator winding in delta (DOL) = 3×Starting line current with stator winding in star

= 3 × 50 =150[a]

17. 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

$N_s = \frac{120f}{P}$

$= \frac{120 \times 50}{6} = 1000 \text{ rpm}$

Given, the rotor speed of induction motor at full load $N_{r\,f\ell} = 940$ 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, $T_{f\ell} = 150$ N – m

For DOL starter, we have $\frac{T_{st}}{T_{f\ell}} = \left(\frac{I_{sc}}{I_{f\ell}}\right)^2 S_{f\ell}$

$= \left(\frac{300}{60}\right)^2 \times 0.06 = 1.5$

$T_{st} = 1.5 \times 150 = 225$ N – m

When star delta starter is used,

$T_{st} = \frac{1}{3}$ times starting torque with

DOL starter = $\frac{1}{3} 225 = 75$ N – m

$I_{st} = \frac{1}{3}$ time starting current with

DOL starter = $\frac{1}{3} \times 300 = 100\text{A}$

18. 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