ACE Engineering Publications

GATE | PSUs

Electrical Engineering

ELECTRICAL MACHINES

Text Book: Theory with worked out Examples and Practice Questions

Electrical Machines

(Solutions for Text Book 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 $b_2 = 2b_1$

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

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

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

$$B_{max2} = \frac{2\times1.2}{4} \times 2 = 1.2\text{ T}$$

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)

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

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: $i(t) = 10 \sin(100\pi t)$ 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: (a, c)

Sol: EMF per turn $E_t = 13$ volts

Number of secondary turns

$$= \frac{\text{secondary voltage}}{E_t}$$

$$N_2 = \frac{220}{13} = 16.92$$

Now the number of turns can't be a fraction, therefore $N_2 = 17$ (nearest whole number)

For $N_2 = 17$

Number of primary turns

$$N_1 = N_2\left[\frac{V_1}{V_2}\right] = 17\left[\frac{2310}{220}\right] = 178.5$$

This shows that N_2 can't be equal to 17 turns. The other nearest integers are 16 or 18. it is preferable to take $N_2 = 18$.

$N_1 = 18(10.5) = 189$ turns

$\therefore$ The required values of N_1, N_2 are 189 and 18 turns.

New value of emf per turns

$$(E_f) = \frac{220}{18}\text{ volts}$$

$\therefore$ net core are can be obtained from.

$$\sqrt{2}\,\pi f\,\phi_{max} = E_t$$

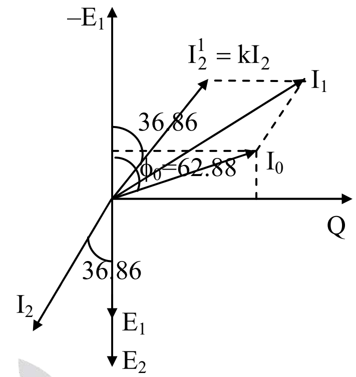
$$\sqrt{2}\,\pi f\,(B_m A_1) = E_t = \frac{220}{18}$$

$$\sqrt{2}\,17\times 50\times 1.4\,A_1 = \frac{220}{18}$$

$\therefore$ $A_1 = 393\text{ cm}^2$

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 $\sin\phi_0 = 0.89$

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

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

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

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

$I_1 = 4.58$ 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: (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

09. 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

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

$W_i = Af + Bf^2$

2500 = A × 50 + B × 50^2 …………. (1)

850 = A × 25 + B × 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 × 50

= 900 W

10. 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

11. 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

12 Ans: (d)

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

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

$\cos\theta_0 = 0.15$

% 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 *l*oss + cu *l*oss at 85A

= 160+174.8

= 334.8 W

Input power = 14.96 kW+334.8W

= 15294.8W

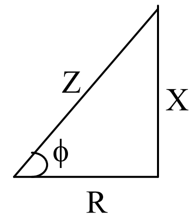
13. Ans: (a)

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

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

$X_2 = 0.2611\ \Omega$

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

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

$Z = 0.281\Omega$

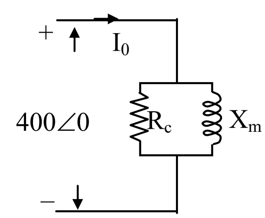
$$I = \frac{V}{Z} = \frac{16}{0.281} = 56.78A \approx 56.65A$$

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

14. Ans: (a)

Sol: Given data:

10 kVA, 400/200 V,



$W_0 = 100$ watt and M =2H.

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

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

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

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

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

$$|I_0| = \sqrt{\left(\frac{1}{4}\right)^2 + \left(\frac{1}{\pi}\right)^2} = 0.41\ \text{A}$$

15. 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 $\rightarrow$?

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

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

16. 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

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

$W_i = 60W$

$W_{Cu} \propto I^2$

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

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

$= 60W$

$W_i + W_{Cu} = 120$ W

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

$= 97.08\%$

17. 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

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

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

By solving equation (1) & (2)

$W_i = 6.8\times10^{-3}$; $W_{Cu} = 0.0136$

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

$= 98.1\%$

18. Ans: (a)

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

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

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

$= 98.1\ \%$

19. 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

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

Copper loss at 3A = 45W

Copper loss at 4A = ?

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

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

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

20. Ans: (c)

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

$= 98.44\ \%$

21. Ans: (c)

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

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

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

$$= \left(\frac{200}{1000}\right)^2\times0.25+0.014$$

$= 0.024$

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

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

22. Ans: (c)

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

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

$W_i = 153.06W$

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

kW = kVA ×cosϕ

kW = 20 × 1 = 20 kW

kWh output = 20×12 = 240 kWh

$W_i = 153.06\times24 = 3.673$ kWh

$W_{Cu} \propto S^2$

$$W_{Cu2} = \left(\frac{20}{15}\right)^2\times153.06$$

$W_{Cu2} = 272.106$

Transformer is ON load for 0 to 12 hrs.

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

$$\eta_{all\,day} = \frac{240\times10^3}{240\times10^3 + 3.673\times10^3 + 3.265\times10^3}$$

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

23. Ans: (b)

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

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

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

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

$$\text{Full load current on H.V side} = \frac{100\times10^3}{11000} = 9.09\text{ A}$$

$$\text{Full load Cu loss} = (9.09)^2 \times 17.126 = 1.415\text{ kW}$$

$$\text{Efficiency} = \frac{100\times0.85}{100\times0.85+1.415+1.25}\times100 = 96.95\ \%$$

24. Ans: (c)

Sol: Given data:

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

80% of full load UPF

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

For min. secondary 10%

$$0.98 = \frac{0.8\times500\times10^3}{0.8\times500\times10^3 + 2\text{Iron Loss}}$$

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

$$\%R = \%\text{ FL cu loss} = \frac{\text{FL cu loss}}{\text{VA Rating}} = \frac{6377.5}{500\times10^3}\times100 = 1.27\ \%$$

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

25. 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

26. 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)

$$R_1' = \left(\frac{1}{10}\right)^2 \times 3.4 = 0.034$$

$X_1' = k^2X_1$

$= (0.01 \times 7.2) = 0.072$

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

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

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

$I_2 = 22.72$ 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.

27. 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

$= 0.046 \times 440 = 20.2$V

Terminal voltage

$V_2 = 440 - 20.2 = 419.75$ V

28. Ans: (b)

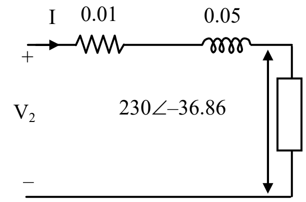
Sol: If voltages are not nominal values % Reg will be zero

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

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

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

29. 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

$E_2 = V + Iz$

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

$= 238.85\angle 1.87$

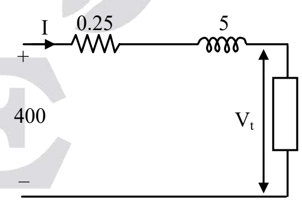
$$\text{Turns ratio} = \frac{E_1}{E_2} = \frac{600}{238.85} = 2.5$$

30. Ans: (c)

Sol: $P = VI\cos\phi$

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

$\Rightarrow \phi = 38.624$



From given data,

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

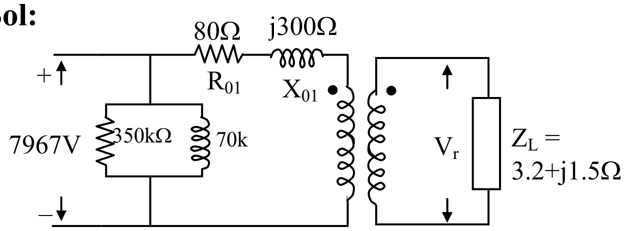
$\Rightarrow V_t = 352.08\angle{-9.81}$

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

$= 70.4$ V

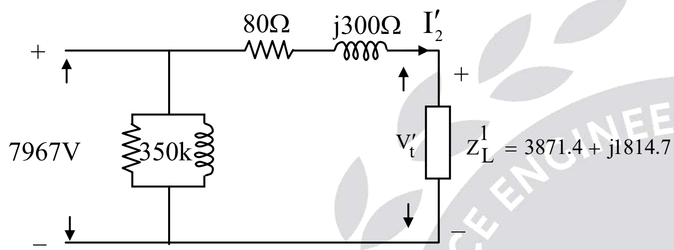
31. Ans: 218.8

Sol:



15kVA and 8000/230V

Equivalent circuit refer to H.V side is



$z^1_L = 4275.6\angle 25.11$

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

$= 310.48\angle 75.06$

$$I^1_2 = \frac{7967}{310.48\angle 75.06 + 4275.6\angle 25.11}$$

$= 1.78\angle{-28.15}A$

$V'_1 = I'_2 \times Z'_L$

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

$= 7600.6\angle -3.04$

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

$= 218.52\angle -3.04$

32. Ans: 4.9%

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

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

$= 4.9\%$

33. Ans: (a)

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 $I_2 = \dfrac{20\times 10^3}{120\times 0.8}$ = 208.33 A

Rated load current = $\dfrac{30\times 10^3}{120}$ = 250 A

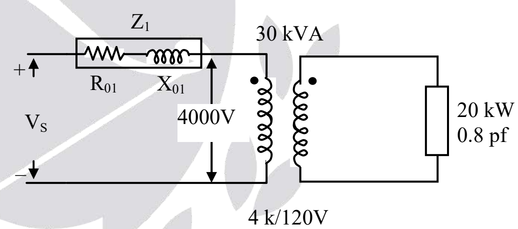
The copper losses for 208.33 A is

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

$$\text{Efficiency} = \frac{20\times 10^3}{20\times 10^3 + 124.99 + 100}\times 100$$

= 98.88%

The equivalent circuit wrt primary is



Primary rated current

$$I_P = \frac{30\times 10^3}{4000} = 7.5 \text{ A}$$

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

34. Ans: (a, c)

Sol: Total losses in transformer

$$= \left[\frac{1}{0.988} - 1\right] \times 500000 \times 0.8$$

$$= 4858.3\text{W}$$

These losses are under the condition of maximum efficiency.

Therefore core losses = ohmic losses at 80% full load

$$= \frac{1}{2} \times 4858.3 = 2429.15\text{W}$$

Full load ohmic losses

$$= 2429.15\left[\frac{100}{80}\right]^2 = 3795.55W$$

$$r_{e_2} = \frac{3795.55}{500000} \times 100 = 0.759\%$$

$$x_{e_2} = \sqrt{z_e^2 - r_e^2} = \left[4.5^2 - 0.759^2\right]^{1/2}$$

$$= 4.4355\%$$

It is already proved that load pf at which voltage regulation is maximum or the load pf at which secondary terminal voltage is minimum is given by

$$\cos\theta_2 = \frac{r_{e2}}{z_{e2}} = \frac{0.759}{4.5} = 0.1687\, lag$$

$$\frac{E_2 - V_2}{E_2} = (r_{e_2}\cos\theta_2 + x_{e_2}\sin\theta_2) \text{ in per unit}$$

$$\frac{E_2 - V_2}{E_2} \times 100$$

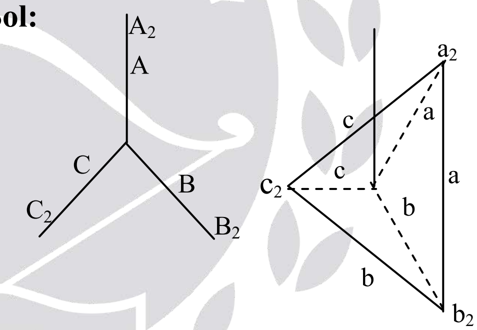
= (0.759 × 0.1687+ 4.4355 × 0.9856)

= 4.5

$V_2 = E_2(1-0.045) = 400 \times 0.955 = 382\text{V}$

35. Ans: (b)

Sol:

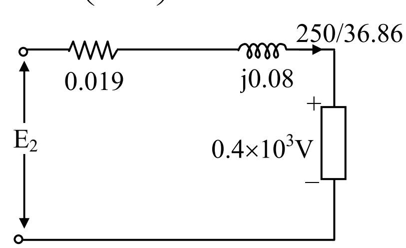


∴ The Possible Connection is Yd1

36. Ans: (a)

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

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



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

$E_2 = 392\angle2.75$ V

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

$$= 6.46 \text{ kV}$$

37. Ans: (d)

Sol: The induced voltages in primary winding are

$V_{BC} = E\angle0^o$

$V_{CA} = E\angle120^o$

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

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

The induced voltages in secondary are

$V_{bc} = E\angle180^o$

$V_{ca} = E\angle300^o$

$V_{ab} = E\angle60^o$

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

Let V_{bc} windings is interchanged.

Resultant voltage

$$= -E\angle180^o + E\angle300^o + E\angle60^o$$

$$= 2E\angle0^o$$

This voltage can burn out the transformer

38. 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

[∵ Lagging Load]

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

$= 3.8\%$

$$E_2 = \frac{V_2(\text{phase})}{1-0.038}$$

$$= \frac{415}{\sqrt{3}\times0.962} = 249.06$$

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

39. Ans: (a)

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

= 50 × 735.5 = 36.775 kW

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

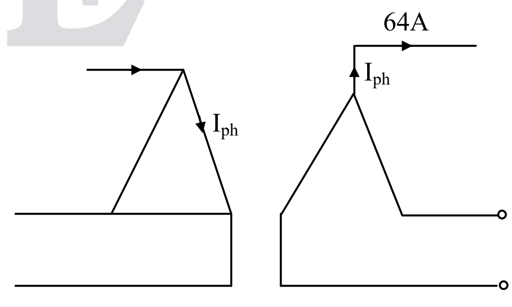
$P_{i/p}$ to induction motor (or) power output of transformer $= \frac{P_{o/p}}{\eta} = \frac{36.77}{0.85} = 40.85\text{kW}$

$$I_L = \frac{P}{\sqrt{3}\times V_L \times\cos\phi}$$

$$= \frac{40.85\times10^3}{\sqrt{3}\times440\times0.85}$$

$= 63.06\ \angle31.78^o$

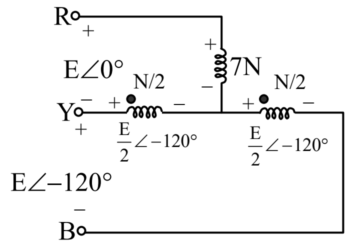
≈ 64 A



$$I_{ph} = \frac{440}{\sqrt{3}\times6600}\times64 = 2.46A$$

40. Ans: (c)

Sol:



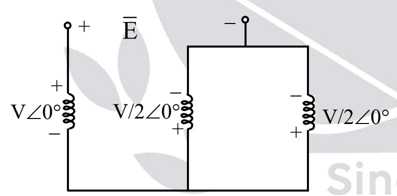
$$E\angle 0° = \overline{V}_{Rs} - \frac{E}{2}\angle -120°$$

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

$$= \frac{\sqrt{3}}{2}E\angle -30°$$

41. Ans: (d)

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



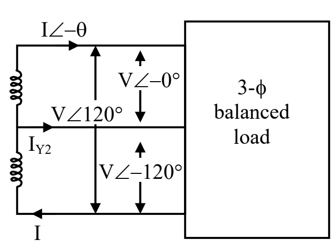
KVL:

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

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

42. 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 $\overline{I} = I\angle -\theta + 120° - 180°$

$= I\angle -\theta - 60°$

43. 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,

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

$= (0.0075 + j0.029)$ pu

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

$= 0.012 + j0.0381$ 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

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

$= 0.01875 + j0.0725$

$= 0.075\angle 75.52$

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

$= 0.04\angle 72.54°$

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

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

$= 700\angle -36.9°$

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

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

$= 460\angle -36.1°$ 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)

44. 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

45. And: (c)

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

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

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,

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

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

$= 1060\,kVA$

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.

46. Ans: (c)

Sol: Secondary rated current

$= \dfrac{400}{6.6} = 60.6\,Amp$

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

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

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

47. 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

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

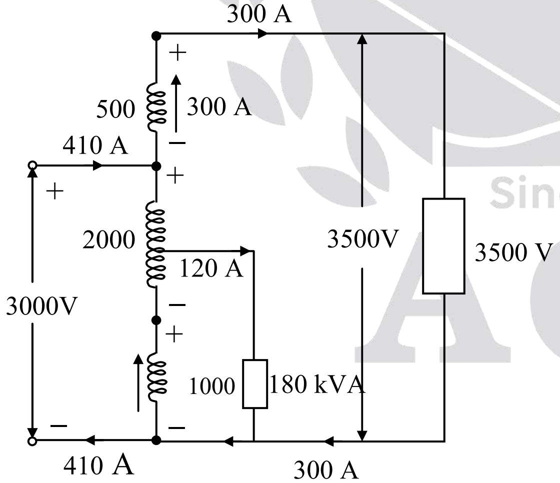
$\therefore$ Rating of AT $= E_{pry} \times I_{pry}$

$= 600 \times 150$

$= 90\text{ kVA}$

48. 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

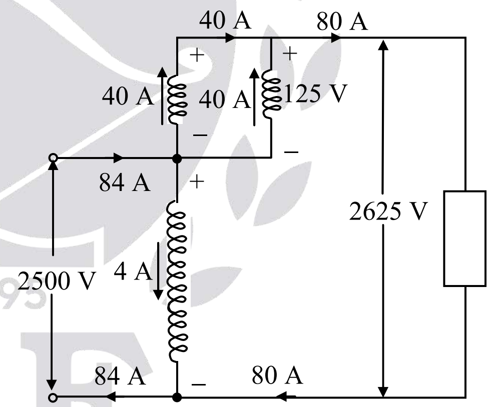
The total current taken from the supply main is $= \frac{1230{,}000}{3000} = 410\text{A}$

49. Ans: (b)

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

50. 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

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

51. 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}

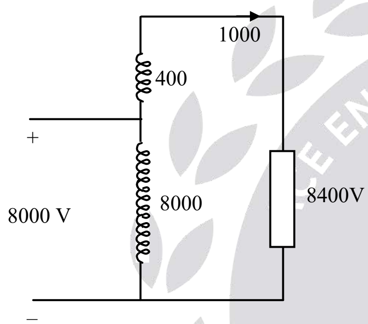
= 10 kVA

and kVA conducted = 210 – 10

= 200 kVA.

52. Ans:(d)

Sol:



Current through 480 V winding is

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

kVA rating of auto transformer

= 8400 × 1000

= 8.4 MVA

For two winding transformer

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

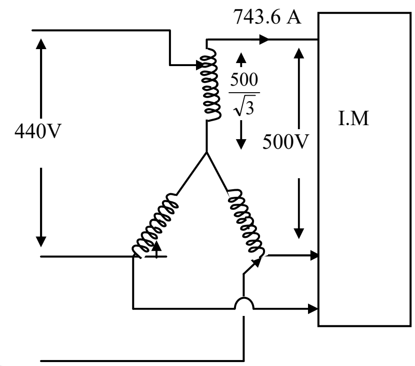
W = 10.79 kW

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

= 99.87%

53. Ans: (a)

Sol:



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

= 743.69A

By equation

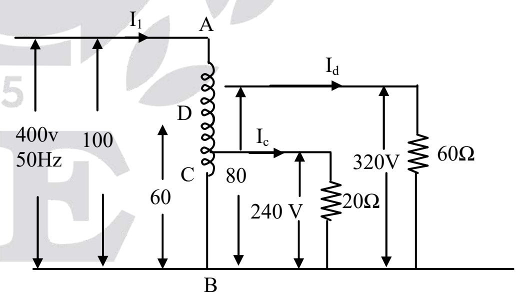
$$\frac{500}{\sqrt{3}}\times743.6 = \frac{440}{\sqrt{3}}\times I_1$$

I_1 = 845.11 A

$I_1 - I_2 = \approx 100$ A

54. Ans: (a)

Sol:



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

For 80 turns = 80 × 4 = 1320 V

For 60 turns = 60 × 4 = 240 V

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

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

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 $I_1 = \dfrac{\text{Total load VA}}{400}$

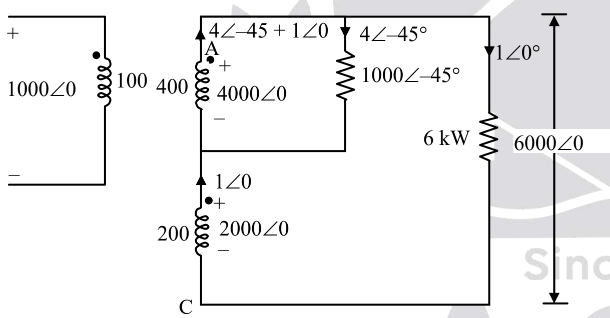
$= \dfrac{2880 + 1705.6}{400}$

$I_1 = 11.464$ A

For resistive load power factor is at unity.

55. Ans: (c)

Sol:



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

$= 4.75\ \angle{-36.55}$

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

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

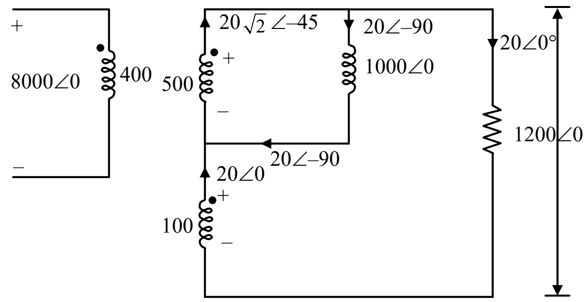
$= 1726.3 - j\ 1131.5$

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

Primary current $= \dfrac{2064}{100} = 20.64\,A$

56. 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

57. 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

58. Ans: (a)

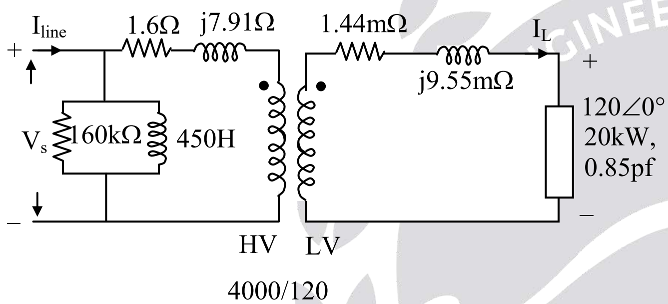
Sol: Given R_1 = 1.6Ω, L_1 = 21mH, R_2 = 1.44mΩ, f = 60Hz, L_2 = 19μH, R_c = 160kΩ,

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

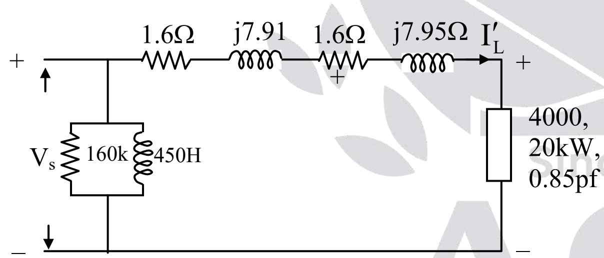
$X_1 = 2\pi f L_1 = 2\times\pi\times60\times21\times10^{-3} = 7.91\ \Omega$

$X_2 = 2\pi f L_2 = 2\times\pi\times60\times19\times10^{-6} = 9.55\ m\Omega$

The equivalent circuit is,



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%

59. 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 μ_r = 1000

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

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

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

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

$= 2.5\text{H}$

2. DC Machines

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) = $\frac{\phi ZNP}{60A}$

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

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

⇒ N = 1609 rpm

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

Sol: Given data:

$V_t = 250$ V, ϕ = constant

$R_a = 0.1\ \Omega$

$P_1 = 100$ 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, $E_g \propto N$

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

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

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

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

$= 6.9\%$

03. Ans: (a, c)

Sol: Here $l = 0.3$, r = 0.2,

speed, $n = \frac{1200}{60} = 20 rps$

It is known that, $B_{av} = \frac{p\phi}{2\pi rl}$

Flux per pole,

$$\phi = \frac{0.5 \times 2\pi \times 0.2 \times 0.3}{4} = 0.04712\,\text{Wb}$$

Generated emf,

$$E_a = \frac{\phi z n p}{a} = \frac{0.04712 \times 500 \times 20 \times 4}{4}$$

$$= 471.2\text{V}$$

Electromagnetic or gross mechanical power developed = $E_a I_a$

$$= 471.2 \times 20$$

$$= 9424 \text{ W}$$

Internal torque $= \frac{E_a I_a}{\omega_m} = \frac{9424}{2\pi \times 20} = 75\text{Nm}$

04. Ans: 0.26

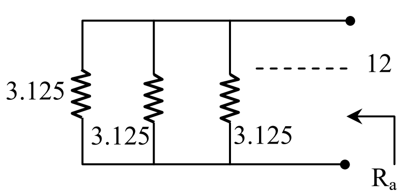
Sol: P = 12, Lap winding

For lap winding no. of parallel paths = P =12

No. of coils in each path = $\frac{250}{12}$

The no. of turns in each path $= \frac{250}{12} \times 6 = 12.5$ turns

The path resistance = 125 × 0.025 = 3.125



Armature resistance = $\frac{3.125}{12}$

$$= 0.26\Omega$$

05. Ans: 13.5A

Sol: V_t = 120V, P_L = 50×60 = 3kW

$R_{sh} = 60\ \Omega$

Load current, $I_L = \frac{P_L}{V_t} = \frac{3000}{120} = 25\text{A}$

Field current $I_{sh} = \frac{120}{60} = 2\text{A}$

∴ Armature current = 25 + 2 = 27A

Wave winding has two parallel paths

∴ Current in each armature conductor

$$= \frac{27}{2} = 13.5\text{A}$$

06. Ans: (b)

Sol:
- When the rotation direction of a DC shunt generator is reversed, Fleming's Right-Hand Rule shows that the induced EMF polarity reverses.
- This reversed EMF drives the shunt field current in the opposite direction.
- The new field current opposes the residual magnetism instead of reinforcing it.
- Since self-excitation depends on residual flux being strengthened, the flux collapses.
- With negligible flux, the generator fails to build up voltage and the terminal voltage drops to:

08. Ans: 63.125, 647.03

Sol: P = 10kW, P = 4, Lap winding

Z = 500, V_t = 220V, θ_m = 4°

$$\theta_e = \frac{P}{2}\theta_m = \frac{4}{2}\times 4° = 8° \text{ electrical}$$

$$I_a = \frac{10\times 10^3}{220} = 45.45\text{A}$$

Demagnetizing amphere turns per pole

$$AT_d/\text{pole} = \frac{ZI_a}{2AP}\cdot\left(\frac{2\theta_e}{180°}\right)$$

Where A = P = 4 [Since, lap winding]

$$AT_d/\text{Pole} = \frac{500\times 45.45}{2\times 4\times 4}\left(\frac{2\times 8°}{180°}\right)$$

$$= 63.125$$

Cross magnetizing amphere turns per pole

$$AT_c/\text{pole} = \frac{ZI_a}{2AP} - 63.125$$

$$= \frac{500\times 45.45}{2\times 4\times 4} - 63.125 = 647.03$$

09. 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.

10. Ans: 100 Ω

Sol: Given data:

V_t = 200 V, R_f = 100 Ω 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 $I_{f0} = \frac{V_t}{R_f} = \frac{200}{100} = 2\text{A}$

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

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

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

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

$\therefore I_{f1} = 1$ A

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

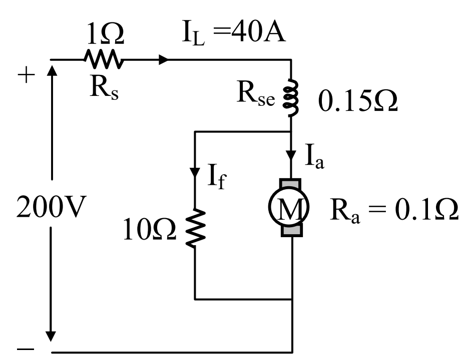
$$\frac{I_{f0}}{I_{f1}} = \frac{R_f + R_e}{R_f}$$

$\Rightarrow R_f + R_e = 2R_f$

$\Rightarrow R_e = 100\ \Omega$

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 $V_{sh} = 200 – I_L\ (R_s + R_{se})$

$= 200– 40\ (0.1+0.15)$

$= 154$V

Therefore, $I_f = 15.4$ A

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

$= 200 – (40 –15.4)0.1 –40(1.15)$

$= 151.54$V

We know that,

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

$$\Rightarrow N_2 = \frac{151.54 \times 1500}{190} = 1196.3 \text{ rpm}$$

12. 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

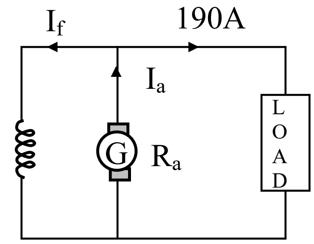
Therefore, region (2) and (4) comes under regenerating mode.

13. Ans: (b)

Sol: Given data, 250V, $I_L = 190$A, $R_{sh} = 125\Omega$ 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

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

∴ Armature copper loss,

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

$$I_a^2 R_a = 3977.7$$

Where, $I_a = I_L + I_f$

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

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

14. Ans: (a)

Sol: At maximum effeiciency,

Variables losses = Constant losses

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

$= 800+500$

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

15. Ans: (a, b, c, d)

Sol: At 800rpm, $E_{a1} = 230 - 20 \times 0.4 = 222V$

For fan, $T_L \propto N^2$ OR $T_2 = K_1 N^2$

For motor, $T_c = k_a\phi I_a$

(a) When magnetic circuit is saturated,

ϕ = constant and $T_c = KI_a$

Under steady state, $T_e = T_c$

$KI_a = K_1 N^2$

$$\frac{KI_{a2}}{KI_{a1}} = \frac{K_1 N_2^2}{K_1 N_1^2}$$

$$I_{a_2} = 20\left[\frac{1000}{800}\right]^2 = 31.25A$$

$$E_{a_2} = V_{t_2} - 31.25 \times 0.5$$

$$\frac{E_{a_2}}{E_{a_1}} = \frac{N_2\phi_2}{N_1\phi_1} = \frac{N_2}{N_1} \quad \text{as } \phi = \text{consant}$$

$$E_{a_2} = 222 \times \frac{1000}{800} = 277.5V$$

$$V_{t_2} = 277.5 + 31.25 \times 0.5 = 293.125V$$

(b) When magnetic circuit is not saturated, $\phi \propto I_a$ and $T_e = K_2 I_a$

$T_e = T_L$, $K_2 I_a^2 = K_1 N^2$

$$\left(\frac{I_{a_3}}{I_{a_1}}\right)^2 = \left(\frac{N_3}{N_1}\right)^2$$

$$I_{a_3} = I_{a_1}\frac{N_3}{N_1} = 20 \times \frac{1000}{800} = 25A$$

$$E_{a_3} = V_{t_3} - 25 \times 0.5$$

$$\frac{E_{a_3}}{E_{a_1}} = \frac{N_3\phi_3}{N_1\phi_1} = \frac{N_3 I_{a_3}}{N_1 I_{a_1}}$$

$$E_{a_3} = 222 \times \frac{1000}{800} \times \frac{25}{20} = 346.87V$$

$$V_{t_3} = 346.87 + 25 \times 0.5 = 359.375V$$

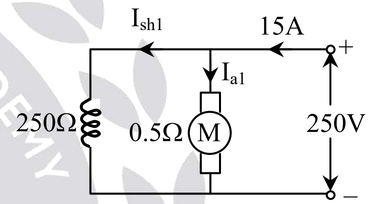
16. Ans: 2797 rpm

Sol: $V = 250V$, $R_a = 0.5\Omega$, $R_{sh} = 250\Omega$

$I_s = 15A$, $N = 1400rpm$, $R_e = 250\Omega$

Case-(i):

$$I_{sh_1} = \frac{250}{250} = 1A$$



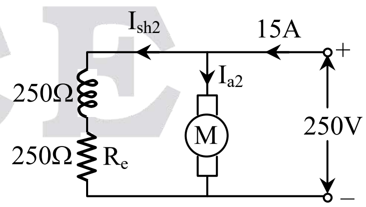
$E_{b1} = V - I_{a1}R_a$

$= 250 - 14 \times 0.5$

$= 243$ V

Case-(ii):

$$I_{sh_2} = \frac{250}{500} = 0.5A$$



$$I_{a_2} = 15 - I_{sh_2} = 14.5A$$

$E_{b2} = V - I_{a2} R_a$

$= 250 - 14.5 \times 0.5$

$= 242.75V$

We know that, $E_b \propto N\phi$ and $\phi \propto I_{sh}$

$$\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \times \frac{I_{sh_2}}{I_{sh_1}}$$

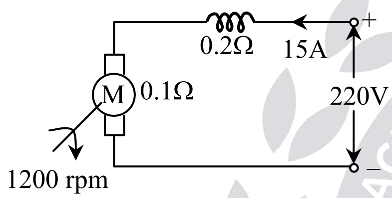
$$\Rightarrow N_2 = \frac{242.75}{243} \times \frac{1}{0.5} \times 1400$$

$$= 2797 \text{ rpm}$$

17. Ans: 2011 rpm

Sol: $V = 220V$, $I_a = 15A$, $N_1 = 1200$ rpm

Case-(i):

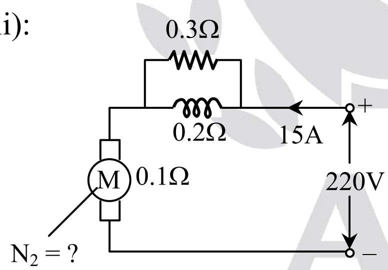


$$E_{b1} = V - I_a [R_a + R_{se}]$$

$$= 220 - 15 [0.1 + 0.2]$$

$$= 215.5V$$

Case-(ii):



$$E_{b2} = V - I_a\left[R_a + \frac{R_d R_{se}}{R_d + R_{se}}\right]$$

$$= 220 - 15\left[0.1 + \frac{0.2 \times 0.3}{0.5}\right]$$

$$= 220 - 15(0.22)$$

$$= 216.7V$$

We know that, $E_b \propto N\phi$

$$\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \times \frac{\phi_2}{\phi_1}$$

$$\frac{216.7}{215.5} = \frac{N_2}{1200} \times \frac{9}{15}$$

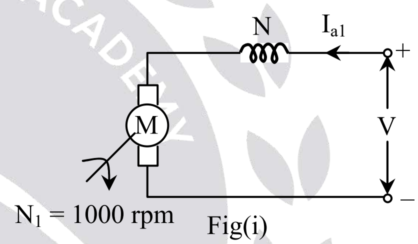
[Since, $\phi_2 \propto$ field current $= \frac{15 \times 0.3}{0.3 + 0.2} = 9A$]

$N_2 = 2011$ rpm

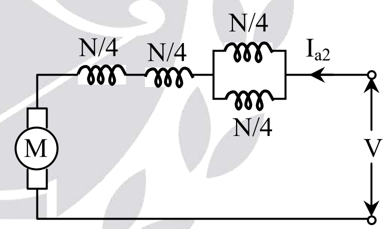
18. Ans: (b)

Sol: $N_1 = 1000$ rpm

Initial field amphere turns = NI_{a1}



Fig(i)



Fig(ii)

Amphere turns in fig(ii),

$$I_{a2}\left[\frac{N}{4} + \frac{N}{4}\right] + \frac{I_{a2}}{2}\left[\frac{N}{4} + \frac{N}{4}\right]$$

$$= I_{a2}\left[\frac{N}{2}\right] + \frac{I_{a2}N}{4}$$

$$= I_{a2}\left[\frac{3N}{4}\right]$$

For constant power drive, $I_{a1} = I_{a2} = I_a$

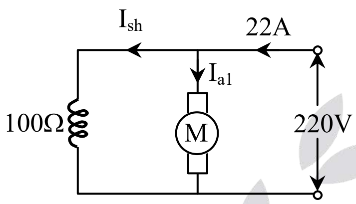
We know that, $N \propto \frac{1}{\phi}$

$$\frac{N_2}{N_1} = \frac{\phi_1}{\phi_2} = \frac{NI_a}{\frac{3N}{4}I_a}$$

$$\therefore\ N_2 = \frac{4}{3}N_1 = \frac{4\times1000}{3} = 1333\ \text{rpm}$$

19. Ans: 3.5Ω

Sol: $N_1 = 1000$ rpm, $N_2 = 800$ rpm



$E_{b1} = V - I_{a1}R_a$

$I_{a1} = 22 - I_{sh} = 22 - 2.2 = 19.8A$

$E_{b1} = 220 - 19.8(0.1) = 218.02V$

Given that, $T \propto N^2$

$$\Rightarrow \frac{\phi I_{a1}}{\phi I_{a2}} = \left(\frac{N_1}{N_2}\right)^2$$

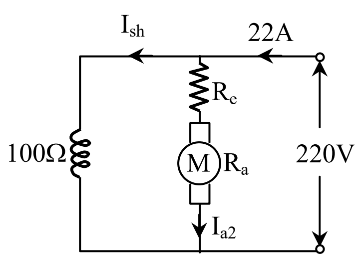
$$I_{a2} = \left(\frac{N_2}{N_1}\right)^2 I_{a1} = \left(\frac{800}{1000}\right)^2 \times 19.8 = 12.672A$$

We know that, $E_b \propto N\phi$

$$\Rightarrow \frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\Rightarrow E_{b2} = 218.02\left(\frac{800}{1000}\right) = 174.416$$

$\therefore\ E_2 = V - I_{a2}\,[R_a + R_e]$



$174.416 = 220 - 12.672[0.1 + R_e]$

$$\therefore\ R_e = \frac{220 - 174.416}{12.672} - 0.1 = 3.5\Omega$$

20. Ans: 47.5

Sol: Given

Separately excited DC motor :

$V_1 = 100$ V $V_2 = ?$

$I_{a1} = 10$ A $N_2 = 500$ rpm

$N_1 = 1000$ rpm $R_a = 1\ \Omega$

$\phi \propto I_f =$ constant

$\phi_1 = \phi_2$

$T_L \propto N^2$

At steady state $T_L = T_{em}$

$T_{em} \propto N^2$

But $T \propto \phi\, I_a$

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{\phi_2 I_{a2}}{\phi_1 I_{a1}} = \left(\frac{N_2}{N_1}\right)^2 \quad (\because \phi_2 = \phi_1)$$

$$\Rightarrow \quad \frac{I_{a2}}{10} = \left(\frac{500}{1000}\right)^2$$

$$\Rightarrow \quad I_{a_2} = 10\times\frac{1}{4} = 2.5A$$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{N_2}{N_1}\times\frac{\phi_2}{\phi_1}$$

$$E_{b_1} = V_1 - I_{a_1}R_a$$

$$E_{b_1} = 100 - 10\times1 = 90\ \text{V}$$

$$\frac{E_{b_2}}{90} = \frac{500}{1000}$$

$$\Rightarrow \quad E_{b_2} = 45\ \text{V}$$

$$V_2 = E_{b_2} + I_{a_2}R_a$$

$$= 45 + 2.5\times1$$

$V_2 = 47.5$ V

21. (i) Ans: (d)

Sol: Motor operation before plugging:

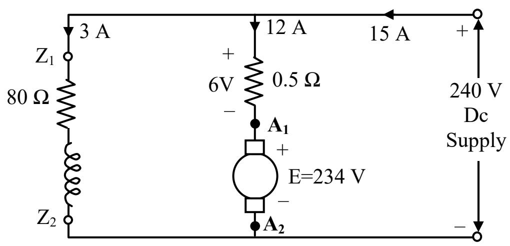


Fig.1.

Circuit immediately after plugging (reversing supply to the armature, while shunt field current direction is unchanged):

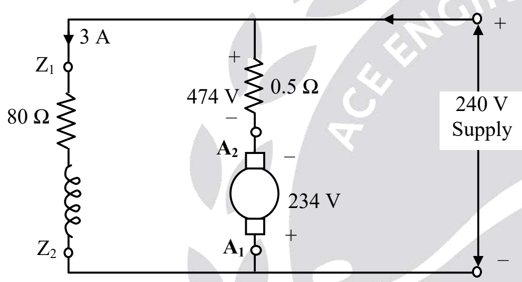


Fig.2.

Since field flux direction is unchanged, and speed also is unchanged (speed cannot change instantaneously due to inertia) the induced emf does not change in magnitude or polarity and is as shown in fig.2. The voltage drop across the armature resistance (by KVL) is then (240 + 234) = 474 V.

(ii). Ans: (a)

Sol: $I_a = \dfrac{V + E_b}{R_a + R}$

$$1.25\times12 = \frac{240+234}{0.5+R}$$

$$R = 31.1\Omega$$

22. Ans: 57.78

Sol: Given data:

$P_0 = 10\text{Hp}$

$I_{fl} = 37.5\text{A}$

$V = 230\text{V}$

$\phi = 0.01\text{Wb}$

$P = 4$

$Z = 666$

$A = 2$

$R_a = 0.267\Omega$

Rotational losses = 600W

At, $N_1 = 1000$ rpm

Output torque = T_{sh} = ?

$$E_b = \frac{\phi ZN}{60}\frac{P}{A}$$

$$= \frac{0.01\times666\times1000}{60}\times\frac{4}{2}$$

$$E_b = 222\text{V}$$

$$I_a = \frac{V - E_b}{R_a} = \frac{230-222}{0.207}$$

$$= 29.96\text{A}$$

Gross mechanical power developed = P_{gm}

$P_{gm} = E_b I_a$

$= 222 \times 29.96$

$= 6651.12\text{W}$

Output power = shaft power

$P_{sh} = P_{gm}$ – rotational losses

$P_{sh} = 6651.12 - 600$

$= 6051.12\text{W}$

$P_{sh} = T_{sh} \times \omega$

$$6051.12 = T_{sh} \times \frac{2\pi\times1000}{60}$$

Output torque = T_{sh} = 57.78N-m

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. ⇒ $Ns_1 = Ns_2$

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

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

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

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

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

⇒ N_s = 600 rpm **(or)**

G_2: p = 12, f = 60 Hz

⇒ N_s = 600 rpm

03. Ans: (c)

Sol: m = 3 slots/pole/phase

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

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

$$K_{d3} = \frac{\sin \frac{3\times 3\times 20^o}{2}}{3\times \sin \frac{3\times 20^o}{2}} = 0.67$$

04. Ans: (b)

Sol: Total Number of conductor = 6 × 180

= 1080

$$f = \frac{NP}{120} = \frac{300\times 20}{120} = 50\text{Hz}$$

Number of turns = $\frac{1080}{2} = 540$

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

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

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

and slots/pole/phase, $m = \frac{180}{3\times 20} = 3$

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

$$= \frac{\sin \frac{3\times 20}{2}}{3\sin 10} = \frac{\sin 30^o}{3\sin 10^o} = 0.95$$

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

$= 4.44\times 0.95\times 50\times 180 \times 25 \times 10^{-3}$

= 949.05V ≈ 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: $\frac{s}{p} = \frac{48}{4} = 12;$

$$m = \text{slots / pole / phase} = \frac{48}{3\times 4} = 4$$

$$\text{Slot angle}\quad \gamma = \frac{180°}{(s/p)} = \frac{180}{12} = 15°;$$

Phase spread $m\gamma = 15 \times 4 = 60°$

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

$$\text{Total turns / phase} = \frac{NT}{3}$$

For 3 – ϕ system $m\gamma$ = 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)

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

$$\text{Turns/phase} = \frac{480}{3} = 160$$

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

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

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

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

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

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

$E_{ph} = 808.68$ 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

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

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

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

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

$E_{ph} = 4.44 \times 0.9027 \times 0.951 \times 0.025 \times 50\times 240$

$= 1143.55$ 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

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

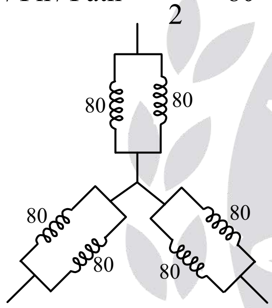
$$E_{1-\phi} = \frac{E_{3-\phi}}{0.5} = \frac{808.68}{0.5} = 1617.36$$

12. Ans: (404 V, 700 V)

Sol: If turns are connected in two parallel paths then

Turns/ph = 160

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



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

$= 404$ 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

$$E_{Phase} = \text{Turns/Ph} = \frac{480}{2} = 240$$

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

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

$= 571.77$ 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: $I_q = I_a\cos\psi = 1\cos(53.97) = 0.588$

$I_d = I_a\sin\psi = 1.\sin(53.97) = 0.808$

$E = V\cos\delta + I_qR_a + I_dX_d$

$= 1\cos(17.1) + 0.588(0) + 0.808(0.8)$

$= 1.603$pu

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 $R_a = 0$.

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

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

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{6.6\times 10^3}{\sqrt{3}} = 3810V$$

$$I_L = \frac{P}{\sqrt{3}V_L\cos\phi} = \frac{2.5\times 10^6}{\sqrt{3}\times 6.6\times 10^3\times 0.8}$$

$I_L = 273.36A = I_{ph}$

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

$$= \frac{3810\times 0.6 + 273.36\times 6}{3810\times 0.8 + 273.36\times 0}$$

$\tan\psi = 1.288$

$\psi = 52.175°$

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

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∠85.42

$$V_{Ph} = \frac{415}{\sqrt{3}} = 239.60$$

$$\cos(\theta+\phi) = \frac{-13.912\times5.015}{2\times239.60}$$

$\theta + \phi = 98.39 \Rightarrow \phi = 12.970$

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 $R_a = 0\ \Omega$.

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

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

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

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

At maximum voltage regulation, θ = ϕ.

Therefore, ϕ = 90° and cosϕ = 0.

Excitation voltage is

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

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

$E_0 = 350$ 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

$$X_s = \frac{V_{oc}}{I_{sc}}\bigg|_{I_f = \text{given}}$$

$$= \frac{360(\text{phase voltage})}{20.83(\text{phase current})} = 17.28\Omega$$

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.

37. Ans: (b)

Sol: First reduce the prime mover input (mechanical power).

This reduces the alternator's active power (kW) output.

You must bring its power contribution to zero so it is neither supplying nor absorbing real power.

If you don't do this first, the machine may continue to carry load or even start motoring.

38. Ans: (a)

Sol: High synchronous reactance and low resistance ensures:

Better stability during load sharing.

Smooth reactive power (kVAR) sharing.

Reduced circulating currents between alternators.

39. Ans: (d)

Sol: Rate of flickering = beat frequency

$= f - f^1$

$= 50.2 - 50$

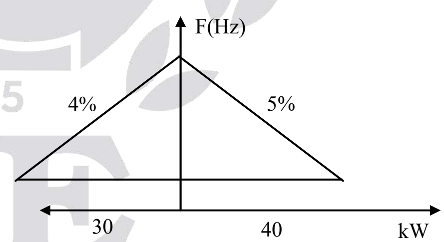
$= 0.2Hz$

$\Rightarrow$ 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

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

$\bar{E}_1$ and $\bar{E}_2$ must be of phase quantities.

$$\therefore I_{sy} = \frac{\left|\frac{3300}{\sqrt{3}} - \frac{3200}{\sqrt{3}}\right|}{2\times 1.7}$$

$I_{sy} = 16.98\text{A}$.

45.

Sol:

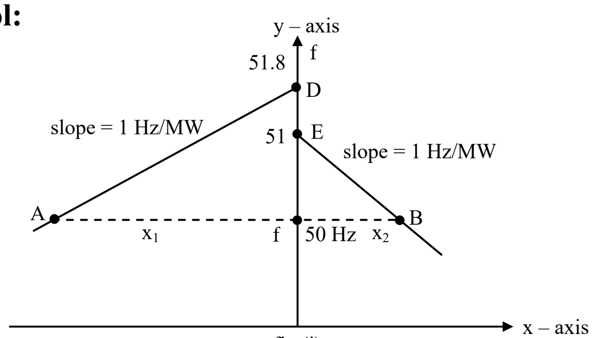


fig (i)

$y = -mx+c$

(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

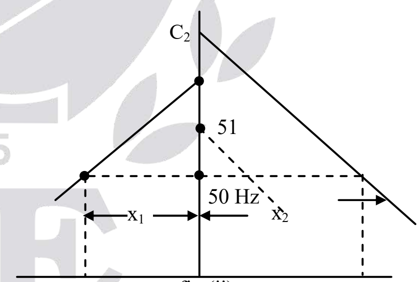


fig (ii)

(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)

$f = -x_2 + c_2 = 50$

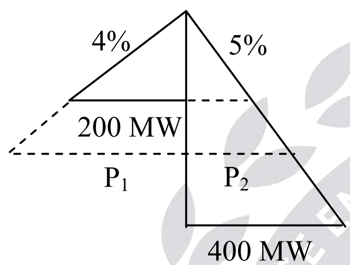
$-20 + c_2 = 50$

$c_2 = 70$

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

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

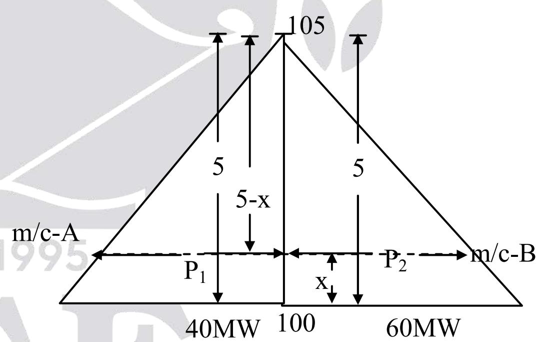
$P_2 = 320$ MW

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



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

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

$P_1 + P_2 = 80$

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

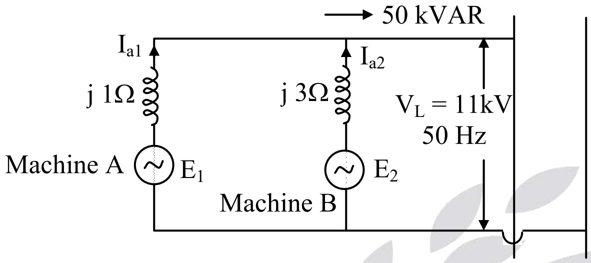
$\Rightarrow x = 1$

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

$P_2 = 12(5-1) = 48\text{MW}$

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 = cosϕ = 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

$$P^1 = P = \frac{E^1 V}{X_s}\sin\delta^1 = \frac{EV}{X_s}\sin\delta$$

$$\frac{8036.3}{10}\sin\delta^1 = \frac{6350}{10}\sin(8.94) = 7.14^o$$

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: $P = \dfrac{EV}{X_S}\sin\delta$

$$\Rightarrow 0.5 = \frac{1.3\times 1}{0.8}\sin\delta$$

$\Rightarrow\ \delta = 17.92^0$

$E = V + j\, I_a X_s$

$$I_a = \frac{E\angle\delta - V\angle 0}{X_s\angle 90}$$

$$= \frac{1.3\angle 17.92 - 1\angle 0}{0.8\angle 90}$$

$= 0.581\angle{-30.639^0}$

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) = $\dfrac{V}{X_s}[E\cos\delta - V]$

$$= \frac{1}{0.8}[1.3\times\cos(17.92) - 1]$$

$= 0.296$ 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

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

Substitute δ = θ = 90

$$Q = \frac{1}{0.8}[1.3\cos(90) - 1] = -1.25\,\text{P.U}$$

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 = 1.3pu, X_s = 1.1pu, P =0.6pu, V=1.0pu

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

$\Rightarrow \delta = 30.53°$

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

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

64. Ans: (a, b, c)

Sol: For a cylindrical rotor synchronous machine the synchronous power or real power is given by, $P = \frac{E_f V_t}{x_s}\sin\delta$

$$0.5 = \frac{1.4\text{x}1}{1.2}\sin\delta$$

$\delta = 25.4°$

1% increase in torque means 1% increase in real power.

dp =1% of its previous value

$$= \frac{1}{100}(0.5) = 0.005\text{p.u}$$

for cylindrical rotor machine, reactive power is

$$Q = \frac{E_f V_t}{x_s}\cos\delta - \frac{V_t^2}{x_s}$$

$$\frac{dQ}{d\delta} = \frac{-E_f V_t}{x_s}\sin\delta$$

$$\frac{dP}{d\delta} = \frac{E_f V_t}{x_s}\cos\delta$$

$$\frac{dQ}{dp} = -0.475(1\%) = -0.475\%$$

65. 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

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

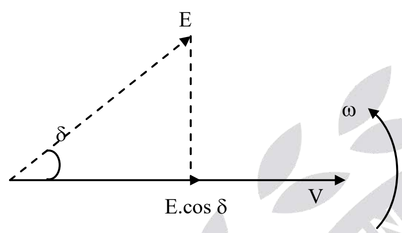
$$T = \frac{P}{\omega} = \frac{41569.2}{2\pi\times\frac{1800}{60}} = 220.53\,\text{N} - \text{m}$$

66. Ans: (a)

Sol: From phasor diagram, 'E' leads the 'V', hence called "Generator".

Here, $E \cos \delta > V$ called over excited generator.

An under excited generator always operators at "laging power factor".



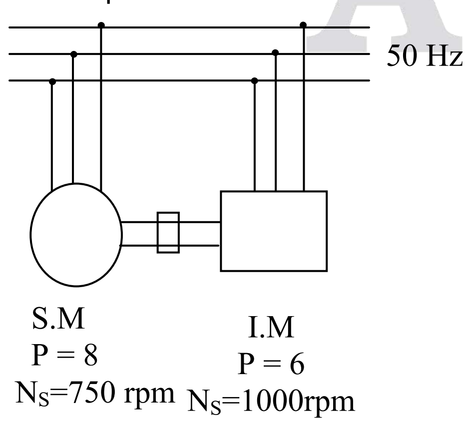
67. Ans: (a)

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.

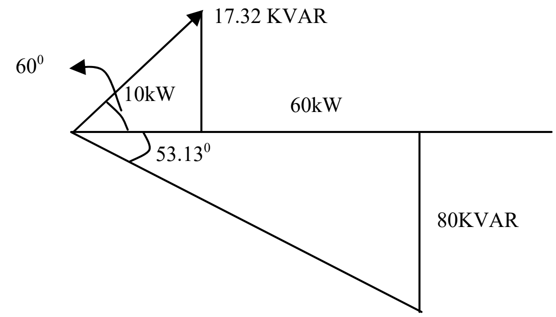
$$\text{slip} = \frac{N_s - N_r}{N_s} = \frac{1000 - 750}{1000} = \frac{1}{4}$$

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



68. Ans: (b)

Sol:



Total kW of load = kV × cosϕ

$P_1 = 100 \times 0.6 = 60$ kW

kVAR Requirement of load

$= P \times \tan\phi = 60 \times \tan 53.13 = 80$ kVAR

KW requirement of synchronous motor

$(P_2) = 10$ kW

Operating p.f of load = 0.5 leads

Phase angle$\phi = \cos^{-1}(0.5) = 60$

$Q = P \tan\phi = 10 \times 10^3 \times \tan 60 = 17.32$ 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

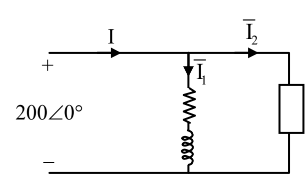
$$\tan\phi = \frac{Q}{P} = \frac{62.68}{70} = 0.895$$

$\phi = 41.842$

p.f = cos ϕ = 0.74 lag

69. 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

70. Ans: (b)

Sol: $V_1 = 400V$ $E = 400V$

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

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

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

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

$\Rightarrow \delta = 18.21°$

71. 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

72. Ans: (d)

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

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

$I_a = 7.3$ A

73. Ans: (a)

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

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

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

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

$\frac{800\times 10^3}{3} = \frac{(1154.7)^2}{2.2\angle 84.8^o}\cos(84.8) - \frac{(1154.7\times 1443.37)}{2.2\angle 84.8^o}\cos(84.8+\delta)$

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

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

$= 254.59\angle 24.9^o$

74. Ans: (b)

Sol: PF = cos (24.9) = 0.907 lead

75. 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)

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

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

$P_{mech} = 761$ kW

76. Ans: (4.84 Nm)

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

$N_s = 1500$

$$T = P/\omega = \frac{760.94\times60}{2\pi\times1500} = 4.84 \text{ Nm}$$

77. Ans: (b)

Sol: $V_L = 230V$

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

$Z_s = 0.6 + j3 = 3.06\angle78.69^o$

$\theta = 78.69^o$

at $I_a = 10A$, UPF ,

$E = V\angle0 - I_a\angle\pm\phi\, Z_s\angle\theta$

$= 132.8\angle0 - 10\angle0\; 3.06\angle78.69$

$= 130.29\angle-13.31^o$

$\because$ Excitation is kept constant E =130.29,

V = constant

Load on the motor is ↑, δ↑, I_a↑ to 40A (given)

$$|I_aZ_s| = \overline{V}(0) - \overline{E}\angle-\delta$$

$$= \sqrt{V^2 + E^2 - 2VE\cos\delta}$$

40×3.06

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

$\delta = 55.4^o$

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

$$I_a = \frac{132.8\angle0 - 130.29\angle-55.4}{3.06\angle78.69^o}$$

$I_a = 40\angle-17.3$

PF = cos (17.3) =0.954 lag

78. Ans: (c)

Sol: $P_{Mech} = P_{in}$ – Copper loss

$= \sqrt{3}\,V_LI_L\cos\phi - 3I_a^2R_a$

$= (\sqrt{3}\times230\times40\times0.953)-(3\times40^2\times0.6)$

$= 12.035$ kW

$$T = \frac{P_{mech}}{\omega} = \frac{12.035\times10^3}{2\pi\times\frac{1000}{60}} = 78.34\,\text{N}-\text{m}$$

79. Ans: (b)

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

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

$$= \frac{1000\times10^3}{\sqrt{3}\times6.6\times10^3\times0.8} = 109.3A = I_{ph}$$

$E = V\angle0 - (I_a\angle\pm\phi\; z\angle\theta)$

$= 3810.5\angle0 - 109.3\angle36.86\times12\angle90^o$

$= 4715.5\angle-12.85^o$

Excitation is constant, V is constant

$$P = \frac{EV}{X_s}\sin\delta = \frac{1500\times10^3}{3}$$

$$= \frac{4715.5\times3810.5}{12}\sin\delta$$

$\Rightarrow \delta = 19.5^o$

80. Ans: (a)

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

$$= \frac{3810.5\angle0 - 4715.5\angle-19.5}{12\angle90}$$

$= 141.4\angle21.95$

PF = cos (21.95^o)

= 0.92 lead

81. Ans: (*)

Sol: Data given

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

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

$I_{line} = I_{phase} = \frac{100\times10^3}{\sqrt{3}\times400} = 144.33$ 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

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

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

82. Ans: (a, d)

Sol:

$$V_t = \frac{3300}{\sqrt{3}} = 1905.2V, E_f = \frac{4000}{\sqrt{3}} = 2309.5V$$

$$Z_s = \sqrt{0.4^2 + 5^2} = 5.016$$

$$\alpha_z = \tan^{-1}\left[\frac{0.4}{5}\right] = 4.57^0$$

Per phase input power is

$$\frac{P}{3} = \frac{V_t E_f}{Z_s}\sin(\delta - \alpha_z) + \left(\frac{V_t}{Z_s}\right)^2 \times r_a$$

$$\frac{1000\times10^3}{3} = \frac{1905.3\times2309.5}{5.016}\sin(\delta - \alpha_z) + \left[\frac{1905.3}{5.016}\right]^2 \times 0.4$$

$\sin(\delta - \alpha_2) = 0.314$

$\delta = 18.31 + 4.57 = 22.88$

$$I_a Z_s = \left[V_t^2 + E_f^2 - 2E_f V_t \cos\delta\right]^{1/2}$$

$\therefore I_a = 184.43$A

$3V_t I_a \cos\theta = P = 100 \times 10^3$

$\therefore \cos\theta = 0.9486$ leading

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

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

$$\%\ \text{Slip} = \frac{N_s - N_r}{N_s} \times 100$$

$$= \frac{1000 - 960}{1000} \times 100 = 4\%$$

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,

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

$$\Rightarrow N_s = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

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,

$$N_{pm} = \frac{120f}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

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.

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

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

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

$$\Rightarrow P_{in} = 16$$

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

$$= 3\times\left(\frac{20}{\sqrt{3}}\right)^2\times 0.4$$

$$= 160\text{ W}$$

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

$P_G = (1 - s)P_r$

$$= \left(1-\frac{3}{50}\right)\times 3840$$

$$= 3609.6\text{ W}$$

Net mechanical power output,

P_{net} = 3609.6 –550 = 3059.6 W

$$\%\text{ efficiency} = \frac{P_{net}}{P_{input}}\times 100 = \frac{3059.6}{4000}\times 100$$

$$= 76.49\%$$

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

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

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

$$N_s = \frac{120f}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

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

$$N_s = \frac{120f}{P} = \frac{120\times 50}{8} = 750 \text{ rpm}$$

Slip at maximum torque,

$$s_{Tmax} = \frac{N_s - N_{rT\max}}{N_s} = \frac{750-660}{660} = 0.12$$

Operating slip s = 0.04

We have $\dfrac{T}{T_{max}} = \dfrac{2\times s\times s_{T\max}}{s^2 + s_{T\max}^2}$

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

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

$T = 0.6 \times 150 = 90$ 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 $s_{Tmax} = \dfrac{R_2 + R_{ext}}{X_{20}}$,

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

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

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

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

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

$R_{ext} = 0.029\ \Omega$

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

Rotor input, $P_{ri} = \dfrac{P_{gmd}}{(1-s_{fl})} = \dfrac{10.6\times10^3}{(1-s_{fl})}$

$$T_{fl} = \frac{P_{ri}}{\omega_s} = \frac{60}{2\pi N_s}\frac{10.6\times10^3}{(1-s_{fl})}$$

$$= \frac{60}{2\times3.14\times1000}\ \frac{10.6\times10^3}{(1-s_{fl})}$$

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

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

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

$= 959.5$ rpm

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 $R_1 = R_2 = \dfrac{R_{01}}{2}$

$$\tau_{st} = \frac{60}{2\pi\times1500}\times\left(\frac{3I_{BR}^2 R_{01}}{2}\right)$$

$$= \frac{60}{2\pi\times1500}\times\frac{30\times10^3}{2} = 95.49 \text{ Nm}$$

15. Ans: (c)

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

$$I_{st,\,supply} = k^2 I_{sc} = 0.7^2\times400 = 196\text{A}$$

16. 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 =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

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

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

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 $\dfrac{T_{st}}{T_{f\ell}} = \left(\dfrac{I_{sc}}{I_{f\ell}}\right)^2 S_{f\ell}$

$$= \left(\frac{300}{60}\right)^2\times0.06 = 1.5$$

$T_{st} = 1.5\times150 = 225$ N – m

When star delta starter is used,

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

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

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

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

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

19. Ans:(a, b, c, d)

Sol: Rotor current at starting

$$I_{2st} = \frac{E_2}{\sqrt{r_2^2 + x_2^2}} = \frac{120}{\sqrt{0.2^2 + 1^2}} = 117.67A$$

Starting torque $(T_{st}) = \frac{3}{w_s}(I_{2st})^2 \frac{r_2}{1}$

$$= \frac{3}{50\pi}(117.67)^2(0.2)$$

$$= 52.9 \text{N.m}$$

Rotor power factor at full load

$$= \frac{r_2}{\sqrt{r_2^2 + (sx_2)^2}} = \frac{0.2}{0.204} = 0.98$$

Full-load torque $(T_{fl}) = \frac{1}{w_s} 3(I_{2fl})^2 \frac{r_2}{s}$

$$= \frac{1}{50\pi} 3.(23.53)^2 \frac{0.2}{0.04}$$

=52.87Nm

20. Ans: (b, c)

Sol: Slip, $s = \left[\frac{1500 - 1440}{1500}\right] = 0.04$

For linear torque-slip characteristics

$$T_e = \frac{3V^2}{\omega_s}\left[\frac{s}{r_2}\right]$$

As V, ω_s and r_2 are constant,

$T_e \propto 0.04$

$\frac{T_e}{2} \propto s_1$

$$\frac{\frac{1}{2}T_e}{T_e} = \frac{s_1}{0.04} \Rightarrow s_1 = \frac{0.04}{2} = 0.02$$

New motor speed $= 1500(1 - 0.02)$

= 1470 rpm

Rated torque $= \frac{10{,}000 \times 60}{2\pi \times 1460}$ Nm

Power output at half of rated torque

$$= \frac{1}{2}\left[\frac{10000 \times 60}{2\pi \times 1460}\right] \times \frac{2\pi \times 1470}{60} = 5.034\text{kW}$$