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ELECTRICAL ENGINEERING

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ELECTRICAL MACHINES

Volume - I : Study Material with Classroom Practice Questions

Electrical Machines

1. Transformers

01. Ans: (b)

Sol: 400/200 V 50 Hz

$B_{max} = 1.2$ T

800V, 50 Hz linear dimension all double

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

$B_{max2} = ?$

$l_2 = 2l_1 \qquad b_2 = 2b_1$

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

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

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

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

02. Ans: (c)

Sol: ℓ **= 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 the 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 wave

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

Note: As given transformer is a 1:1 T/F, the induced voltage on both primary & secondary is same

04. Ans: (a)

Sol: i(t) = 10 sin (100π t) A

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

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

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

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

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

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

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

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

($\therefore$ I_w is core loss component)

$$\text{Reluctance } R_l = \frac{\ell}{\mu A}$$

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

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

$\therefore$ 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)

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

$$= \sqrt{(3.2)^2 - (0.617)^2} = 3.139\text{ A}$$

$I_{N2} = 4.44$A

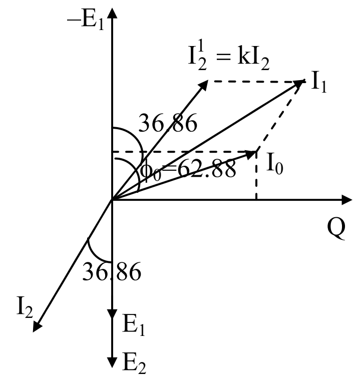
$$I_0 = \sqrt{I_w^2 + I_N^2}$$

$$= \sqrt{(0.617)^2 + (4.44)^2}$$

$= 4.48$ A ≈ 4.5 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 $\sin\phi_0 = 0.89$

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

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

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

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

$I_1 = 4.58^a$

Power factor;

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

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

08. Ans: (c)

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

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

$= 90.76\angle -37.77A$

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 $= (I_{line})^2 \times 0.18$

$= (90.86)^2 \times 0.18$

$= 1484$ W

09. Ans: (b)

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

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

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

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

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

$W_{h2} = 348.79$

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

$W_e \propto v^2$

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

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

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

10. Ans: (a)

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

$V_2 = 220V$, $f_2 = 25Hz$

$W_i = 850$ W

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

$W_i = Af + Bf^2$

$2500 = A \times 50 + B \times 50^2$ ……… (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: $W_h = \frac{W_i}{2}$; $W_e = \frac{W_i}{2}$

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

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

$W_{h2} = 0.844\ W_{h1} = 0.422\ W_{i1}$

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

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

$W_{e2} = 0.40\ W_i$

$W_{i2} = W_{h2} + W_{e2} = 0.422\ W_{i1} + 0.40\ W_{i1}$

$W_{i2} = 0.822\ W_{i1}$

Reduction in iron loss is around $1 - 0.822$

$= 0.178 \approx 0.173$

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 some.

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

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

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

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: 20 kVA 330 0/220V 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

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

FL cu loss = %R × VA rating

= 0.01 ×20,000 = 200 Watt

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

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

At 90.9A ⇒ cu loss = 200 W

85At ⇒ cu loss = ?

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

Total loss when 14.96 kW o/p

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

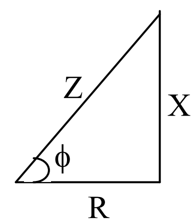
= 160+174.8 = 334.8 W

Input power = 14.96 kW+334.8W

= 15294.8W

14. Ans: (a)

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



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

$R = Z\cos\phi$

$R = 0.533 \times 0.2$

$R_1 = 0.106\ \Omega$

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

Reactance at f = 25Hz

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

$X_2 = 0.2611\ \Omega$

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

$Z = 0.281\Omega$

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

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

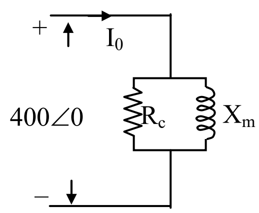
15. Ans: (a)

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

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

$X_m = 2\pi f\,(aM) \Rightarrow 2\times\pi\times50\times 4 = 400\pi\Omega$

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



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

$= 0.41$ A

16. Ans: (d)

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

$W_h = W_e = 10W$

Initially test is conducted on LV side

Now $\dfrac{v}{f}$ ratio is $\dfrac{100}{50} = 2$

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

Now $\dfrac{V}{f}$ ratio is constant, $W_h \propto f$ and

$W_e \propto f^2$.

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

$W_{e2} = W_{e1} \times \left(\dfrac{f_2}{f_1}\right)^2 = 10 \times \left(\dfrac{40}{50}\right)^2 = 6.4$ 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 $\dfrac{5}{k}$ i.e 10A

For 10A $\rightarrow$ 25 watt

5 A $\rightarrow$?

$W_{c2} = \left(\dfrac{I_2}{I_1}\right)^2 W_{c1} = \left(\dfrac{5}{10}\right)^2 \times 25 = 6.25$ W

17. Ans: (b)

Sol: $\eta = \dfrac{kVA \times \cos\phi}{kVA \times \cos\phi + W_1 + W_{Cu}}$

$W_i = 60W$

$W_{Cu} \propto I^2$

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

$W_{Cu} = \left(\dfrac{10}{6}\right)^2 \times 21.6 = 60W$

$W_i + W_{Cu} = 120$ W

$\%\eta = \dfrac{4K \times 1}{4K \times 1 + 120} \times 100$

$= 97.08\%$

18. Ans: (c)

Sol: $\eta = 98\%$

Lets take kVA = 1p.u

p.f = 1

η at full load : $0.98 = \dfrac{1 \times 1}{1 \times 1 + W_i + W_{Cu}}$

$W_i + W_{Cu} = 0.0204$ ……..(1)

For 1/2 full load

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

$W_i + 0.25\,W_{Cu} = 0.0102$ ……… (2)

By solving equation (1) & (2)

$W_i + W_{Cu} = 0.0204$

$W_i + 0.25W_{Cu} = 0.0102$

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

$\eta_{3/4} = \dfrac{0.75\times1\times1}{0.75\times1\times1 + 6.8\times10^{-3} + (0.75)^2 \times 0.0136}$

$= 98.1\%$

19. Ans: (a)

Sol: η_{max} =

% load at which maximum efficiency possible

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

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

= 98.1 %

20. Ans: (d)

Sol: 10 kVA,2500/250 V

OC 250V 0.8A, 50W

SC 60V 3A, 45W

Iron losses = 50 W = W_I

$$I_{(4V)} = \frac{10000}{2500} = 4A \text{ (rated current)}$$

cu loss at 3A = 45W

cu loss at 4A = ?

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

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

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

21. Ans: (c)

Sol: $$\eta_{\underset{0.8}{max}} = \frac{7.9\times0.8\times10^3}{7.9\times08\times10^3+(2\times50)}\times100 = 98.44\%$$

22. Ans: (c)

Sol: $R_1 = 0.25\ \Omega$; $R_2 = 0.014\ \Omega$

Iron Loss = 240 W

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

$$= \left(\frac{200}{1000}\right)^2\times0.25+0.014 = 0.024$$

$$I_{2\,max} = \sqrt{\frac{\text{Iron loss}}{R_{02}}} = \sqrt{\frac{240}{0.024}} = 100A$$

23. Ans: (c)

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

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 kW

W_i = 153.06 × 24 = 3.673 kW

$W_{Cu} \propto S^2$

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

W_{Cu2} = 272.106

Transformer is ON load for 0 to 12 hrs so

W_{Cu2}= 272. 106 × 12 = 3265.28 W

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

$\%\eta_{all\ day}$ = 97.19% ≈ 97.2%

24. Ans: (*)

Sol: Given Iron loss = 1.25 kW, cosϕ = 0.85

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

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

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

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

= 9.09 A

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

= 1.415 kW

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

= 96.95 %

25. Ans: (c)

Sol: 1100/400v, 500 kVA, η_{max} = 98%

80% of full load UPF

% Z = 4.5% PF ⇒ max VR = $\frac{\%R}{\%Z}$

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

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

$= \frac{6377.5}{500\times10^3}\times100 \Rightarrow 1.27\ \%$

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

26. Ans: (b)

Sol: Terminal voltage =?

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

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

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

= (1.27 × 0.283) + (4.317 × 0.959)

% VR = 4.49% = 0 .0449 Pu

Total voltage drop on secondary side

= PU VR ×E_2

= 0.0449 × 400 = 18V

$V_2 = E_2$ – Voltage drop

= 400 –18 = 382V

27. Ans: (a)

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

$X_{02} = X_1' + X_2$

$R_1' = K^2R_1$ → (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 × 7.2)

= 0.072

R_{02} = 0.034 + 0.028 = 0.062Ω

X_{02} = 0.072 + 0.060 = 0.132Ω

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

I_2 = 22.72 A

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

Reg = 0.0133

% Reg = 1.33% is same on both sides

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

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

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 × 0.8 + 5 × 0.6 = 4.6%

= 0.046 pu

Voltage drop when with respect to secondary

= p.u. VR × secondary Voltage

= 0.046 × 440 = 20.2V

Terminal voltage

$V_2 = 440 - 20.2 = 419.75$ V

29. Ans: (b)

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

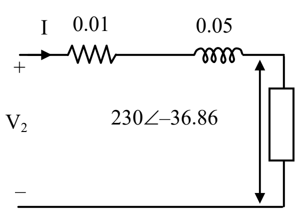
$R_{Pu}\cos\phi - X_{pu}\sin\phi = 0$

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

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

30. Ans: (c)

Sol:



$R_{pu} = 0.01$

$X_{pu} = 0.05$

$V_1 = 600$V

$V_2 = 230$V, 0.8 lag

Take rated current as 1pu

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

$= 0.0509\angle 41.83$pu

Convert this in volts

$= 0.0509\angle 41.83 \times 230$

$= 11.707\angle 41.83$ V

$E_2 = V + Iz$

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

$= 238.85\angle 1.87$

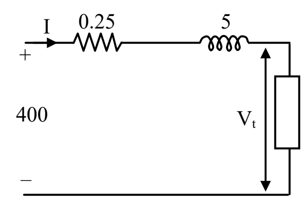
Turns ratio = $\frac{E_1}{E_2} = \frac{600}{238.85} = 2.5$

31. Ans: (c)

Sol: $P = VI\cos\phi$

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

$\Rightarrow \phi = 38.624$



From given data,

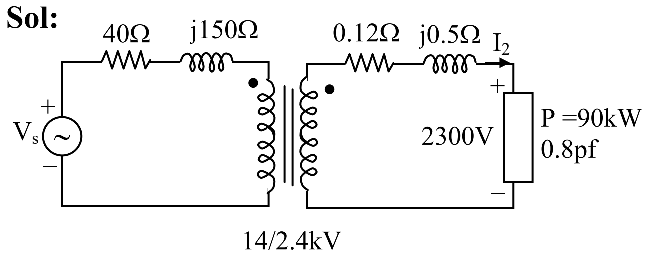
$-400 + (0.25 + j5)16\angle{-38.624} + V_t = 0$

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

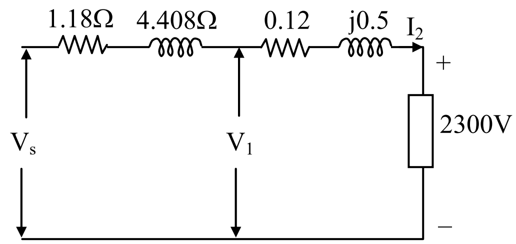
Refer LV side $V_t = \frac{352.08}{5} = 70.4$ V

32. Ans: (*)

Sol:



The equivalent circuit refer to L.V side is



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

Where V_1 = voltage applied across the transformer.

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

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

$= 2300 + 19.36$

$V_1 = 2319.36V$

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

$= 0.807\%$

33. Ans: 96.7%

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

$= (48.91)^2 \times 1.3$

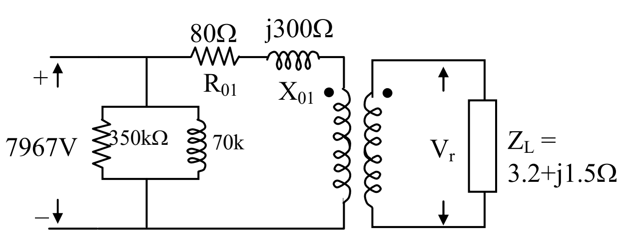
$= 3109.8$ W

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

$= 96.67\%$

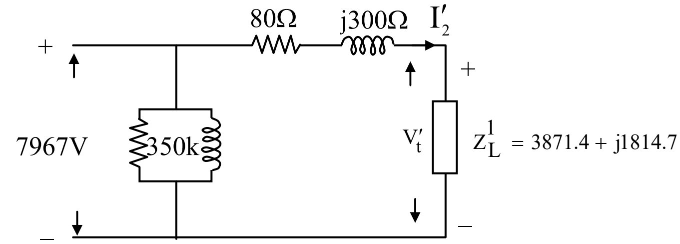
34. Ans: 218.8

Sol:



15kVA and 8000/230V

Equivalent circuit refer to H.V side is



$Z_L^1 = 4275.6\angle25.11$

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

$= 310.48\angle75.06$

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

$= 1.78\angle{-28.15}$A

$V_1' = I_2' \times Z_L'$

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

$= 7600.6\angle{-3.04}$

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

$= 218.52\angle{-3.04}$

35. Ans: 4.9%

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

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

$= 4.9\%$

36. Ans: (*)

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

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

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

$P_0 = 20$ kW & $\cos\phi = 0.8$lag

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

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

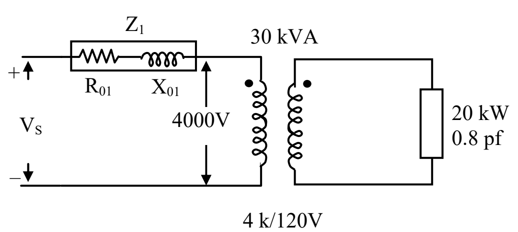
The copper losses for 208.33 A is

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

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

$= 98.88\%$

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

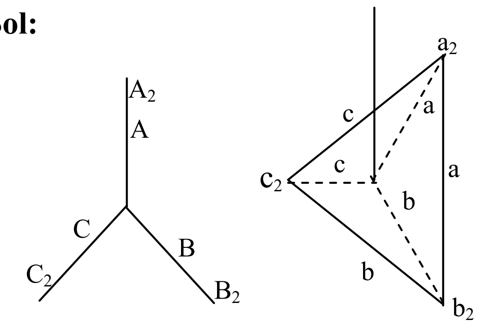
$$V_S = V_2' + I_2'\left[R_1\cos\phi + X_1\sin\phi\right]$$

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

$= 4079.5$ V

37. Ans: (b)

Sol:

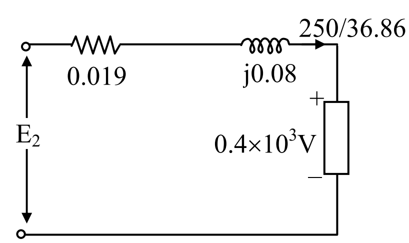


$\therefore$ The Possible Connection is Yd1

38. Ans: (a)

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

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



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

$E_2 = 392\angle2.75$ V

$$E_1 = \left(\frac{6.6}{0.4}\right)\times392 = 6468\text{V} = 6.46 \text{ kV}$$

39. Ans: (d)

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

[∵ Lagging Load]

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

$= 3.8\%$

$$E_2 = \frac{V_2 ph}{1-0.038} = \frac{415}{\sqrt{3}\times 0.962} = 249.06$$

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

42. Ans: (a)

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

$= 50 \times 735.5 = 36.775$ kW

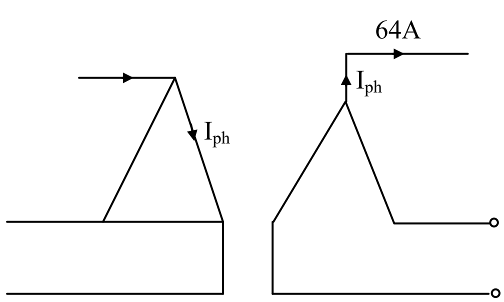
$P_{o/p}$ of induction motor = 36.77 kW

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

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

$= 63.06\ \angle 31.78^o$

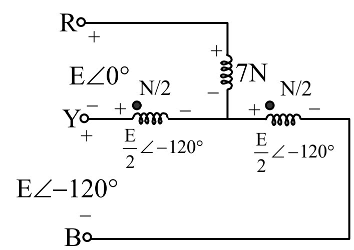
≈ 64 A



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

43. Ans: (c)

Sol:



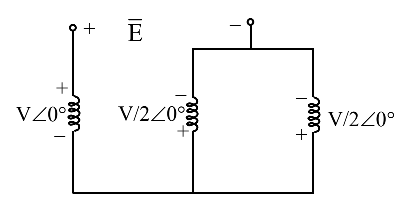
$$E\angle 0° = \bar{V}_{Rs} - \frac{E}{2}\angle -120°$$

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

$$= \frac{\sqrt{3}}{2} E\angle -30°$$

44. Ans: (d)

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



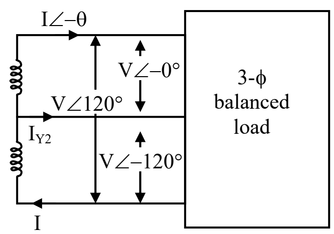
KVL:

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

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

45. Ans: (b)

Sol:



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

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

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

$= I\angle-\theta-60°$

46. Ans: (a)

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

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

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

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

Or $z_{e1} = 0.03$

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

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

In complex notation,

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

$= (0.0075 + j0.029)$ 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. $\bar{S}_1 = \bar{S}\dfrac{\bar{z}_{e2}}{\bar{z}_{e1}+\bar{z}_{e2}}$

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

$= 460\angle-36.1°$ kVA

$S_2 = (460)(\cos 36.1°)$ at pf $\cos 36.1°$ 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 × 0.76 + 0.0290 × 0.631)
= 1.225(0.024119) = 0.029546

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

Or V_2 = (0.970454)(400) = 388.182 V

48. And: (c)

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

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.

49. Ans: (c)

Sol: Secondary rated current

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

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

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

Full-load voltage drop for transformer 1,

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

$$= (60.6)\,(0.825)\,(1) + 0 = 50\text{ V}$$

∴ 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_1rated = $\frac{15000}{600}$ = 25 A

I_2 rated = $\frac{15000}{120}$ = 125 A

In AT, due to series additive polarity

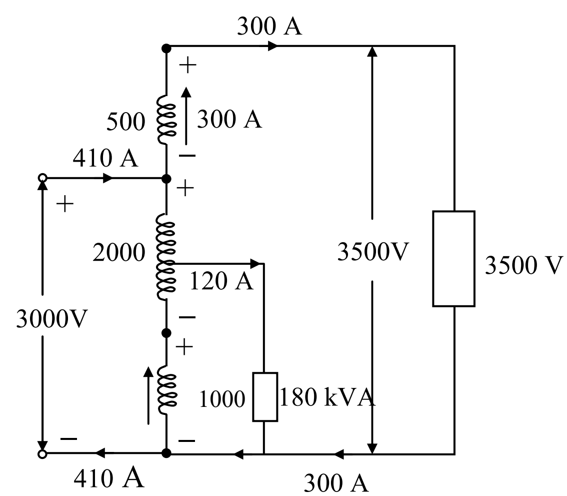
I_{pry} = 125 + 25 = 150 A

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

= 600 × 150 = 90 kVA

51. Ans: (b)

Sol:



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

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

The kVA supplied = 1050 + 180

= 1230 kVA

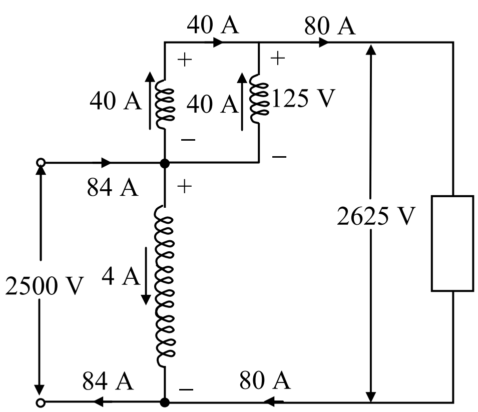
The total current taken from the supply main is $= \frac{1230{,}000}{3000} = 410A$

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

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

∴ Total output current is 40 + 40 = 80A

∴ Auto –transformer kVA rating

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

54. Ans: (a)

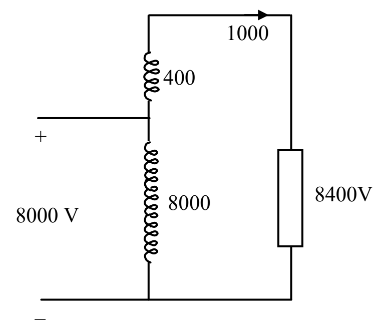
Sol: The rated current of h.v winding is 4 A. Therefore, the current drawn from the supply is 84A.

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

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

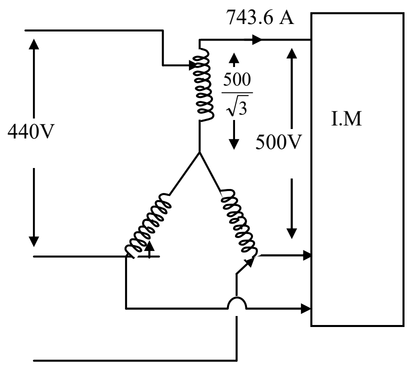
W = 10.79 kW

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

= 99.87%

56. Ans: (a)

Sol:



$$I_2 = \frac{610\times 0.745\times 10^3}{\sqrt{3}\times 500\times 0.8\times 0.882} = 743.69\text{A}$$

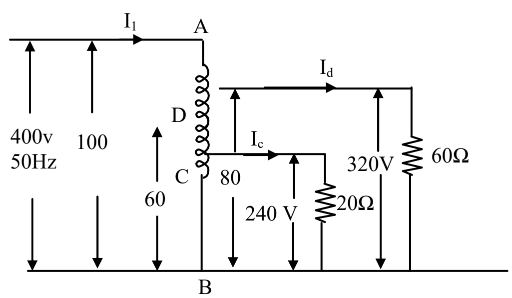
By equation

$$\frac{500}{\sqrt{3}}\times 743.6 = \frac{440}{\sqrt{3}}\times I_1 \Rightarrow I_1 = 845.11 \text{ A}$$

$I_1 - I_2 = \approx 100$ A

57. Ans: (a)

Sol:



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

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

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

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

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

VA rating fo 20Ω load is

$240\times I_c = 240\times 12 = 2880\text{VA}$

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

$\Rightarrow 320\times 5.33 = 1705.6$ VA

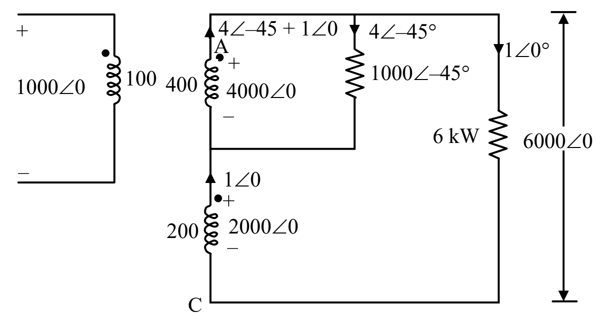
Primary current $I_1 = \frac{\text{Total load VA}}{400}$

$= \frac{2880+1705.6}{400} = 11.464$ A

For resistive load power factor is at unity.

58. Ans: (c)

Sol:



Load current = 4∠–45 + 1∠0

= 4.75 ∠–36.55

mmf = 400 × 4.75 ∠ –36..55 + 200∠0

= 1900 ∠–36.55 + 200

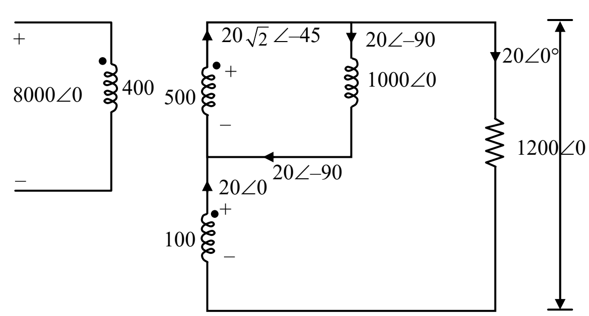
= 1726.3 – j 1131.5

Total secondary mmf = 2064.07∠–33.24

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

59. Ans: (b)

Sol:



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

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

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

$= 1000[2+10-j10]$

$= 1000[12 - j10]$

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

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

$\cos\phi_2 = 0.8$

$\phi_2 = 36.86$

$\cos\phi_3 = 0.71$

$\phi_3 = 44.76$

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

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

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

$I_1 = 14A$

p.f = cos(39.6) = 0.77 lag

61. Ans: (a)

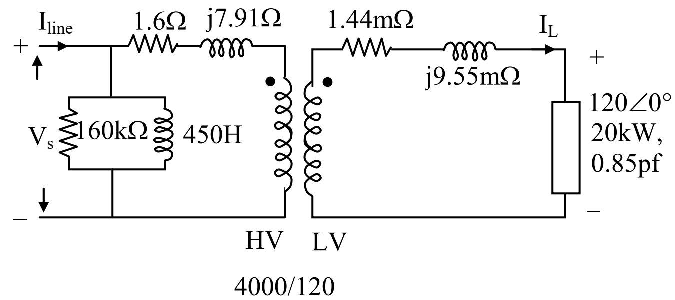
Sol: Given $R_1 = 1.6\Omega$, $L_1 = 21mH$, $R_2 = 1.44m\Omega$, f = 60Hz, $L_2 = 19\mu H$, $R_c = 160k\Omega$,

$L_m = 450$ H, P = 20 kW, $V_2 = 120V$ and $\cos\phi = 0.85$lag.

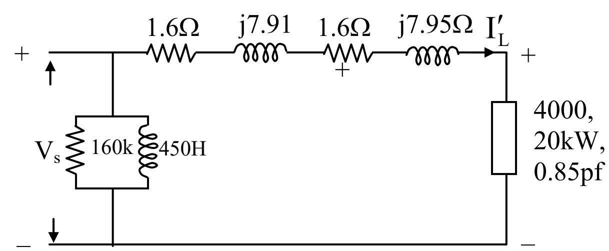
$X_1 = 2\pi fL_1 = 2\times\pi\times60\times21\times10^{-3} = 7.91\ \Omega$

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

The equivalent circuit is,



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:

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

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

$$= \frac{20\times10^3}{20\times10^3+110.6+103.32}\times100$$
$= 98.94\%$

62. Ans: (b)

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

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

and $\mu_r = 1000$

$$\text{Inductance } L = \frac{\mu N^2 A}{\ell}$$
$$= \frac{\mu_0\mu_r N^2 A}{\ell}$$
$$= \frac{4\pi\times10^{-7}\times1000\times500^2\times100\times10^{-4}}{40\pi\times10^{-2}}$$
$= 500^2\times100\times10^{-7}$

= 2.5H

2. 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

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

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 $\rightarrow$ 3000 rpm

4 poles $\rightarrow$ 1500 rpm

6 poles $\rightarrow$ 1000 rpm

8 poles $\rightarrow$ 750 rpm

10 poles $\rightarrow$ 600 rpm

12 poles $\rightarrow$ 500 rpm

20 poles $\rightarrow$ 300 rpm

We know that, the rotor of an induction motor always tries to rotate with speed closer to synchronous speed, there fore the synchronous speed closer to 285 rpm for 50 Hz supply is 300 rpm and poles are 20 poles. So its 20 poles induction motor

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,

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

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, $R_1 = 0.4\ \Omega$, $I_L = 20$ A and P_m = 550 W

Stator copper losses = $3I^2R_1$/phase

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

= 160 W

Airgap power P_r = 4000 – 160

= 3840 W

Internal torque developed = $\frac{60}{2\pi N_s} P_r$

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

= 24.45 Nm

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

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

Given, the rotor speed of induction motor, at maximum torque

N_{rTmax} = 940 rpm

Therefore, per unit slip at maximum torque,

$$s_{Tmax} = \frac{N_s - N_{rT\max}}{N_s} = \frac{1000 - 940}{1000} = 0.06$$

We have, slip at maximum torque is given by

$$s_{Tmax} = \frac{R_2}{x_{20}}$$

From this,

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

10. Ans: (a)

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

Stand still rotor reactance per phase X_{20} = 7 Ω

We have slip at maximum torque given by

$$s_{Tmax} = \frac{R_2}{X_{20}} = \frac{0.21}{7} = 0.03$$

The synchronous speed of the motor is

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

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 $\frac{T}{T_{max}} = \frac{2\times s\times s_{T\,max}}{s^2 + s_{T\,max}^2}$

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

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

T = 0.6 × 150 = 90 N-m

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

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

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

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

$N_s = \frac{120f}{P} = \frac{120\times 50}{6} = 1000$ 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, $P_{ri} = \frac{P_{gmd}}{(1-s_{fl})} = \frac{10.6\times 10^3}{(1-s_{fl})}$

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

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

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

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

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

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

15. Ans: (c)

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

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

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

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

Given, the rotor speed of induction motor at full load $N_{r\,fl}$ = 940 rpm

Therefore, per unit slip at full load,

$$S_{T\max} = \frac{N_s - N_{r f\ell}}{N_s} = \frac{1000-940}{1000} = 0.06$$

Full load torque, T_{fl} = 150 N – m

For DOL starter, we have

$$\frac{T_{st}}{T_{f\ell}} = \left(\frac{I_{sc}}{I_{f\ell}}\right)^2 S_{f\ell} = \left(\frac{300}{60}\right)^2\times0.06 = 1.5$$

T_{st} = 1.5×150 = 225 N – m

When star delta starter is used,

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

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

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

DOL starter $= \frac{1}{3}\times300 = 100A$

18. Ans: (b)

Sol: The synchronous speed of the motor is

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

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)×50 = 98 Hz

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. $\Rightarrow \quad Ns_1 = Ns_2$

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

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

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

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

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

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

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

04. Ans: (b)

Sol: Total Number of conductor = 6 × 180

= 1080

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

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

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

$= 949.05V \approx 960$ 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}

$= T \times 2 \times k_p \times K_{du}$

For fullpitched winding $K_p = 1$.

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

06. Ans: (b)

Sol: $\frac{s}{p} = \frac{48}{4} = 12;$

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

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

phase spread mγ = 15 × 4 = 60°

Winding factor $\Rightarrow K_w = K_p . K_d \rightarrow (1)$

α = 1 slot pitch = 1 × 15° = 15°

$$K_d = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m.\sin\left(\frac{\gamma}{2}\right)} = \frac{\sin\left(\frac{60°}{2}\right)}{4.\sin\frac{15°}{2}} = \frac{1}{8som7.5°}$$

$$K_p = \cos\frac{\alpha}{2} = \cos\left(\frac{15°}{2}\right) = \cos(7.5°)$$

$\therefore$ 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: (a)

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-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

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

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

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

$$K_d = \frac{\text{Sin}(90/2)}{6\,\text{Sin}(15/2)} = 0.9027$$

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

$= 1143.55$ V

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

$= \sqrt{2} \times 1143.55$

$= 1617.22$ V

10. Ans: (a)

Sol: To eliminate n^{th} harmonic the winding could be short pitched by (180^0/n). As the winding is short pitched by 36^0 fifth harmonic is eliminated.

11. Ans: (1616)

Sol: EMF inductor 1 - ϕ connection

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

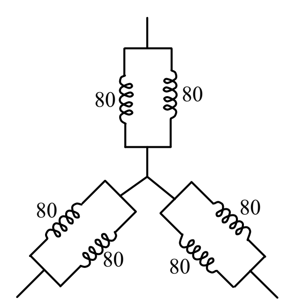
$$E_{1-\phi} = \frac{E_{3-\phi}}{0.5} = \frac{808.68}{0.5} = 1617.36$$

12. Ans: (404 V, 700 V)

Sol: If turns are connected in two parallel paths then

Turns/ph = 160

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



$E_{ph} = 4.44\times0.951\times0.957\times0.025\times50\times80$

$= 404$ V

$E_L = \sqrt{3} \times E_{ph} = 700$ V

13. Ans: (571 V, 808 V)

Sol: If the turns are connected among two parallel paths for two phase connection

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

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

$E_{Phase} = 4.44\times0.957\times0.951\times0.025\times50\times120$

$= 571.77$ V

$E_{L-L} = \sqrt{2} \times E_{Phase}$

$= \sqrt{2} \times 571.77$

$E_{L-L} = 808.611$ V

14. Ans: (b)

Sol: Main field is produced by stator so it's stationary w.r.t stator.

For production of torque two fields (Main field & armature field) must be stationary w.r.t. each other. So rotor (armature) is rotating at N_s. But as per torque production principle two fields must be stationary w.r.t each other. So the armature field will rotate in opposite direction to rotor to make. It speed zero w.r.t stator flux.

15. Ans: (d)

Sol: Field winding is an rotor, so main field so produced will rotate at 'N_s' w.r.t stator.

Field winding is rotating, field so produced due to this also rotates in the direction of rotor.

Field produced is stationary w.r.t. rotor.

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.

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

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

$\therefore$ $\Psi = 45$

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

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

$$E_0^2 = (V\cos\phi + I_a R_a)^2 + (V\sin\phi \pm I_a X_s)^2$$

$I_a = 13.912$

$$E_0 = \sqrt{(239.06\times0.08 + 13.912\times0.4)^2 + (239.06\times0.996 + 13.912\times5)^2}$$

$E_0 = 309.38$ V

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

$$= \frac{309.38 - 239.06}{239.06}\times100$$

$= 29.41\%$

27. Ans: – 6.97%

Sol: Regulation at 0.9 p.f lead at half rated condition is when $I_{a_2} = \frac{I_{a_1}}{2} = 6.95$

$$E = \sqrt{(239.06\times0.8+6.9562\times0.4)^2 + (239.06\times0.6-6.956\times5)^2}$$

E = 222.38 V

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

$$= \frac{222.38 - 239.06}{239.06}\times100 = -6.97\%$$

28. Ans: 75

Sol: Given data, V_L = $200\sqrt{3}$, S = 3 kVA, X_s = 30 Ω and R_a = 0 Ω.

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

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

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

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

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: (a)

Sol: That synchrozing current will produce synchronizing power. Which will demagnetize the M/C M_2 and Magnetize the M/C M_1

30. 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.

31. 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.

32. 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
$kVAR_1 \uparrow$	$kVAR_2 \downarrow$
$kVA_1 \uparrow$	$kVA_2 \downarrow$
$I_{a1} \uparrow$	$I_{a2} \downarrow$
$P.f_1 \downarrow$	$P.f_2 \uparrow$

33. 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.

34. 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.

38. Ans: (d)

Sol: Rate of flickering = beat frequency

$= f - f^l$

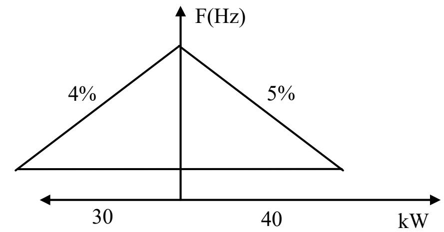
$= 50.2 - 50 = 0.2\text{Hz}$

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

= 12 filckers/min

39. 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 $= P_1 + P_2$

$= 300 + 320 \le 620$ kW

40. 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.

42. Ans: (c)

Sol: For synchronizing an alternator, the speed of alternator need not be same as already existing alternator.

43. Ans: (a)

Sol: Synchronizing current per phase

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

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

$$\therefore\ I_{sy} = \frac{\left|\frac{3300}{\sqrt{3}} - \frac{3200}{\sqrt{3}}\right|}{2\times1.7}$$

$I_{sy} = 16.98A.$

44.

Sol:

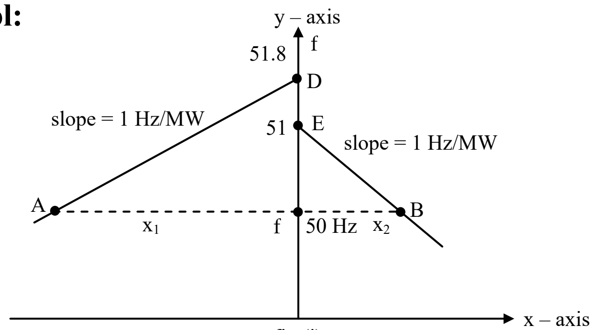


fig (i)

$y = -mx + c$

(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

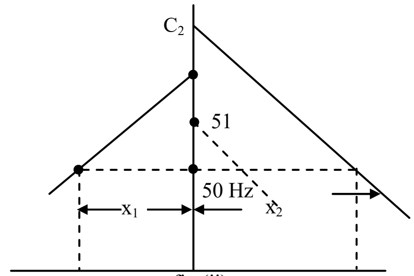


fig (ii)

(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)

$f = -x_2 + c_2 = 50$

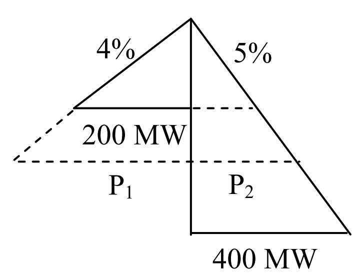
$-20 + c_2 = 50$

$c_2 = 70$

45.

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

$\Rightarrow f = 50 - (50 \times x\,\%)$

$= 50 - 50 \times \frac{4.615}{100} = 47.69 \approx 47.7\text{Hz}$

(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

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

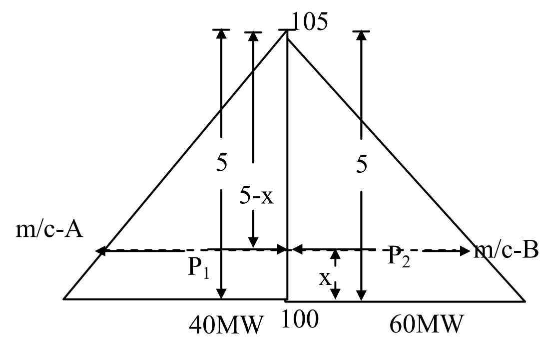
$P_2 = 320$ MW

Total load = $P_1 + P_2 = 320 + 200$

= 520 MW set can supply.

46. Ans: (c)

Sol: Let power factor is unity, M/C-A =40 MW and M/C-B = 60 MW



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

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

$P_1 + P_2 = 80$

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

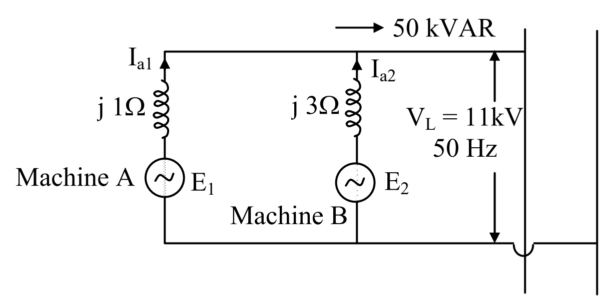
$\Rightarrow x = 1$

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

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

47. 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°)

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

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

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

$= \frac{11\times10^3}{\sqrt{3}}\angle0 - 1312.16\angle90 \times 1\angle90$

$= 6350.8\angle0 - 1312.16\angle180$

$= 7662.96$ 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., $\frac{E_1}{E_2} = \frac{7662.96}{10,287.28} = 0.7448$

48. 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

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

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

49. 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

50. Ans: (0.523 lag)

Sol: p.f = cos(58.4) = 0.523 lag

51. 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

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

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

$E = 4447\angle9.867$

The current (I_a) at which the p.f is unity (∵ $R_0 = 0$)

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

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

I_a = 252.716 A

52. 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

53. Ans: (26.88°)

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

54. Ans: (b)

Sol: $P = \frac{EV}{X_S}\sin\delta \Rightarrow 0.5 = \frac{1.3\times1}{0.8}\sin\delta$

$\Rightarrow \delta = 17.92^0$

$E = V + j\, I_a X_s$

$$I_a = \frac{E\angle\delta - V\angle0}{X_s\angle90} = \frac{1.3\angle17.92 - 1\angle0}{0.8\angle90}$$

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

55. Ans: (a)

Sol: From above solution Answer is 0.581

56. Ans: (0.860 lag)

Sol: From above solution power factor is

p.f = $\cos\phi = \cos(30.639)$ = 0.860 lag

57. Ans: (0.296 PU)

Sol: Reactive power (Q) = $\frac{V}{X_s}\left[E\cos\delta - V\right]$

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

= 0.296 P.U

58. Ans: (2.05 PU)

Sol: The current at which maximum power output is ________

Under maximum output conditions $\delta = \theta$

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

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

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

59. Ans: (0.792 lead)

Sol: Power factor at maximum power output is

p.f = cos(37.56) = 0.792 lead

60. Ans: (–1.25 PU)

Sol: reactive power at maximum

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

Substitute $\delta = \theta = 90$

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

61. 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, $R_a = 0$

$P = V I_a\cos\phi \Rightarrow 1 = 1.11\times I_a\times1$

$\Rightarrow I_a$ = 0.9 pu

$\therefore$ The voltage behind the synchronous reactance i.e $E = V + I_a Z_s$

$= 1.11\angle0 + 0.9\angle0 \times 0.8\angle90°$

$= 1.11 + j\,0.72$

$= 1.323\ \angle 32.969°$

62. Ans: 0.1088

Sol: $E_f = 1.3pu$, $X_s = 1.1pu$, $P = 0.6pu$, $V = 1.0pu$

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

$$\Rightarrow \delta = 30.53°$$

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

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

63. 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

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

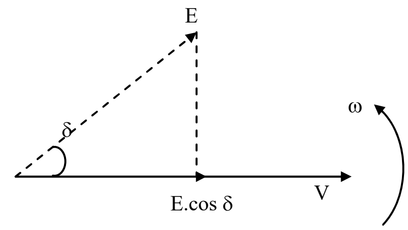
$$T = \frac{P}{\omega} = \frac{41569.2}{2\pi\times\frac{1800}{60}} = 220.53\,\text{N} - \text{m}$$

64. 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".



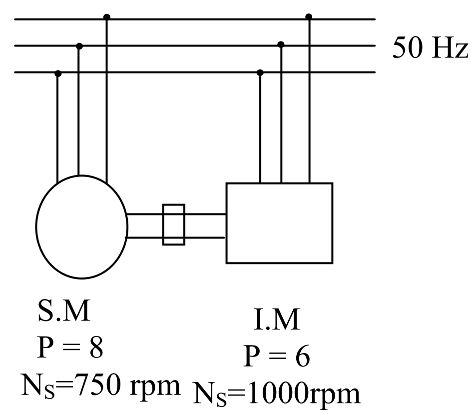
65. Ans: (a)

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.

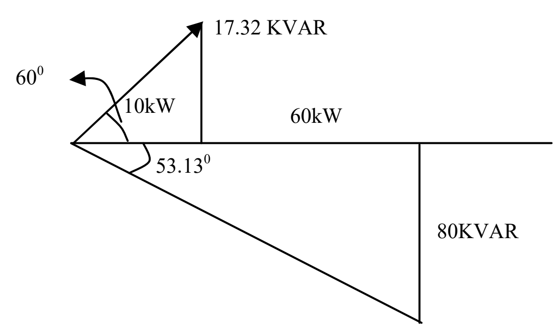
$$\text{slip} = \frac{N_s - N_r}{N_s} = \frac{1000-750}{1000} = \frac{1}{4}$$

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



66. 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

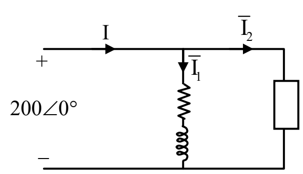
$$\tan\phi = \frac{Q}{P} = \frac{62.68}{70} = 0.895$$

ϕ = 41.842

p.f = cos ϕ = 0.74 lag

67. Ans: 24 A

Sol:



$$\bar{I}_1 = \frac{200\angle 0}{4 + j3}$$

= 40∠–36.87°

= 40cos(36.87) –j40sin36.87

= 32 –j24 A

Assume that the motor draws a current j24 A, then overall pf = 1, therefore answer is 24 A

68. Ans: (b)

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

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

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

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

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

$\Rightarrow \delta = 18.21°$

69. Ans: (c)

Sol: From the armature current 7.3∠–9.1°

9.1° is the angle difference between V and I.

∴ cos ϕ = cos(–9.1°)

PF = 0.987 Lag

70. Ans: (d)

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

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

$I_a = 7.3^a$

71. Ans: (a)

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

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

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

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

$$\frac{800\times10^3}{3}=\frac{(1154.7)^2}{2.2\angle84.8^o}\cos(84.8)-\frac{(1154.7\times1443.37)}{2.2\angle84.8^o}\cos(84.8+\delta)$$

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

$$=\frac{1154.7\angle0-1443.37\angle21.43}{2.2\angle84.8^o}$$

$$=254.59\angle24.9^o$$

72. Ans: (b)

Sol: PF = cos (24.9) = 0.907 lead

73. Ans: (760.9 kW)

Sol: Mechanical power developed

$P = E_aI_a^*$

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

$$P=\frac{\frac{2500}{\sqrt3}\times\frac{2000}{\sqrt3}}{2.209}\cos(84.80-21.51)-\frac{\left(\frac{2500}{\sqrt3}\right)^2}{2.209}\cos(84.80)$$

$P_{phase} = 253.364$ kW

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

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

$= 800\times10^3 - (3\times254^2\times0.2)$

$P_{mech} = 761$ kW

74. Ans: (4.84 Nm)

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

$N_s = 1500$

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

75. Ans: (b)

Sol: $V_L = 230$V

$$\Rightarrow V_{ph}=\frac{230}{\sqrt3}=132.8\text{V}$$

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

$\theta = 78.69^o$

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

76. Ans: (c)

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

$= \sqrt3\,V_LI_L\cos\phi - 3I_a^2R_a$

$= (\sqrt3\times230\times40\times0.953)-(3\times40^2\times0.6)$

$= 12.035$ kW

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

77. Ans: (b)

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

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

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

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

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

$= 4715.5\angle{-12.85^o}$

Excitation is constant, V is constant

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

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

$\Rightarrow \delta = 19.5^o$

78. 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°)

= 0.92 lead

79. 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 = $3\times144.33^2\times0.13 = 8125$ W

Total losses = Stray losses + Cu losses

= 4000 + 8125

= 12125 W

$\%\eta = \frac{\text{input} - \text{losses}}{\text{input}}\times100$

$= \frac{75000-12125}{75000}\times100$

= 83.83%

80. Ans: (a)

Sol: Equivalent circuit/ph:

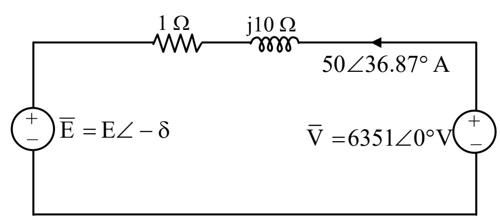


Fig. 1

Since problem specifies that excitation emf $\bar{E}$ lags the terminal voltage $\bar{V}$, motor operation is implied.

So, the current received by the motor is specified as 50∠36.87° A. (That is why the reference direction of $\bar{I}$ is shown as entering $\bar{E}$ at its '+' terminal. Of course we could have reversed the current direction in the figure, and writen the value as −50∠36.87° A).

(i) Calculation of excitation emf:

$6351\angle0^\circ = E\angle-\delta + [50\angle36.87^\circ](1+j10)$

Solving, E = 6625.

($\delta = 3.73^\circ$, $\bar{E} = 6625\angle-3.73^\circ$)

(ii) The machine, acting as a motor, is drawing a leading current. Hence it is overexcited. By reducing the excitation, it can be made to draw current at upf. In that case $\bar{I}$ and $\bar{E}$ will change, but $\bar{I}$ will be in phase with $\bar{V}$.

(iii) Calculation of armature current and load angle:

At upf operation, let the current per phase drawn by the motor be I amp.

Assuming that the power input per phase remains unchanged while the excitation is reduced, 6351(I) = 6351500.8.

I = 40 A.

Replacing the current in the circuit of fig. 1 with this value and applying KVL,

$6351\angle 0° = 40\angle 0°(1+j10) + E\angle -\delta$.

E and δ can be calculated from this equation by separately equating the real and imaginary parts.

Ecos+40 = 6351 .... (1)

and $-E\sin\delta + 400 = 0$ .... (2)

$\delta = 3.63°$

4. DC Machines

01. Ans: (c)

Sol: Induced emf in a DC Generator

$$E = \frac{\phi ZN}{60}\times\frac{P}{A}$$

$$= \frac{0.06\times(32\times6\times2)\times250}{60}\times\frac{8}{2}$$

E = 384V

02. Ans: 0.05 Wb , 0.33 V/turn

Sol: Given, P = 2, E = 200V, Z = 600, N = 400 rpm, dt = 0.15 sec,

φ/pole = ? and emf/turns = ?

(i) $E = \frac{\phi ZNP}{60A}$

$$200 = \frac{\phi\times600\times400\times2}{60\times2}$$

$$\Rightarrow \phi/\text{pole} = \frac{1}{20}$$

$= 0.05$ Web

(ii) λ = flux linkages = 1000 × 0.05

= 50 Wb –turns

$$e = \frac{d\lambda}{dt} = \frac{50}{0.15} = 333.33\text{V}$$

$$\text{emf / turns} = \frac{333.33}{1000}$$

= 0.33 V/turn

03. Ans: (d)

Sol: P = 6, lap winding, Z = 480, Ra = 0.06Ω

Next changed to ware

$$R_a \propto \frac{1}{A^2}\text{(parallel paths)}$$

$$\frac{R_L}{R_w}=\left(\frac{A_w}{A_L}\right)^2 \Rightarrow \frac{0.06}{R_w}=\left(\frac{2}{6}\right)^2$$

$R_w = 0.54\Omega$

05.

Sol: (a) lap winding:

P = 4, A = 4, Z = 500

$$\therefore \text{Armature AT / pole} = \left(\frac{Z}{2P}\right)\left(\frac{I_a}{A}\right)$$

$$= \left(\frac{500}{2\times4}\right)\left(\frac{100}{4}\right)$$

$= 1562.5$ AT / pole

$$AT_{demagnetizing} = \left(\frac{2\theta}{180}\right)\left(\frac{Z}{2P}\right)\left(\frac{I_a}{A}\right)$$

$$= \left(\frac{2\times8}{180}\right)\left(\frac{2}{2\times4}\right)\left(\frac{100}{4}\right)$$

= 138.8AT/pole

AT cross-magnetizing

$$= \left(\frac{180-2\theta}{180}\right)\left(\frac{Z}{2P}\frac{I_a}{A}\right)$$

$$= \left(\frac{180-16}{180}\right)\left(\frac{500}{2\times4}\times\frac{100}{4}\right)$$

=1423.7 AT/pole

(b) Wave winding

P = 4; A = 2

$$\text{Armature AT/pole} = \left(\frac{Z}{2P}.\frac{I_a}{A}\right)\text{AT / pole}$$

$$= \left(\frac{500}{2\times4}\right)\left(\frac{100}{2}\right)$$

= 3125 AT/pole

$$\text{AT demagnetizing} = \left(\frac{2\theta}{180}\right)\left(\frac{Z}{2P}.\frac{I_a}{A}\right)$$

$$= \left(\frac{2\times8}{180}\right)\left(\frac{500}{2\times4}\right)\left(\frac{100}{2}\right)$$

= 277.77 AT/pole

$$\text{AT cross-magnetizing} = \left(\frac{180-2\theta}{180}\right)\left(\frac{Z}{2P}\frac{I_a}{A}\right)$$

$$= \left(\frac{180-16}{180}\right)\left(\frac{500}{2\times4}\times\frac{100}{2}\right)$$

= 2847.2 AT/pole

06. Ans: 17

Sol: $V_t I_L = 100\text{kW} \Rightarrow I_L = \frac{100\times1000}{400} = 250\text{A}$

MMF required on each interpole is

$$MMF_{IP} = \left(\frac{Z}{2P}.\frac{I_a}{A}\right)+\left(\frac{l_{ag}}{\mu_0}.B\right)$$

$$= \left(\frac{500}{2\times6}\times\frac{250}{6}\right)+\left(\frac{1\times10^{-2}}{4\pi\times10^{-7}}\times0.3\right)$$

= 4123.43 AT/pole

As we know that interpole winding connected in series winding of armature.

$$\therefore N = \frac{2460}{I_a} = \frac{2460}{250}$$

= 16.49 turns

$\Rightarrow$ N = 17 turns/pole

07. Ans: (b)

GNA axis also called brush axis (or) axis of commutation which is always perpendicular to the main field flux axis (ϕ_m).Commutating poles are placed in GNA axis to eliminate cross magnetization effect under q-axis.

Number of commutating poles = Number of main field poles $\rightarrow$ for large rating motors and less for small rating motors.

08. Ans: (a)

Sol: Compensating winding & Inter pole winding connected in series with the armature winding. Compensating flux is used to nullify the cross magnetization effect under polar axis i.e d-axis only but commutating poles flux used to compensate cross magnetization effect under inter polar region i.e. q-axis and also limits reactance voltage.

09. Ans: 12.5 mWb , 125 c.m^2

Sol: Given, P = 10, N = 1000 rpm, Z = 2000,

A = 10, V = 400V and B = 1T

Armature copper loss = 400 W

$$I_a = \frac{10\times10^3}{400} = 25 \text{ A}$$

$$I_a^2 R_a = 400$$

$\Rightarrow R_a = 16/25\ \Omega$

$E = V + I_a R_a$

$= 400 + 25\ (16/25)$

$= 416$ V

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

$$416 = \frac{\phi\times2000\times1000\times10}{60\times10}$$

$\Rightarrow \phi$/pole = 12.5 mWb

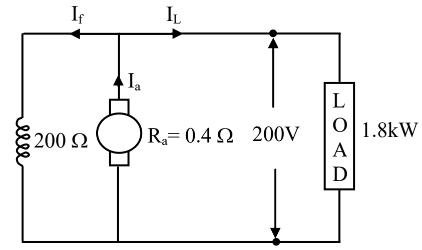
We know that, $B = \frac{\phi}{A}$

$$\Rightarrow \text{Area of pole shoe} = \frac{12.5\times10^{-3}}{1} m^2$$

$\therefore$ Area = 125 cm^2

10. Ans: (c)

Sol:



Generated EMF

$\Rightarrow E_g = V + I_a.R_a \rightarrow (1)$

Electrical load, $P_L = V.I_L = 1.8$ KW

$$\Rightarrow I_L = \frac{1800}{200} = 9A \quad I_f = \frac{V}{R_f} = \frac{200}{200} = 1A$$

For generator $\Rightarrow I_a = I_L + I_f$

$= 9A + 1A = 10A$

From eq(1),

$E_g = 200 + (10)\ (0.4) = 204$ V

11. Ans :(49.61 A, 161.24 V)

Sol: $P = VI_{a_1} \Rightarrow I_{a_1} = \frac{5k}{100} = 50A$

$$E_{g_1} = V + I_{a_1} R_a = 100 + 50(0.5)$$

$$= 100 + 25 = 125V$$

$P = V_2 I_{a_2} = 8000$ ------------ (1)

$$E_{g_2} = V_2 + I_{a_2} R_a$$

$$E_{g_2} = \frac{8000}{I_{a_2}} + I_{a_2}(0.5) \text{ ---------(2)}$$

$$\frac{E_{g_2}}{E_{g_1}} = \frac{\phi_2 N_2}{\phi_1 N_1} = \frac{I_{a_2}}{50} \times \frac{1500}{100}$$

$$\frac{E_{g_2}}{125} = \frac{15 I_{a_2}}{50} \Rightarrow E_{g_2} = 3.75 I_{a_2} \text{ -------- (3)}$$

Substitute equation (3) in (2)

$$3.75 I_{a_2} = \frac{8000}{I_{a_2}} + I_{a_2}(0.5)$$

$$(3.75-0.5) I_{a_2}^2 = 8000$$

$$I_{a_2} = 49.61 A$$

$$V_2 = \frac{8000}{49.61} = 161.25 V$$

12. Ans: (d)

Sol: $V = 300V$, $I_L = 200$ A

$R_a = 0.05\ \Omega$, $R_{sc} = 0.04\Omega$

$R_{sh} = 200\ \Omega$, B.D = 1 V, E_g = ?

$$I_f = \frac{V}{R_{sh}} = \frac{300}{200} = 1.5 \text{ A}$$

$I_a = I_L + I_f = 201.5$ A

For long shunt compound generator

$E_g = V + I_a R_a + I_L R_{se} + B.D$

$= 300 + (201.5 \times 0.05) + (200 \times 0.04) + 1$

$E_g = 319.075 \text{ V} \approx 320 \text{ V}$

13. Ans: 550

Sol: $V_t = 145$ V (Grid)

$I_{a_1} = 150$ A; $N_1 = 800$ rpm

$R_a = 0.1\ \Omega$

$N_2 = 1000$ rpm ; $V_{t_2} = 145$ V (Grid)

$I_{a_2} = ?$

$\Rightarrow E_{g_1} = V_t + I_{a_1} r_a$

$= 145 + (150)(0.1) = 160$ V

$$\frac{E_{g_1}}{E_{g_2}} = \frac{N_1}{N_2}$$ [$\because$ $E_g = K_a \phi \omega$, ϕ = const]

$$E_{g_2} = \left(\frac{1000}{800}\right)(160)$$

$= 200$ V

$$\Rightarrow I_{a_2} = \frac{200-145}{0.1} = 550 A$$

$I_{a_2} = 550$ A

14. Ans: (c)

Sol: Given external load characteristic curve is linear, therefore from curve value of 'V' corresponding to 50A is 95 V

$\Rightarrow$ V = 95V, I_L = 50A

$$\therefore R_L = \frac{V}{I_L} = \frac{95}{50} = 1.9\ \Omega$$

Alternate method:

$E = V + I_a R_a$.

$100 = 90 + 100 R_a$

$\Rightarrow 100 R_a = 100 - 90 \Rightarrow R_a = 0.1\ \Omega$

At 50 Amps, $V = E - I_a R_a$

$= 100 - (50 \times 0.1)$

$= 95$V

$$R_L = \frac{V}{I_L} = \frac{95}{50} = 1.9\Omega$$

15. Ans: (c)

Sol: $R_{C1} = 50\ \Omega$, $N_1 = 1000$ rpm

$R_{C2} = 80\ \Omega$; N_2 = ?

$$\frac{N_2}{N_1} = \frac{R_{C1}}{R_{C2}}$$

$$N_2 = \frac{50}{80} \times 1000 = 625 \text{ rpm}$$

16. Ans: 8

Sol: Separately excited DC motor

Flux remain constant

Case (i): At No load

$N_1 = 1000$ rpm $V_1 = 200V$

$R_a = 1\Omega$ $I_{a1} = 0 \Rightarrow T_{a1} = 0$

$E_{b1} = V_1$

Case(ii): Full load

$T_2 = T_{rated}$

I_{a2} = Full load armature current

$V_2 = ?$

$N_2 = 500$ rpm

$$\frac{Eb_2}{Eb_1} = \frac{N_2}{N_1} = \frac{500}{1000}$$

$$E_{b2} = \frac{1}{2} \times 200 = 100V$$

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

$V = 100 + I_{a2}(1)$

$V = 100 + I_{a2}$ ………… (1)

Case(iii):

$T_3 = 50\%$ of T_{rated}

$T_3 = 0.5\ T_{rated}$

$T \propto I_a$

$$\frac{T_3}{T_2} = 0.5 = \frac{I_{a3}}{I_{a2}}$$

$I_{a3} = 0.5 I_{a2}$ ………….. (2)

But $\frac{N_3}{N_2} = \frac{E_{b3}}{E_{b2}}$

$$\frac{520}{500} = \frac{E_{b3}}{E_{b2}} \Rightarrow \frac{520}{500} = \frac{E_{b3}}{100}$$

$E_{b3} = 104$

$E_{b3} = V - I_{a3} R_a$

From (1) & (2)

$E_{b3} = 100 + I_{a2} - (0.5\ I_{a2})R_a$

$104 = 100 + I_{a2} - (0.5 I_{a2})1$

$4 = 0.5\ I_{a2} \Rightarrow I_{a2} = 8A$

17. Ans: (a)

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

$$\frac{N_2}{1140} = \frac{0.9E_{b_1}}{E_{b_1}} \times \frac{\phi_1}{0.95\phi_1}$$

$N_2 = 1080$ rpm

18. Ans: 1.2712

Sol: Motor operation:

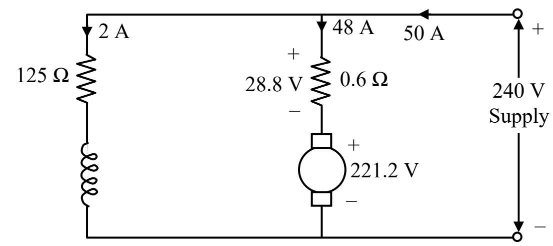


Fig.1.

Generator operation:

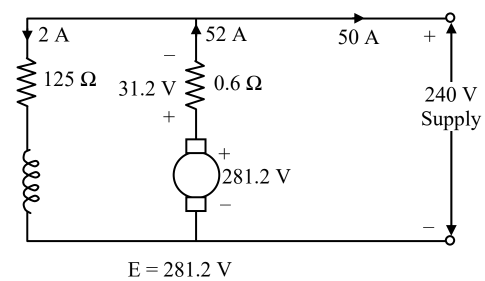


Fig.2.

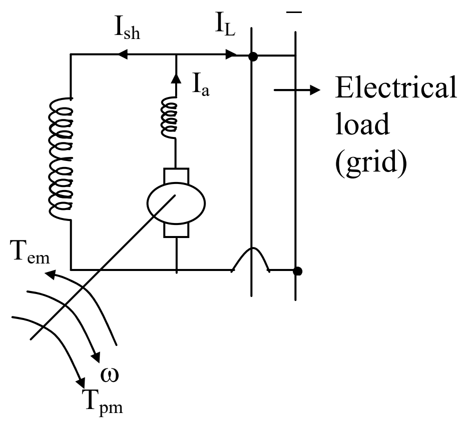
Since the field current is the same in both cases, neglecting armature reaction, flux is constant in both cases and (speed as a generator)/(speed as a motor) = (281.2/221.2) = 1.2712.

19. Ans: (b)

Sol: Practically in motor, the torque direction is similar direction to that of rotor rotation.

In generator the torque direction is opposite direction to that of rotor rotation.

Before Belt Snaps (p.m fails)



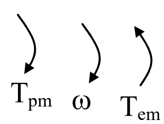
I_L, I_a delivering ⇒ called generator

Let I_{sh}, I_a are positive

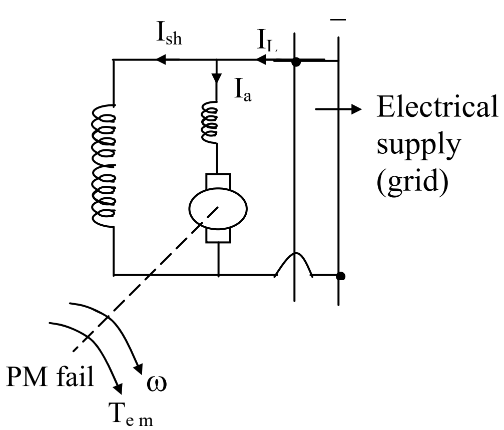
$\therefore \phi = \phi_{sh} + \phi_{se}$

Hence act as compound generator

$T_{em} \propto (+\phi)(+I_a)$



After Belt Snaps (p.m fails)



I_L, I_a → absorbed ⇒ called motor

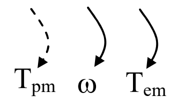
Here I_{sh} positive, I_a is Negative

$\therefore \phi = \phi_{sh} - \phi_{se}$

[∵ I_a direction changed]

Act as differential motor

$T_{em} \propto (+\phi)(-I_a)$



We know, after prime mover fails,

$T_{em} \propto (+\phi)(-I_a) \Rightarrow T_{em} \propto -(\phi . I_a)$.

∴ Torque direction is reversed, i.e, direction of rotor rotation in differential compound motor is similar direction to that of over compound generator.

20. Ans: (a)

Sol: Full load Armature current $(I_{a1}) = 40A$

When 1Ω is inserted in series with armature

$R_{aeq} = 1.5\Omega$

Stalling Torque is the Torque at which speed falls to zero

$$\text{Speed (N)} \propto \frac{E_b}{\phi}$$

$$\text{When } N = 0 \Rightarrow E_b = V - I_{a_2} R_{aeq} = 0$$

$$240 - I_{a_2}(1.5) = 0$$

$$I_{a_2} = \frac{240}{1.5} = 160A$$

$$\text{Torque } \alpha\, \phi I_a$$

$$\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}} \quad [\because \phi = \text{const}]$$

$$\frac{T_2}{T_1} = \frac{160}{40} = 4$$

21. Ans: (d)

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

$N_1 = 600$ rpm, T_L= constant

$I_L = 21A$, $R_e = 250\Omega$, $N_2 = ?$

$I_{a_1} = I_L - I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = 1A$

$= 21 - 1 = 20A$

$I_{sh_2} = \frac{V}{R_{sh} + R_e} = \frac{250}{250 + 250} = 0.5A$

$T \propto \phi I_a$

$T \propto I_{sh} I_a = \text{constant}$

$I_{sh_1} I_{a_1} = I_{sh} I_{a_2} \Rightarrow 1 \times 20 = \frac{1}{2} \times I_{a_2}$

$I_{a_2} = 40A$

$N \propto \frac{E_b}{\phi}$

$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{I_{sh_1}}{I_{sh_2}}$

$\frac{N_2}{600} = \frac{250 - (40 \times 0.5)}{250 - (20 \times 0.5)} \times \frac{1}{0.5}$

$N_2 = 1150$ rpm

22. Ans: (i) 2.778 Ω (ii) 3.498 Ω

Sol: Given data:

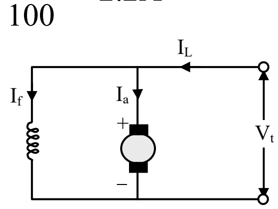
$V_t = 220V$

$N_1 = 1000$ rpm, $I_L = 22A$

$R_f = 100\Omega$, $R_a = 0.1\Omega$

$N_2 = 800$ rpm

$I_f = \frac{220}{100} = 2.2A$



$I_a = I_L - I_f = 22 - 2.2 = 19.8A$

$E = V - I_a R_a = 220 - 49.8 \times 0.1 = 218.02$

$E \propto \phi N$ (for shunt motor 'ϕ' constant)

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

$E_2 = 218.02 \times \left(\frac{N_2}{N_1}\right)$

$= 218.02 \times \left(\frac{800}{1000}\right) = 174.416V$

Case (i):

$T_L \propto N$

$T_e \propto \phi I_a$ and under steady state condition

$T_L = T_e$.

$\frac{I_{a1}}{I_{a2}} = \frac{N_1}{N_2}$

$I_{a2} = I_{a1} \times 0.8 = 15.84A$

$E_2 = V_t - I_{a2}(R_a + R_{ext})$

$174.416 = 220 - 15.84(0.1 + R_{ext})$

$R_{ext} = 2.877 - 0.1 = 2.7770\Omega$

Case (ii):

$T_L \propto N^2$ and $T_e \propto \phi I_a$

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

$I_{a2} = 19.8 \times (0.8)^2 = 12.672A$

$E_{b2} = V_t - I_{a2}(R_a + R_{ext})$

$= 174.416$

$= 220 - 12.672(0.1 + R_{ext}) = 3.497\Omega$

23. Ans: (c)

Sol: $N_1 = 1180$ rpm $N_2 = 1250$ rpm

$V = 125V$ $V = 125V$

$\phi_1 \propto I_{sh} = \dfrac{V}{R_{sh}}$ $\quad \phi_2 \propto I_{sh_2} = \dfrac{V}{R_{sh} + R_e}$

$E_b \cong V$ $\quad = \dfrac{V}{R_{sh} + 5}$

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

$$\frac{1250}{1180} = \frac{V}{V} \times \frac{\frac{V}{R_{sh}}}{\frac{V}{R_{sh}+5}}$$

$$\Rightarrow \frac{125}{118} = \frac{R_{sh}+5}{R_{sh}} = 1 + \frac{5}{R_{sh}}$$

$$R_{sh} = 84.2\Omega$$

24. Ans: (*)

Sol: $\dfrac{N_2}{N_1} = \dfrac{E_{b_2}}{E_{b_1}} \times \dfrac{\phi_1}{\phi_2}$

As torque is constant $\Rightarrow \dfrac{\phi_1}{\phi_2} = \text{const.}$

$$E_{b_2} = V - I_a(R_{se} \parallel R_d) - I_a R_a$$

$$= 500 - 100(0.3 \parallel 0.6) - 100 \times 0.4$$

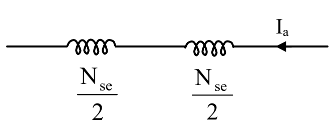
$$= 500 - 100(0.2 + 0.4)$$

$$\frac{N_2}{600} = \frac{500 - 100(0.2+0.4)}{500 - 100(0.4+0.3)}$$

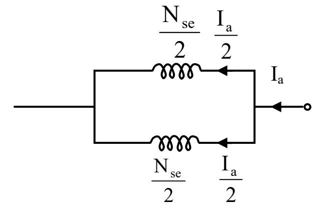
$$N_2 = 613.95 \text{ rpm}$$

25. Ans: (c)

Sol:



Ampere turns $AT_{se} = \dfrac{N_{se} I_a}{2}$



$$\text{Ampere } (AT_p) = \frac{N_{se}}{2} \cdot \frac{I_a}{2} + \frac{N_{se}}{2} \frac{I_a}{2}$$

$$= \frac{N_{se} I_a}{2}$$

Constant torque condition

$T_1 = T_2$

$\phi_1 I_{a1} = \phi_2 I_{a2}$

$AT_{se} I_{a1} = AT_p I_{a2}$

$N_{se} I_{a1} = \dfrac{N_{se} I_{a2}}{2} I_{a2}$

$I_{a2} = \sqrt{2}\, I_{a1}$

($\because$ N_2 is the speed, when series field windings are connected in parallel)

$$\frac{N_2}{N_1} = \frac{AT_{se}}{AT_p}$$

$$\frac{N_2}{N_1} = \frac{N_{se} I_{a1}}{\frac{N_{se} I_{a2}}{2}}$$

$$\frac{N_2}{N_1} = \sqrt{2}$$

By substituting $I_{a2} = \sqrt{2} I_{a1} = 500\sqrt{2}$ rpm

26. Ans: (b)

Sol: $P \propto TN = \text{constant}$

$T_1 N_1 = T_2 N_2$

$I_{a1}^2 \times N_1 = I_{a2}^2 N_2$

$I_{a1}^2 \times 1 = I_{a2}^2 \times 0.25$

$$\frac{I_{a_1}}{I_{a_2}} = 0.5$$

$V_1 = 1\text{pu}, \quad N_2 = 0.25 \text{ pu}$

$N_1 = 1\text{pu}$

$T \propto I_a^2$

$V_{a_1} I_{a_1} = V_{a_2} I_{a_2}$

$1 \times 0.5 I_{a_2} = V_{a_2} I_{a_2}$

$V_{a_2} = 0.5\,\text{pu}$

27.

Sol: According to motor ratings and neglecting losses $\Rightarrow E_b = V_t = 250V$

N = 1000 rpm

$$\Rightarrow \omega = \frac{2\pi(1000)}{60} = 104.7 r/\sec$$

$$\Rightarrow I_{rated} = \frac{20 \times 746}{250} = 59.68 \text{ A}$$

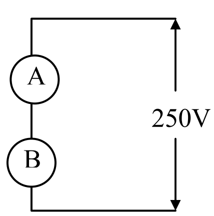
$\Rightarrow E_b = K_a \phi \omega; \phi \propto I_a$ (series motor)

$$E_b = KI_a\omega \Rightarrow K = \frac{250}{59.68 \times 104.7}$$

K = 0.04

If the two motors are connected in series and rotating a common shaft.

$\omega_A = 5\omega_{shaft}$ and $\omega_B = 4\omega_{shaft}$



$E_A + E_B = 250V$

$E_A = KI_a\omega_A$

$E_A = KI_a (5\omega_{shaft})$; $E_B = KI_a (4\omega_{shaft})$

$$\frac{E_A}{E_B} = \frac{5}{4}$$

$\Rightarrow E_A = 1.25E_b$

$E_A - 1.25E_b = 0$

$E_A + E_b = 0$

$-\quad -$

$-2.25E_b = -250$

$$E_B = \frac{250}{2.25} = 111.11\,V$$

$E_A = 138.8V$

$\therefore E_A = 138.8V, E_B = 111.11V$

$E_A = 138.8 = KI_a 5\omega_{shaft} \Rightarrow 138.8 = (0.04)(5)I_a\omega_{shaft}$

$694 = I_a\omega_{shaft}$

As losses are neglected

$P_{input} = P_{output}$

$VI = T\omega \Rightarrow (250)I_a = (810)(\omega_{shaft})$

$I_a = 3.24\ (\omega_{shaft})$

$I_a\omega_{shaft} = 694$

$3.24\ \omega_{shaft}^2 = 694 \Rightarrow \omega_{shaft} = 14.63 \text{rad/sec}$

$$N_s = \frac{60\omega}{2\pi} = 139.75\text{rpm}$$

$\therefore\ I_a = (3.24)(14.63) = 47.40A$

28. Ans: (b)

Sol: Since data is not given, for simplicity neglect all losses including armature copper losses. This means we assume $R_a = 0$.

Problem specifies that at any speed, armature current has the same value, which is equal to the rated value.

Let V_{rated} and I_{rated} be the rated values. Then rated input = rated output = $V_{rated}\ I_{rated}$ = 50 kW.

(i). To obtain half the speed by armature voltage control (field current is assumed to remain unchanged), armature voltage must be made $\frac{V_{rated}}{2}$. This result is proved as follows. For the shunt motor, $E = K\phi\omega_r = V - I_aR_a = V$ since R_a is neglected.

Let field excitation be kept constant. Then neglecting armature reaction, $K\phi$ is constant, say K_1 and $V = K_1\omega_r$. At rated operation $V_{rated} = K_1\omega_{r_{rated}}$. To get $\omega_r = \frac{1}{2}\omega_{r_{rated}}$; V must be $V_{rated}/2$.

$$\text{Power} = \frac{V_{rated}}{2} I_{rated} = 25 \text{ kW}$$

(ii). With V kept at V_{rated}; ω_r is to be changed to $\frac{3}{2}\omega_{r_{rated}}$ by field control. But the current is still I_{rated} from the given data.

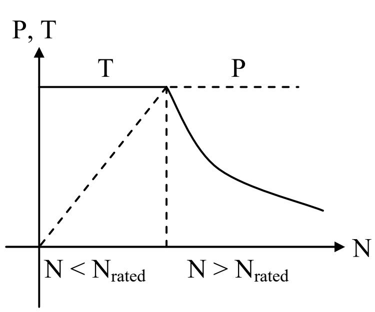
Hence power = $V_{rated}\, I_{rated}$ = 50 kW.

Method-II:

By armature voltage control we can control speeds below rated value. But below rated speed, the machine acts as a constant torque variable power drive, where $P_{out} \propto N$

$$\therefore \frac{P_2}{P_1} = \frac{N_2}{N_1} \Rightarrow \frac{P_2}{50k} = \frac{0.5N_1}{N_1}$$

P_2 = 25 kW



By field control method we can control speeds above rated Value. But above rated speed, the machine behaves as a constant power variable torque drive

$\therefore P_{out} = P_{rated} = 50$ kW

29. Ans: 7

Sol: Given, $V_t = 400V, I_{a_1} = 37A, I_{a_2} = 25.5A$, $r_a = 0.8\ \Omega$

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

$$\Rightarrow \text{Where } \alpha = \frac{I_{a_2}}{I_{a_1}} = \frac{25.5}{37}$$

$$R_1 = \frac{V_t}{I_{a_1}} = \frac{400}{37}$$

$$\left(\frac{25.5}{37}\right)^n = \left(\frac{0.8\times 37}{400}\right)$$

Take logarithm on both sides,

$$n \log_{10}^{0.689} = \log_{10}^{0.074}$$

$$n = 6.98 \approx 7$$

The number of resistance elements, n = 7

31. Ans: (i) d (ii) (a)

Sol: (i) $E_b = V - I_aR_a$

$$= 240 - I_a(0.5)$$

$$I_L = I_a + I_{sh} \Rightarrow I_a = I_L - I_{sh}$$

$$= 15 - 3 = 12A$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{80} = 3A$$

$$E_b = 240 - 12(0.5) = 234V$$

Net voltage

$$= V + E_b = 240 + 234$$

$= 474V$

(ii) $I_b = \dfrac{V + E_b}{R_a + R_b} = 1.25 I_{f\ell}$

$= \dfrac{240 + 231}{0.5 + R_b}$

$= 1.25 \times 12$

$474 = 15(0.5 + R_b)$

$R_b = \dfrac{474 - 7.5}{15} = 31.1\Omega$

33. Ans: 57.78

Sol: Given data

$P_0 = 10Hp$

$I_{fl} = 37.5A$

$V = 230V$

$\phi = 0.01Wb$

$P = 4$

$Z = 666$

$A = 2$

$R_a = 0.267\Omega$

Rotational losses = 600W

At, $N_1 = 1000$ rpm

Output torque , $T_{sh} = ?$

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

$= \dfrac{0.01 \times 666 \times 1000}{60} \times \dfrac{4}{2}$

$E_b = 222V$

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

$= 29.96A$

Gross mechanical power developed = P_{gm}

$P_{gm} = E_b I_a$

$= 222 \times 29.96$

$= 6651.12W$

Output power = shaft power

$P_{sh} = P_{gm}$ – rotational losses

$P_{sh} = 6651.12 - 600$

$= 6051.12W$

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

$6051.12 = T_{sh} \times \dfrac{2\pi \times 1000}{60}$

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

34. Ans: (a)

Sol: At no load developed power

$(P) = E_b I_a$

$E_b = 25 - 1.5 \times 0.8 = 23.8V$

$P = 23.8 \times 1.5 = 35.7$ W

Under no load condition the developed power is useful to overcome friction & windage Losses.

$\therefore$ friction & windage Losses = 35.7W

Under loaded condition Armature Cu loss

$= (3.5)^2 \times 0.8 = 9.8W$

$\therefore$ Total losses = 35.7+9.8

= 45.5W

Input to motor = $V \times I_a$

$= 25 \times 3.5$

$= 87.5W$

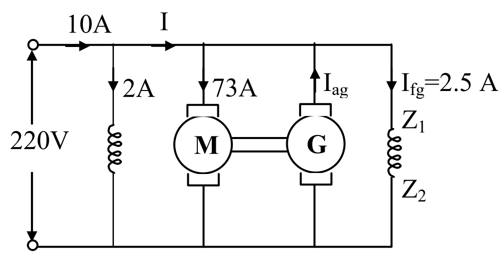
Efficiency $\eta = \dfrac{\text{input} - \text{Losses}}{\text{input}} \times 100$

$= \dfrac{87.5 - 45.5}{87.5} \times 100$

= 48 %

35.

Sol: Given data:



$V_t = 220V$, $I_{fg} = 2.5A$

$I_{fa} = 2A$, $I_{am} = 73A$

$R_{ag} = R_{am} = 0.05\Omega$

$I_L = 10A$

$I_{ag} = I_{am} + I_{fg} + I_{fa} - I_L$

$= 73 + 2 + 2.5 - 10 = 67.5$

$\therefore$ Armature circuit loss in generator

$= (67.5)^2 \times 0.05$

$= 227.81W$

Armature circuit loss in motor

$= (73^2 \times 0.05)$

$= 266.45W$

Power drawn from the supply (Excluding the field loss in two machines) $= V_tI$

$I = I_L - I_{fg} - I_{fm} = 10 - 2.5 - 2 = 5.5A$

$P_{loss} = 220 \times 5.5 = 1210W$

$\therefore$ No- load rotational loss in both the machines

$W_0 = V_tI - r_a(\left(I_{ag}^2 + I_{am}^2\right)$

$= 220 \times 5.5 - 0.05\,[(67.5)^2 + (73)^2]$

$= 715.735W$

$\therefore$ No-load rotational loss for each machine

$$= \frac{W_0}{2} = 357.86 \text{ W}$$

For generator, output $= V_tI_{ag}$

$= 220 \times 67.5 = 14850$

Total losses, $W_g = \dfrac{W_g}{2} + V_tI_{f2} + I_g^2 r_a$

$W_g = 357.86 + 220 \times 2.5 + 227.815$

$= 1135.675W$

$$\therefore \eta_g = \left[1 - \frac{\text{loss}}{\text{losses} + \text{output}}\right] \times 100$$

$$= \left[1 - \frac{1135.67}{1135.67 + 14850}\right] \times 100$$

$= 92.89\%$

For motor, input $= V_t(I_{am} + I_{fm})$

$= 220(73+2) = 16500W$

Total losses, $W_m = \dfrac{W_0}{2} + I_{am}^2 r_a + V_tI_{fg}$

$= 357.86 + 266.45 + 220 \times 2$

$= 1064.31$

$$\eta_m = \left[1 - \frac{\text{losses}}{\text{Input}}\right]$$

$$= \left(1 - \frac{1064.31}{16500}\right) = 93.371\%$$