2017

MADE EASY WORKBOOK

Detailed Explanations of Try Yourself Questions

Electrical Engineering

Electrical Machines

MADE EASY Publications

1 DC Machines

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$E_a = K_a \phi_1 N_1$$

$$400 - 0.25 \times 25 = K_a \phi_1 \times 1200 \quad \text{...(1)}$$

$$400 - (2.75 + 0.25) \times 15 = K_a \phi_2 \times N_2 \quad \text{...(2)}$$

Dividing equation (2) by (1),

$$\frac{355}{393.75} = \frac{N_2}{1200} \times \frac{\phi_2}{\phi_1} = \frac{N_2}{1200} \times 0.7$$

or, $N_2 = 1545.6$ rpm

T2 : Solution

There is a change of flux/pole due to armature reaction

$$E_{b_1} \propto \phi_1 N_1 \;,\; I_f = \frac{230}{200} = 1.15 \text{ A}$$

$$(V - IR) \propto \phi_1 N_1$$

$$[230 - (10 - 1.15)\,(0.1)] \propto 1400\,\phi_1 \quad \text{...(i)}$$

$$[230 - (200 - 1.15)\,(0.1)] \propto N_2\,\phi_1 \quad \text{...(ii)}$$

Dividing (i) by (ii), $\dfrac{210.1}{229.1} = \dfrac{N_2}{1400} \times 0.96$

$$N_2 = 1337 \text{ rpm}$$

$\because$ $T_d \times \omega = E_b \times I_a$

$\therefore$ Torque developed $(T_d) = \dfrac{210.1 \times (200 - 1.15)}{(2\pi \times 1337)/60} = 298.4$ N-m

T3 : Solution

(c)

$$V = 240\text{ V},\ R_a = 40\text{ A}$$
$$N_1 = 1500\text{ rpm},\ I_{a_1} = 40\text{ A}$$
$$T \propto I_a^2$$
$$\therefore \quad I_{a_1}^2 = I_{a_2}^2 \text{ i.e., } I_{a_1} = I_{a_2} = 40\text{ A}$$

During starting the induced emf is zero, hence the current is limited only by the resistance in the armature circuit.

$$\therefore \quad \text{The total resistance} = \frac{240}{40} = 6\ \Omega$$

extra resistance to be added in series with armature = 6 – 0.3 = 5.7 Ω

T4 : Solution

$I_a(R_a + R_{se})$ voltage is assumed to be negligible.

Hence,
$$V = E_a = K_e n I_a \quad (\phi \propto I_a) \qquad \text{...(i)}$$
$$T = K_T I_a^2 = K_L n^2 \qquad \text{...(ii)}$$

All coils are connected in series,
$$240 = K_e \times 800 \times 16 \qquad \text{...(iii)}$$
$$K_T \times (16)^2 = K_L \times (800)^2$$
or,
$$16\sqrt{K_T} = 800\sqrt{K_L} \qquad \text{...(iv)}$$

Two parallel groups of two in series
$$\text{Coil current} = \frac{I_a}{2}$$
$$240 = K_e \times n \times \frac{I_a}{2} \qquad \text{...(v)}$$
$$K_T I_a \times \frac{I_a}{2} = K_L n^2$$
or,
$$\sqrt{K_T}\, I_a = \sqrt{2}\sqrt{K_L}\, n \qquad \text{...(vi)}$$

From (iii) and (v) we get,
$$n I_a = 32 \times 800 \qquad \text{...(vii)}$$

From (iv) and (vi) we get
$$\frac{I_a}{16} = \frac{\sqrt{2}\, n}{800} \qquad \text{...(viii)}$$

From (vii) and (viii) we get,
$$n = 951\text{ rpm}$$
$$I_a = 26.9\text{ A}$$

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2 Transformers

Detailed Explanation of Try Yourself Questions

T1 : Solution

Net iron cross section, $A_i = 400 \times 0.9$

$= 360 \text{ cm}^2 \text{ or } 0.036 \text{ m}^2$

Peak value of flux, $\phi_{max} = B_{max} \times A_i$

$= 1.2 \times 0.036 = 0.0432 \text{ Wb}$

HV side phase voltage, $E_{P_1} = \dfrac{2200}{\sqrt{3}} = 1270 \text{ V}$

LV side phase voltage, $E_{P_2} = 110 \text{ V}$

Turns per phase on low voltage windings,

$$N_2 = \frac{E_{P_2}}{4.44\ \phi_{max} \times f} = \frac{110}{4.44 \times 0.0432 \times 50} = 11.47 \approx 12$$

Turns per phase on high voltage winding,

$$N_1 = N_2 \times \frac{E_{P_1}}{E_{P_2}} = \frac{12 \times 1270}{110} = 138$$

$$\text{sum} = 12 + 138 = 150$$

T2 : Solution

If $x = \text{p.u.}$

load at maximum efficiency, then

$$0.4\,x^2 = 0.35$$

$$x = 0.935$$

∴ The load at $\eta_{max} = 0.935 \times 25$

$= 23.375 \text{ kVA} \approx 23.4 \text{ kVA}$

T3 : Solution

$$N_1 : N_2 : N_3 = T_1 : T_2 : T_3 = 10 : 2 : 1$$

The mmf balance equation is:

$$T_1 \vec{I}_1 = T_2 \vec{I}_2 + T_3 \vec{I}_3$$

The total primary current, $\vec{I}_1 = \frac{T_2}{T_1}\vec{I}_2 + \frac{T_3}{T_1}\vec{I}_3$

or, $\vec{I}_1 = \frac{T_2}{T_1} \times 45(0.8 - j0.6) + \frac{T_3}{T_1} \times 50(0.71 - j0.70)$

$$= 9(0.8 - j0.6) + 5(0.71 - j0.70)$$
$$= 10.75 - j8.9 = 14\angle{-39.6^\circ} \text{ A}$$

Now, $\cos 39.6^\circ = 0.77$

i.e. The primary current is 14 A and P.F. = 0.77 (lag).

T4 : Solution

(b)

Full load current on HV side (rated) $= \frac{10,000}{2500} = 4$ A

Ohmic loss at full load current of 4 A = P_{oh}

$$P_{oh} = 45 \times \left(\frac{4}{3}\right)^2$$

[as ohmic loss of 45 W is due to 3A short circuit current]

At 0.8 pf and 1/4th of the full load;

Core loss, $P_c = 50$ W

Ohmic loss,

$$P_{oh1} = \left(\frac{1}{4}\right)^2 \times P_{oh} = \frac{1}{4^2} \times 45 \times \frac{4^2}{3^2} = 5 \text{ W}$$

$$\text{output} = \frac{1}{4} \times 10000 \times 0.8 = 2000 \text{ W}$$

$\therefore$ η at 1/4 of full load $= \left(1 - \frac{50+5}{2000+50+5}\right) \times 100 = 97.32\%$

T5 : Solution

(b)

As $$E = \sqrt{2}\pi f N\phi$$

where $$\phi = B \times A$$

Assuming transformer to be ideal

$$\frac{E_1}{E_2} = \frac{N_1\phi_1}{N_2\phi_2} = \frac{N_1 B_1 A_1}{N_2 B_2 A_2}$$

$$\Rightarrow \quad \frac{400}{800} = \frac{N \times B_1 \times \pi R^2}{\frac{N}{2} \times B_2 \times \pi(2R)^2}$$

$$\Rightarrow \quad B_1 = B_2 = 1.2\ \text{T}$$

T6 : Solution

The pu impedances expressed on a common base of 600 kVA are

$$\vec{Z}_1 = 0.012 + j0.06 = 0.061\angle 79^\circ \text{ pu}$$

$$\vec{Z}_2 = 2(0.014 + j0.045) = 0.094\angle 73^\circ \text{ pu}$$

$$\vec{Z}_1 + \vec{Z}_2 = 0.04 + j0.15 = 0.155\angle 75^\circ \text{pu}$$

The load is $$\vec{S}_L = 800\,(0.8 - j0.6)$$

$$= 800\angle -36.86^\circ \text{ kVA}$$

$$\vec{S}_1 = 800\angle -36.86^\circ \times \frac{0.094\angle 73^\circ}{0.155\angle 75^\circ}$$

$$= 485\angle -38.86^\circ = 377 - j304.2$$

$$\vec{S}_2 = 800\angle -36.86^\circ \times \frac{0.061\angle 79^\circ}{0.155\angle 75^\circ}$$

$$= 315\angle -32.86^\circ = 264 - j170.9$$

It may be noted that,

- the transformer are not loaded in proportion to their ratings.
- at a total load of 800 kVA, the 300 kVA transformer operates with 5% overload because of its pu impedance (on common kVA base) being less than twice that of the 600 kVA transformer.

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3 Induction Machine

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$\frac{T_{est}}{T_{e\max}} = \frac{\frac{1}{2}T_{e\max}}{T_{e\max}} = \frac{2}{\frac{s_{mT}}{1} + \frac{1}{s_{mT}}}$$

$\Rightarrow$ $s_{mT}^2 - 4s_{mT} + 1 = 0,$

$\Rightarrow$ $s_{mT} = 3.73 \text{ or } 0.27$

Neglecting higher value, $s_{mT} = 3.73$

So, $s_{mT} = 0.27$

Now, $\frac{r_2'}{s_{mT}} = x \Rightarrow r_2' = 0.2 \times 0.27 = 0.054\ \Omega$

External resistance required $= 0.054 - 0.04 = 0.014\ \Omega$

Without external resistancem

$$\text{p.f.} = \frac{0.04}{\sqrt{0.04^2 + 0.2^2}} = 0.196$$

With external resistance,

$$\text{p.f.} = \frac{0.054}{(0.054^2 + 0.2^2)^{1/2}} = 0.261$$

So, percentage improvement in p.f.

$$= \frac{0.261 - 0.196}{0.196} \times 100 = 33.16\%$$

T2 : Solution

$$\sqrt{3}\, E I \cos\phi = \frac{\text{output}}{\eta} = \frac{3 \times 746}{0.83}$$

$$\therefore \quad I = \frac{3 \times 746}{\sqrt{3} \times 500 \times 0.8 \times 0.83} = 3.89 \text{ A}$$

$\therefore$ The phase current at full load (Δ-connected) $= \dfrac{3.89}{\sqrt{3}} = 2.25$ A

$$I_{sc} = \frac{aE_1}{\sqrt{R_2^2 + X_2^2}} = 3.5 \times 2.25 = 7.86 \text{ A} \qquad \left(\frac{E_2}{E_1} = a\right)$$

$$\therefore \quad \sqrt{R_2^2 + X_2^2} = \frac{aE_1}{7.86}$$

Δ / Y switch,

$$I = \frac{\dfrac{aE_1}{\sqrt{3}}}{\sqrt{R_2^2 + X_2^2}} = \frac{aE_1}{\sqrt{3}} \times \frac{7.86}{aE_1} = 4.54 \text{ A}$$

T3 : Solution

Given,

$$P = 6,$$
$$f = 50 \text{ Hz},$$
$$N_{max} = 875 \text{ rpm},$$
$$T_{max} = 160 \text{ Nm},$$
$$s_{fl} = 0.04,$$
$$r_2 = 0.2\ \Omega/\text{phase}$$

Synchronous speed, $(N_s) = \dfrac{120 \times f}{P} = \dfrac{120 \times 50}{6} = 1000$ rpm

$$\therefore \quad s_{max,T} = \frac{N_s - N_{max}}{N_s} = \frac{1000 - 875}{1000}$$

$$= \frac{125}{1000} = 0.125$$

Now, applying the relation,

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\dfrac{S_{fl}}{S_{max,T}} + \dfrac{S_{max,T}}{S_{fl}}}$$

We have:

$$T_{fl} = \left(\frac{2}{\dfrac{s_{fl}}{s_{max,T}} + \dfrac{s_{max,T}}{s_{fl}}}\right) \times T_{max} = \left(\frac{2}{\dfrac{0.04}{0.125} + \dfrac{0.125}{0.04}}\right) \times 160 \approx 92.89 \text{ Nm}$$

T4 : Solution

Given,

$$f = 50 \text{ Hz},$$
$$P = 4$$
$$\text{Power input } (P_{in}) = 4000 \text{ W}$$
$$\text{Phase current} = \frac{I_L}{\sqrt{3}} = \frac{20}{\sqrt{3}} A$$
$$\text{Total stator } i^2 r \text{ loss} = 3 \times I_s^2 \times r_s = 3 \times \left(\frac{20}{\sqrt{3}}\right)^2 \times 0.4 = 160 \text{ W}$$

Power across air gap,

$$P_G = P_{in} - \text{stator } i^2 r \text{ loss}$$
$$= 4000 - 160 = 3840 \text{ W}$$

Synchronous speed,

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

$\therefore$

$$\omega_s = \frac{2\pi \times 1500}{60} \text{ rad/sec}$$

Internal torque developed,

$$T_e = \frac{P_G}{\omega_s} = \frac{3840 \times 60}{2\pi \times 1500} \approx 24.45 \text{ Nm}$$

T5 : Solution

Given,

$$P = 4,$$
$$f = 50 \text{ Hz},$$
$$N_r = 1440 \text{ rpm}$$

Synchronous speed,

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

$\therefore$ Slip at rated torque,

$$s = \frac{1500 - 1440}{1500} = 0.04$$

The linear torque-slip characteristics is given by

$$T_e = \frac{3}{\omega_s} \cdot \frac{V^2}{r_2} \times s$$

Since, ω_s, V and r_2 is constant, $T_e \propto s$

When slip is 0.04, $T_{e1} \propto 0.04$ ...(i)

and at reduced load torque, $\frac{1}{4} T_{e1} \propto s_1$ ...(ii)

From equations (i) and (ii),

$$\frac{s_1}{0.04} = \frac{1}{4}$$

$\therefore$

$$s_1 = 0.01$$

New motor speed,

$$N_{new} = 1500\,(1 - 0.01)$$
$$= 1485 \text{ rpm}$$

$$\text{Rated torque} = \frac{8 \times 1000 \times 60}{2\pi \times 1440}$$
$$= 53.05 \text{ Nm}$$

Power output at one-fourth of rated torque

$$= \frac{1}{4} \times \text{Rated torque} \times \text{New speed}$$

$$= \frac{1}{4} \times 53.05 \times \frac{1485 \times 2\pi}{60} = 2.062 \text{ kW}$$

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4 Synchronous Machine

Detailed Explanation of Try Yourself Questions

T1 : Solution

(b)

$$\text{Phase voltage} = \frac{6600}{\sqrt{3}} = 3810 \text{ V}$$

$$I = \frac{1500}{6.6 \times \sqrt{3}} = 131 \text{ A}$$

$\vec{I}$ as reference,

$$\text{Drop} = I\vec{z} = 131(0.4 + j6)$$

$$= 52 + j786$$

$$\text{The terminal voltage} = 3810(0.8 + j0.6)$$

$$= 3048 + j2286 \text{ V}$$

$\therefore$ The generated voltage $= 3100 + j3072$ V

$$= 4.364\angle 44.7° \text{ kV} \quad ...(i)$$

with I as reference, if x kV is the load phase voltage

$$\text{Terminal voltage} = 0.8x - j0.6x \text{ kV}$$

$$I\vec{z} = 0.052 + j0.786 \text{ kV}$$

$\therefore$ Generated voltage $= (0.8x + 0.052) + j(0.786 - 0.6x) \quad ...(ii)$

From equation (i) and (ii),

$\therefore (0.8x + 0.052)^2 + (0.786 - 0.6x)^2 = 4.364^2$

$\therefore \quad x^2 - 0.86x - 18.424 = 0$

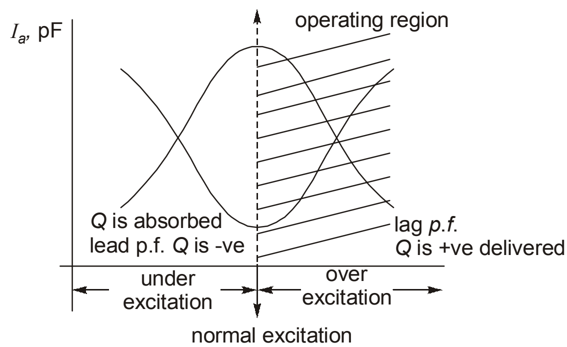
$$x = 4.744$$

$$\text{line voltage} = 4.744 \times \sqrt{3} \times 1000$$

$$= 8216.85 \text{ V}$$

T2 : Solution

(c)



Feeds leading KVAR to the bus but absorbs the lagging kVAR.

T3 : Solution

$$P = \frac{E_f \cdot V_t}{X_d}\sin\delta + \frac{V_t^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

$$= \frac{(1.1)\,(1.0)}{0.6}\sin\delta + \frac{(1.0)^2}{2}\left(\frac{1}{0.3} - \frac{1}{0.6}\right)\sin 2\delta$$

$$= \frac{1.1}{0.6}\sin\delta + \frac{1}{1.2}\sin 2\delta$$

$$\frac{dp}{d\delta} = 0 \text{ for } P = P_{max}$$

$$0 = \frac{1.1}{0.6}\cos\delta + \frac{2}{1.2}\cos 2\delta$$

$\Rightarrow$ $1.1\cos\delta + \cos 2\delta = 0$

$\Rightarrow$ $2\cos^2\delta - 1 + 1.1\cos\delta = 0$

$\Rightarrow$ $$\cos\delta = \frac{-1.1 \pm \sqrt{(1.1)^2 + 4(2)(1)}}{4} = 0.4836$$

$$\delta = 61.12°$$

T4 : Solution

0.8 p.f. leading, $\text{kVA} = \frac{1280}{0.8} = 1600 \text{ kVA}$

$\therefore$ The current, $I = \frac{1600}{\sqrt{3} \times 13.5} = 68.4 \text{ A}$

$$\text{The phase voltage} = \frac{13500}{\sqrt{3}} = 7794 \text{ V}$$

with current as reference,

$$\text{Terminal voltage} = 7794(0.8 - j0.6)$$
$$= 6235 - j4676$$
$$\text{Impedance drop} = 68.4(1.5 + j30)$$
$$= 102.6 + j2052$$

$\therefore$ Generated voltage $= 6338 - j2624 = 6860\angle -22.5$

$\therefore$ $$\text{The regulation} = \frac{6860 - 7794}{7794} \times 100 = -12\%$$

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5 Single-Phase Motor & Special Machine and Energy Conversion Principles

Detailed Explanation *of* Try Yourself Questions

T1 : Solution

[Ans: 5.22]