ESE GATE PSUs

State Engg. Exams

MADE EASY WORKBOOK 2025

Detailed Explanations of Try Yourself *Questions*

ELECTRICAL ENGINEERING

Electrical Machines

MADE EASY PUBLICATIONS

1 DC Machines

Detailed Explanation of Try Yourself Questions

T1 : Solution

$$E_a = K_a \phi_1 N_1$$

$$400 - 0.25 \times 25 = K_a \phi_1 \times 1200 \qquad ...(1)$$

$$400 - (2.75 + 0.25) \times 15 = K_a \phi_2 \times N_2 \qquad ...(2)$$

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

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

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

$$[230 - (10 - 1.15)(0.1)] \propto 1400\, \phi_1 \qquad ...(i)$$

$$[230 - (200 - 1.15)(0.1)] \propto N_2\, \phi_1 \qquad ...(ii)$$

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

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

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

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

T3 : Solution

(c)

$$V = 240 \text{ V}, R_a = 40 \text{ A}$$

$$N_1 = 1500 \text{ rpm}, \; I_{a_1} = 40 \text{ A}$$

$$T \propto I_a^2$$

$\therefore$
$$I_{a_1}^2 = I_{a_2}^2 \text{ i.e., } I_{a_1} = I_{a_2} = 40 \text{ A}$$

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

$\therefore$ The total resistance $= \dfrac{240}{40} = 6\ \Omega$

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,

$$n = 951 \text{ rpm}$$

$$I_a = 26.9 \text{ A}$$

■■■■

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

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

$$x = 0.935$$

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

$$= 9(0.8 - j\,0.6) + 5\,(0.71 - j\,0.70)$$
$$= 10.75 - j\,8.9 = 14\angle{-39.6°}\text{ A}$$

Now, $\cos 39.6° = 0.77$

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

$$\vec{Z}_1 = 0.012 + j\,0.06 = 0.061\angle 79° \text{ pu}$$

$$\vec{Z}_2 = 2(0.014 + j\,0.045) = 0.094\,\angle 73° \text{ pu}$$

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

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

$$= 800\angle -36.86° \text{ kVA}$$

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

$$= 485\angle -38.86° = 377 - j304.2$$

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

$$= 315\angle -32.86° = 264 - j170.9$$

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.

■■■■

3 Induction Machines

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

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

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

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

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

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

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

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

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

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, $f = 50$ Hz,

$P = 4$

Power input (P_{in}) $= 4000$ W

$$\text{Phase current} = \frac{I_L}{\sqrt{3}} = \frac{20}{\sqrt{3}} A$$

$$\text{Total stator } i^2r \text{ loss} = 3 \times I_s^2 \times r_s = 3 \times \left(\frac{20}{\sqrt{3}}\right)^2 \times 0.4 = 160 \text{ W}$$

Power across air gap, $P_G = P_{in} - \text{stator } i^2r \text{ loss}$

$= 4000 - 160 = 3840$ W

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

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

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, $P = 4$,

$f = 50$ Hz,

$N_r = 1440$ 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,

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

$$\text{Rated torque} = \frac{8\times1000\times60}{2\pi\times1440}$$
$$= 53.05 \text{ Nm}$$

Power output at one-fourth of rated torque

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

$$= \frac{1}{4}\times53.05\times\frac{1485\times2\pi}{60} = 2.062 \text{ kW}$$

■■■■

4 Synchronous Machines

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,

$$\text{Drop} = I\vec{z} = 131(0.4 + j6)$$
$$= 52 + j786$$
$$\text{The terminal voltage} = 3810(0.8 + j0.6)$$
$$= 3048 + j2286 \text{ V}$$
$$\therefore \quad \text{The generated voltage} = 3100 + j3072 \text{ V}$$
$$= 4.364\angle 44.7° \text{ kV} \quad ...(i)$$

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

$$\text{Terminal voltage} = 0.8x - j0.6x \text{ kV}$$
$$I\vec{z} = 0.052 + j0.786 \text{ kV}$$
$$\therefore \quad \text{Generated voltage} = (0.8x + 0.052) + j(0.786 - 0.6x) \quad ...(ii)$$

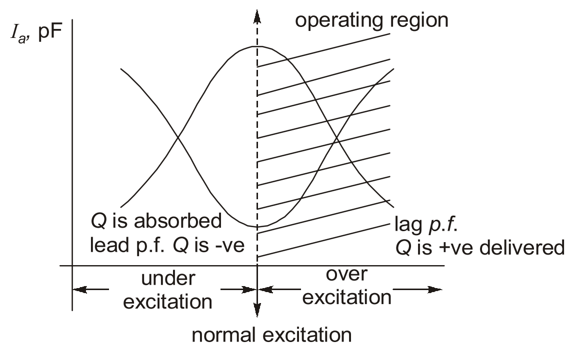
From equation (i) and (ii),

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

$$\therefore \quad x^2 - 0.86x - 18.424 = 0$$
$$x = 4.744$$
$$\text{line voltage} = 4.744 \times \sqrt{3} \times 1000$$
$$= 8216.85 \text{ V}$$

T2 : Solution

(a)



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

T3 : Solution

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

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

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

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

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

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

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

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

$$\delta = 61.12^\circ$$

■■■■

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

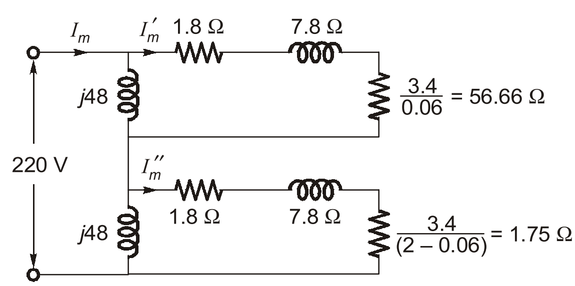
Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans: 5.22]

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

$$s = \frac{1000 - 940}{1000} = 0.06$$



$$\begin{aligned} Z_{eq} &= (1.8 + 7.8j + 56.66) \parallel (j48) + (1.8 + 7.8j + 1.75) \parallel (j48) \\ &= 23.236 + 35.186j \end{aligned}$$

$$I = \frac{V}{Z_{eq}} = \frac{220}{23.236 + 35.186j} = 5.22\angle{-56.56}$$

■■■■