

ESE GATE PSUs

State Engg. Exams

MADE EASY
WORKBOOK 2024



**Detailed Explanations of
Try Yourself *Questions***

ELECTRICAL ENGINEERING

Electrical Machines



MADE EASY
Publications

1

DC Machines



Detailed Explanation of Try Yourself Questions

T1 : Solution

$$E_a = K_a \phi_1 N_1$$

$$400 - 0.25 \times 25 = K_a \phi_1 \times 1200 \quad \dots(1)$$

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

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,

$$N_2 = 1545.6 \text{ rpm}$$

T2 : Solution

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

$$E_{b1} \propto \phi_1 N_1, \quad I_f = \frac{230}{200} = 1.15 \text{ A}$$

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

$$[230 - (10 - 1.15)(0.1)] \propto 1400 \phi_1 \quad \dots(i)$$

$$[230 - (200 - 1.15)(0.1)] \propto N_2 \phi_1 \quad \dots(ii)$$

Dividing (i) by (ii),

$$\frac{210.1}{229.1} = \frac{N_2}{1400} \times 0.96$$

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

\therefore

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

\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)

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

$$N_1 = 1500 \text{ rpm}, I_{a1} = 40 \text{ A}$$

$$T \propto I_a^2$$

$$\therefore I_{a1}^2 = I_{a2}^2 \text{ i.e., } I_{a1} = I_{a2} = 40 \text{ A}$$

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

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

$$\text{extra resistance to be added in series with armature} = 6 - 0.3 = 5.7 \Omega$$

T4 : Solution

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

$$\text{Hence, } V = E_a = K_e n I_a \quad (\phi \propto I_a) \quad \dots(i)$$

$$T = K_T I_a^2 = K_L n^2 \quad \dots(ii)$$

All coils are connected in series,

$$240 = K_e \times 800 \times 16 \quad \dots(iii)$$

$$K_T \times (16)^2 = K_L \times (800)^2$$

$$\text{or, } 16\sqrt{K_T} = 800\sqrt{K_L} \quad \dots(iv)$$

Two parallel groups of two in series

$$\text{Coil current} = \frac{I_a}{2}$$

$$240 = K_e \times n \times \frac{I_a}{2} \quad \dots(v)$$

$$K_T I_a \times \frac{I_a}{2} = K_L n^2$$

$$\text{or, } \sqrt{K_T} I_a = \sqrt{2} \sqrt{K_L} n \quad \dots(vi)$$

From (iii) and (v) we get,

$$n I_a = 32 \times 800 \quad \dots(vii)$$

From (iv) and (vi) we get

$$\frac{I_a}{16} = \frac{\sqrt{2} n}{800} \quad \dots(viii)$$

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, $E_{P_1} = \frac{2200}{\sqrt{3}} = 1270 \text{ V}$

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,
$$\begin{aligned} \vec{I}_1 &= \frac{T_2}{T_1} \times 45(0.8 - j0.6) + \frac{T_3}{T_1} \times 50(0.71 - j0.70) \\ &= 9(0.8 - j0.6) + 5(0.71 - j0.70) \\ &= 10.75 - j8.9 = 14 \angle -39.6^\circ \text{ A} \end{aligned}$$

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) = $\frac{10,000}{2500} = 4 \text{ A}$

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, $P_c = 50 \text{ W}$

Ohmic loss,

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

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

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

T5 : Solution

(b)

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

where $\phi = B \times A$

Assuming transformer to be ideal

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

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

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

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

$$\begin{aligned} \vec{S}_L &= 800 (0.8 - j0.6) \\ &= 800 \angle -36.86^\circ \text{ kVA} \end{aligned}$$

$$\begin{aligned} \vec{S}_1 &= 800 \angle -36.86^\circ \times \frac{0.094 \angle 73^\circ}{0.155 \angle 75^\circ} \\ &= 485 \angle -38.86^\circ = 377 - j304.2 \end{aligned}$$

$$\begin{aligned} \vec{S}_2 &= 800 \angle -36.86^\circ \times \frac{0.061 \angle 79^\circ}{0.155 \angle 75^\circ} \\ &= 315 \angle -32.86^\circ = 264 - j170.9 \end{aligned}$$

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 Machines



Detailed Explanation of Try Yourself Questions

T1 : Solution

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

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

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

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

$$\text{So, } s_{mT} = 0.27$$

$$\text{Now, } \frac{r'_2}{s_{mT}} = x \Rightarrow r'_2 = 0.2 \times 0.27 = 0.054 \, \Omega$$

$$\text{External resistance required} = 0.054 - 0.04 = 0.014 \, \Omega$$

Without external resistance

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

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

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

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

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

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

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

$$\Delta/Y \text{ switch, } I = \frac{\frac{aE_1}{\sqrt{3}}}{\sqrt{R_2^2 + X_2^2}} = \frac{aE_1}{\sqrt{3}} \times \frac{7.86}{aE_1} = 4.54 \text{ A}$$

T3 : Solution

Given,

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

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

$$\begin{aligned} \therefore s_{\max, T} &= \frac{N_s - N_{\max}}{N_s} = \frac{1000 - 875}{1000} \\ &= \frac{125}{1000} = 0.125 \end{aligned}$$

Now, applying the relation,

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

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

T4 : Solution

Given,

$$f = 50 \text{ Hz,}$$

$$P = 4$$

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

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

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

$$\begin{aligned} \text{Power across air gap, } P_G &= P_{in} - \text{stator } i^2r \text{ loss} \\ &= 4000 - 160 = 3840 \text{ W} \end{aligned}$$

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

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

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

T5 : Solution

Given,

$$P = 4,$$

$$f = 50 \text{ Hz,}$$

$$N_r = 1440 \text{ rpm}$$

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

$$\therefore \text{Slip at rated torque, } s = \frac{1500 - 1440}{1500} = 0.04$$

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,

$$\begin{aligned}N_{\text{new}} &= 1500 (1 - 0.01) \\&= 1485 \text{ rpm}\end{aligned}$$

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

Power output at one-fourth of rated torque

$$\begin{aligned}&= \frac{1}{4} \times \text{Rated torque} \times \text{New speed} \\&= \frac{1}{4} \times 53.05 \times \frac{1485 \times 2\pi}{60} = 2.062 \text{ kW}\end{aligned}$$

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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,

$$\begin{aligned} \text{Drop} &= I\vec{Z} = 131(0.4 + j6) \\ &= 52 + j786 \end{aligned}$$

$$\begin{aligned} \text{The terminal voltage} &= 3810(0.8 + j0.6) \\ &= 3048 + j2286 \text{ V} \end{aligned}$$

$$\begin{aligned} \therefore \text{The generated voltage} &= 3100 + j3072 \text{ V} \\ &= 4.364 \angle 44.7^\circ \text{ kV} \end{aligned} \quad \dots(i)$$

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

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

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

$$\therefore \text{Generated voltage} = (0.8x + 0.052) + j(0.786 - 0.6x) \quad \dots(ii)$$

From equation (i) and (ii),

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

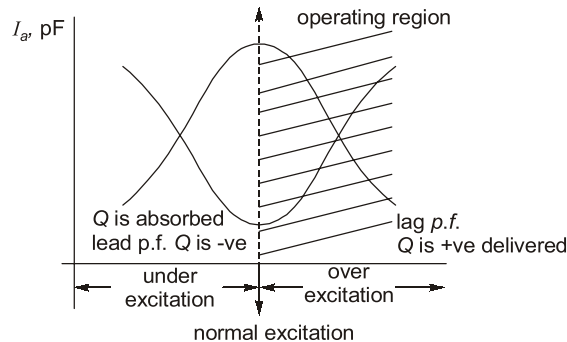
$$\therefore x^2 - 0.86x - 18.424 = 0$$

$$x = 4.744$$

$$\begin{aligned} \text{line voltage} &= 4.744 \times \sqrt{3} \times 1000 \\ &= 8216.85 \text{ V} \end{aligned}$$

T2 : Solution

(a)



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

T3 : Solution

$$\begin{aligned}
 P &= \frac{E_f \cdot V_t}{X_d} \sin \delta + \frac{V_t^2}{2} \left(\frac{1}{X_q} - \frac{1}{X_d} \right) \sin 2\delta \\
 &= \frac{(1.1)(1.0)}{0.6} \sin \delta + \frac{(1.0)^2}{2} \left(\frac{1}{0.3} - \frac{1}{0.6} \right) \sin 2\delta \\
 &= \frac{1.1}{0.6} \sin \delta + \frac{1}{1.2} \sin 2\delta
 \end{aligned}$$

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

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

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

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

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

$$\delta = 61.12^\circ$$

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5

Single-Phase Motor & Special Machine and Energy Conversion Principles



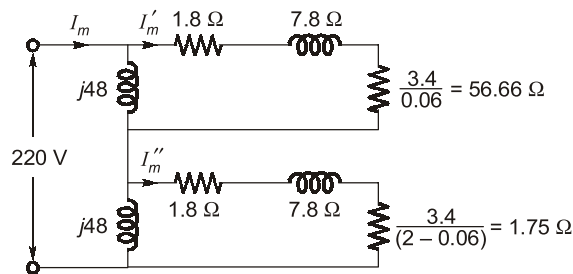
Detailed Explanation of Try Yourself Questions

T1 : Solution

[Ans: 5.22]

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

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



$$Z_{eq} = (1.8 + 7.8j + 56.66) \parallel (j48) + (1.8 + 7.8j + 1.75) \parallel (j48)$$

$$= 23.236 + 35.186j$$

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

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