GATE

MADE EASY
Workbook 2025

Detailed Explanations of Workbook *Questions*

Instrumentation Engineering

Electrical Machines

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1 Transformers

Answers Transformer

1. (d)	2. (a)	3. (c)	4. (c)	5. (d)	6. (c)	7. (d)	8. (b)	9. (c)	10. (d)
11. (d)	12. (c)	13. (a)	14. (b)	15. (a)	16. (a)	17. (d)	18. (d)	19. (b)	20. (d)
21. (b)	22. (a)	23. (a)	24 (d)	25. (c)	26. (c)	27. (c)	28. (b)	29. (a)	30. (c)
31. (d)	32. (b)	33. (b)	34. (b)	35. (d)	36. (b)	37. (d)	38. (d)	39. (d)	40. (b)
41 (d)	42. (d)	43. (d)	44. (a)	45. (a)	46. (a)	47. (a)	48. (d)	49. (b)	50. (a)
51. (b)	52. (b)	53. (a)	54. (c)	55. (c)	56. (d)	57. (a)	58. (a)	59. (c)	60 (d)
61. (c)	62. (c)	63. (d)	64. (b)	65. (a)	66. (c)	67. (b)	68. (b)	69. (d)	70. (d)
71. (d)	72. (0.25)	73. (30)	74. (10)	75. (b)	76. (a, b, d)	77. (a, b, c, d)	78. (b, c, d)		

Explanations Transformer

3. (c)

Bushings are terminals not protective device.

4. (c)

Conservator also work as reserve oil store. But, most appropriate answer is '*c*' i.e. to accommodate change in oil level during load cycle. Through conservator transformer breaths into atmosphere.

5. (d)

Dust and Moisture is already taken care by Silica Jel. Due to heating oxidation of transformer oil is there.

6. (c)

Grains are oriented to increase μ_r.

7. (d)

$P_e = K_e B^2 f^2 t^2$ where t is thickness.

8. (b)

The leakage in the flux is reduced by bringing the two coils closer. In a core type transformer this is achieved by winding half low voltage (*LV*) and half high voltage (*HV*) winding on each limb of the core.

The *LV* winding is wound on the inside and *HV* on the outside to reduce the amount of insulation needed. Insulation between the core and the inner winding is then stressed to low voltage.

16. (a)

$\phi = B \cdot A$ i.e. A (area of the core) $\propto \frac{1}{B}$ for constant ϕ.

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17. **(d)**

For power transformer of large rating the tapping are located near the centre up of phase winding to reduce magnetic asymmetry.

23. **(a)**

$$E = 4.44\, f\, N\phi_{max}$$

Hence, option (a) is correct.

24. **(d)**

for same exciting current

$$\frac{100}{50} = \frac{x}{40} = \frac{V}{f} = \text{constant}$$

$$x = 80 \text{ V}$$

26. **(c)**

$$E = \sqrt{2}\pi\, \phi_m f\, N_{Ph}$$

$$\phi_m = \frac{400}{\sqrt{2}\pi \times 50 \times 80} = 22.5 \text{ mWb}$$

30. **(c)**

No-load losses (essentially core losses not F & W losses) are low and depend upon the applied voltage in an induction machine.

33. **(b)**

Percentage voltage regulation for lagging p.f.

$$= (\in_r \cos\theta + \in_x \sin\theta) \times 100$$

as $\in_r = 0.01$ and $\in_x = 0.04$

$$\therefore \%\ VR = (0.01 \times 0.8 + 0.04 \times 0.6) \times 100$$

$$= 3.2\%$$

$\therefore$ % VR for leading p.f.

$$= (0.01 \times 0.8 - 0.04 \times 0.6) \times 100$$

$$= -1.6\%$$

34. **(b)**

Voltage regulation = $I(R\cos\phi - X\sin\phi)$ ...(1)

at leading power factor

Voltage regulation = $I(R\cos\phi + X\sin\phi)$ ...(2)

at lagging power factor

From equation (1), zero voltage regulation is possible at leading power factor.

Hence, option (b) is correct.

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35. **(d)**

$$\%\ \text{V.R.} = [(\%R) \times \cos\phi \pm (\%X) \times \sin\phi]$$

$$= 2 \times 0.8 + 4 \times 0.6 = 4$$

or, V.R. = 4%

36. **(b)**

$$P_e \propto V^2 \Rightarrow P_e \text{ (at 330 V)}$$

$$= \left(\frac{330}{220}\right)^2 \times 50 = 112.5 \text{ W}$$

37. **(d)**

Copper loss = $(1/2)^2 \times 6400 = 1600$ W

Iron loss does not depend upon the load but upon the applied voltage.

38. **(d)**

Air-core means non-iron core so there will be no hysteresis losses.

39. **(d)**

Magnetising flux $\phi \propto \frac{V}{f}$ but core loss depends upon the frequency.

40. **(b)**

Hysteresis loss not depend on thickness of lamination and time.

41. **(d)**

Eddy current loss $P_e = k_e B_{max}^2 f^2 t^2$

$$B_{max} \propto \frac{V}{f}$$

So, $P_e = k_e V^2 t^2$,

where, t = thickness

f = frequency

B_{max} = flux density

So, P_e will be same or no change in eddy current loss.

42. **(d)**

Core losses will be lesser in case of using high frequency ferrite core.

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43. (d)

At maximum efficiency variable loss = fixed loss

$$x_2 \times (P_a)_{fl} = P_{iron} \text{ loss}$$

$$x = \sqrt{\frac{40.5}{50}} = 0.9$$

44. (a)

$$P_{irm\ loss} = Af^2 + Bf$$

$$100 = A(40)^2 + B(40) \quad ...(1)$$

$$72 = A(30)^2 + B(30) \quad ...(2)$$

Solving (1) and (2),

$$A = \frac{1}{100}$$

Eddy current losses

$$= \frac{1}{100}(50)^2 = \frac{50 \times 50}{100} = 25 \text{ Watt}$$

45. (a)

$$\eta = \frac{\text{output}}{\text{output + loss}} = \frac{4 \times 1}{4 \times 1 + 0.2 + 0.2} \times 100$$

$$= 90.9\%$$

50. (a)

$$\eta = \sqrt{\frac{P_1}{P_2}} \quad \text{where, } \eta = \frac{75}{100} = \frac{3}{4}$$

$$\therefore \quad \frac{p_1}{p_2} = \frac{9}{16}$$

51. (b)

$$\text{Core-loss component} = \frac{5000}{220} = 22.73 \text{ A}$$

52. (b)

Short circuit test is performed to find copper losses not core losses.

55. (c)

$$I_{fl}\text{(full load current)} = \frac{10 \times 10^3}{2500} = 4\text{A}$$

$$\text{Full load copper loss} = 45 \times \frac{4^2}{3^2} = 80 \text{ W}$$

$$\text{Core loss} = 50 \text{ W}$$

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$$\eta = \frac{10 \times 0.8 \times 0.5 \times 1000}{10 \times 0.8 \times 0.5 \times 1000 + \left(50 + \left(\frac{1}{2}\right)^2 80\right)} \times 100$$

$$\eta = 98.28\%$$

56. (d)

$$VI\cos\phi_0 = P$$

$$\Rightarrow \quad \cos\phi_0 = \frac{600}{2000 \times 0.5} = 0.6$$

$$\Rightarrow \quad I\cos\phi_0 = I_w$$

$$\Rightarrow \quad I_w = 0.5 \times 0.6 = 0.3$$

$$\Rightarrow \quad I_\mu = \sqrt{(0.5)^2 - (0.3)^2}$$

$$= 0.4 \text{ A}$$

59. (c)

A part of the winding being common, leakage flux and therefore leakage reactance is less.

60. (d)

V_1 = 2000 – 200 = 1800 V due to opposite polarity connection

$(\text{kVA})_{auto}$ = 1800 × 50

$$\Rightarrow \quad I_2 = \frac{1800 \times 50}{2000} = 45 \text{ A}$$

62. (c)

Let, V_1 (primary) > V_2 (secondary)

so, $V_1 + V_2 = 2640$ ...(*i*)

$V_1 - V_2 = 2160$ ...(*ii*)

from (*i*) and (*ii*) V_1 = 2400 V and V_2 = 240 V

$\therefore \quad V_1 : V_2 = 10 : 1$

63. (d)

$$S_{trans} = S_{in}\left(1 - \frac{V_L}{V_H}\right) \times 100\%$$

$$= S_{in}\left(1 - \frac{161}{230}\right) \times 100\% = 30\% \text{ of } S_{in}$$

64. (b)

Power transferred conductively = 3 × 0.8

= 2.4 kW

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65. (a)

Power transformed industrially = $V_2 I_2 (1-k)$
Power transformed conductively = $V_2 I_2 k$

$$\frac{V_2}{I_2}(1-k) = \frac{V_2}{I_2}k$$

$$1-k = k = 0.5$$

66. (c)

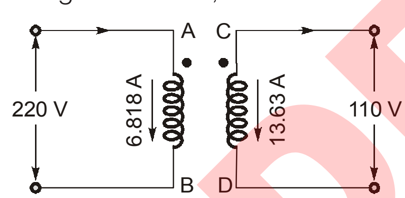
In transformer there is no direct connection between primary and secondary. So the power only transferred through induction. But in Auto transformer there is a conductive path between primary and secondary. So power transferred through both conduction and induction.

67. (b)

Near unity gain in voltage the auto transformer works efficiently. Maximum power transferred by conduction. So very less current in the winding. So losses are less.

68. (b)

The winding transformer,

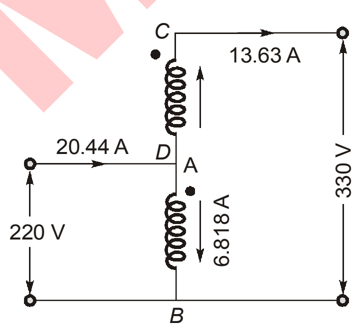


1.5 kVA, 220 V/110 V

$$I_1 = \frac{1.5\times10^3}{220} = 6.818\,\text{A}$$

$$I_2 = \frac{1.5\times10^3}{110} = 13.63\,\text{A}$$

When connected as a 220 V/330 V auto transformer,



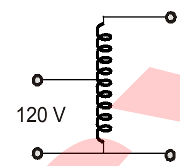
kVA rating of the transformer

$$= 330 \times 13.63 \times 10^{-3}$$

$$= 4.497\text{ kVA} \approx 4.488\text{ kVA}$$

Hence, option (b) is correct.

69. (d)



$$120 + 12 = 132\text{ V}$$

For step-up connection

70. (d)

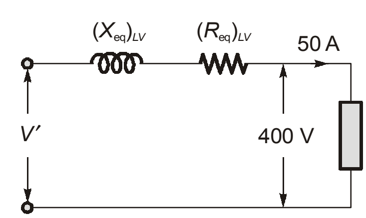
20 kVA, 2000/400 V
SC test data:
60 V, 4 A, 100 W
From test data:

$$100 = 4^2 \times R_{eq}$$

$$R_{eq} = \frac{100}{16} = 6.25\ \Omega$$

and $$Z_{eq} = \frac{60}{4} = 15\ \Omega$$

So, $$(X_{eq})_{HV} = \sqrt{15^2 - (6.25)^2} = 13.63\ \Omega$$



$$(I_{rated})_{LV} = \frac{20000}{400} = 50\text{ A}$$

$$(R_{eq})_{LV} = \frac{6.25}{(5)^2} = 0.25\ \Omega$$

$$(X_{eq})_{LV} = \frac{13.63}{(5)^2} = 0.545\ \Omega$$

V' = Input voltage reference to LV side

$$= V + IR_{eq}\cos\phi + IX_{eq}\sin\phi$$

$$= 400 + 50\times0.25\times0.8 + 50\times0.545\times0.6$$

$$= 426.35\text{ V}$$

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Input voltage referred to HV side

$$= 426.35 \times 5 = 2131.75 \text{ V}$$

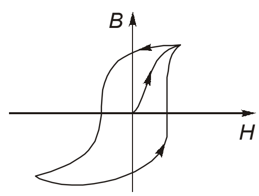
Note:

As test data is not given at rated current,
Rated current of HV side,

$$I_{\text{rated}}\Big|_{HV} = \frac{20000}{2000} = 10 \text{ A}$$

But the given current is 4 A.
In this case no need to calculate the value on rated value because impedance parameters will be same because of linear relation.

71. (d)



$$\text{Area} = 60.000 \text{ units}$$

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

y-axis, 1 unit $= 10^{-4}$ Wbm^{-2}

x-axis, 1 unit $= 10^{2}$ Am^{-1}

Volume of material = 0.01 m^3

$P_H = (60.000 \times 50 \times 10^{-4} \times 10^{2} \times 0.01)$ W = 300 W

72. (0.25)

$$L = 250 \times 10^{-3} \text{ H}; \quad R_0 = 300\ \Omega$$

$$B_L = \frac{1}{2\pi f L} = \frac{1}{2\pi(50)250 \times 10^{-3}}$$

$$= 0.012732$$

$$G_0 = \frac{1}{300} = 3.33 \times 10^{-3}$$

$$\cos\theta = \frac{G_0}{\sqrt{G_0^2 + B_L^2}} = 0.25 \text{ lag}$$

73. (30)

As capacitor's varied maximum value of voltage occurs when it is in resonance condition.
At resonance condition,

$$I = \frac{V}{R} = \frac{10}{10} = 1 \text{ A}$$

$$V_L = V_C = 30 \text{ V}$$

$$I\omega L = 30 \text{ V}$$

$$\omega L = 30$$

$$L = \frac{30}{1000} = 30 \text{ mH}$$

74. (10)

$$\phi = \frac{MMF}{S} = \frac{NI}{\frac{l}{a\mu_0\mu_r}} = \frac{NI}{l}(a\mu_0\mu_r)$$

$$B = \frac{d}{a} = \frac{\frac{NI}{l}(a\mu_0\mu_r)}{a}$$

$$B = \frac{NI\mu_0\mu_r}{l}$$

$$B = \frac{200(5 \times 10^{-3})(4\pi \times 10^{-7})(3000)}{2\pi\left(\frac{12 \times 10^{-2}}{2}\right)}$$

$$B = 10 \text{ millitesla}$$

75 (b)

At maximum efficiency,

Core loss = Copper losses = 80 W

Copper loss at rated current

$$= (25)^2 \times 0.5 = 312.5 \text{ W}$$

When maximum efficiency occurred,

$$I^2_m R = 80$$

$$I^2_m = \frac{80}{0.5} = 160$$

$$I_m = 12.649 \text{ A}$$

$$\% \text{ of rate of current} = \frac{12.649}{25} \times 100 = 50.60\%$$

76. (a, b, d)

For maximum efficiency,

$$x^2 P_{cu(FL)} = P_i$$

$$x = \sqrt{\frac{P_i}{P_{cuFL}}} = \sqrt{\frac{100}{215}} = 0.682$$

$$\%\ \eta = \frac{x \cdot \text{kVA} \cos\phi}{x\ \text{kVA} \cos\phi + 2pi}$$

$$= \frac{6819.94 \times 100}{6819.94 + 200}$$

$$= 0.9715 \times 100 = 97.15\%$$

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$$\Rightarrow \quad I_{pFL} = \frac{5\text{ kVA}}{V_p} = \frac{10000}{2200} = \frac{50}{11}\text{ Amp}$$

$$I_{p(n_{max})} = x \times I_{pfL} = \frac{50}{11} \times 0.682$$

$$= 3.10\text{ Amp}$$

⇒ Equivalent resistance of transformer referred to secondary is

$$\Rightarrow \quad r_p = \frac{P_{cuFL}}{I_{nFL}^2} = \frac{215}{\left(\frac{500}{11}\right)^2} = 0.10406\ \Omega$$

⇒ % load at which efficiency is maximum = 68.2%.

77. (a, b, c, d)

- The $\frac{LV}{HV}$ ratio : $a = \frac{150}{750} = 0.2$
- Since $I_2 = 4$ A, the current in the primary is

$$I_1 = \frac{I_2}{a} = \frac{4}{0.2} = 20\text{ A}$$

- The voltage on the secondary side is

$$V_2 = \frac{V_1}{a} = \frac{240}{0.2} = 1200\text{ V}$$

Thus, the power supplied to the load is

$$P_L = V_2 I_2 \cos\theta = 1200 \times 4 \times 0.8$$

$$= 3840\text{ W}$$

- The maximum flux in the core is

$$\Phi_m = \frac{E_1}{4.44 fN_1} = \frac{V_1}{4.44 fN_1}$$

$$= \frac{240}{4.44 \times 50 \times 150} = 7.21\text{ mWb}$$

78. (b, c, d)

The core volume and copper used in auto-transformer is less as compared to two winding transformer and also primary and secondary are wound on same limb, so there is less leakage flux results into less leakage reactance. For same flux, it has less reluctance and hence less magnetizing current.

■■■■

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2 Induction Machines

Answers Induction Machines

1. (a)	2. (b)	3. (d)	4. (d)	5. (c)	6. (c)	7. (b)	8. (c)	9. (b)	10. (b)
11. (b)	12. (b)	13. (a)	14. (a)	15. (b)	16. (a)	17. (a)	18. (a)	19. (b)	20. (c)
21. (a)	22. (a)	23. (a)	24. (a)	25. (c)	26. (c)	27. (b)	28. (b)	29. (a)	30. (a)
31. (c)	32. (d)	33. (b)	34. (b)	35. (c)	36. (d)	37. (b)	38. (a)	39. (b)	40. (a)
41. (d)	42. (d)	43. (c)	44. (d)	45. (b)	46. (b)	47. (b)	48. (b)	49. (c)	50. (d)
51. (c)	52. (a)	53. (d)	54. (a)	55. (a)	56. (c)	57. (b)	58. (b)	59. (b)	60. (a)
61. (b)	62. (c)	63. (a)	64. (a)	65. (b)	66. (b)	67. (b)	68. (d)	69. (d)	70. (b)
71. (c)	72. (c)	73. (39.56)	74. (a, b, d)		75. (c, d)				

Explanations Induction Machines

1. (a)

- If rotor slots are skewed by 2 harmonic pole-pitches, then the effect of slot harmonics (Parasitic torques) can be eliminated.
- Since the skewed rotor slot is not parallel to stator slot in an induction motor, there is more leakage reactance. As a result, induction motor has lower starting and maximum torques.
- With skewed rotor bars, the revolving flux, in effect, encounters an air gap of uniform reluctance and this results in a uniform torque and quieter operation.

3. (d)

When S_1 (no. of stator slots) is an integral multiple of S_2 (no. of rotor slots), cogging is sure to occur.

4. (d)

Small air gap ⇒ lower reluctance ⇒ higher inductance ⇒ smaller magnetising current as

$I \propto \frac{1}{L}$ from the equation $N\phi = LI$.

6. (c)

Radial length of air gap influences the reluctance ($\propto$1/inductance) of the magnetic circuit.

7. (b)

Resultant flux = $\frac{3}{2}\phi_m$ for 3-ϕ system.

8. (c)

Induction motor is use mostly in industries and most of the loads are inductive nature so that I/M operate at lagging power factor at no-load,

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where most of the power goes to armature loss and winding loss which are fixed losses, so at no load p.f. is very low near to 0.2.

29. (a)

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

$$\therefore \quad s = \frac{750 - 727.5}{750} = 0.03$$

$\therefore$ Slip frequency of rotor emf = sf

$$= 0.03 \times 50 = 1.5 \text{ Hz}$$

30. (a)

$$f_r = s \times f_s$$

31. (c)

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

$$s = \frac{N_s - N_r}{N_s}$$

$$0.05 = \frac{1000 - N_r}{1000}$$

$$\therefore \quad N_r = 950 \text{ rpm}$$

32. (d)

$$f_r = s\, f_s$$

$$\Rightarrow \quad 2 = s \times 50$$

$$\Rightarrow \quad s = \frac{2}{50} = 0.04$$

$$N = \frac{120 \times 50(1 - 0.04)}{8}$$

$$= 720 \text{ rpm}$$

42. (d)

$$N_r = (1 - s)\, N_s$$

$$= (1 - 0.04) \times \frac{120 \times 50}{P}$$

$$= 0.96 \times \frac{6000}{P} = \frac{5760}{P}$$

For speed to be maximum, maximum number of poles = 2.

$$\therefore \quad N_r = \frac{5760}{2} = 2880 \text{ rpm}$$

45. (b)

$$\text{Gross power} = P_d = (1 - s)\, P_g$$

$$= (1 - 0.1) \times 100 = 90 \text{ kW}$$

46. (b)

R_C in the induction motor equivalent circuit does not represent the no-load loss, it represents only the core loss of the induction motor.

47. (b)

$$P_m = 3I_2^2\, r_2 \left(\frac{1 - s}{s}\right)$$

$$15 \times 1000 = (3I_2^2 r_2) \cdot \left(\frac{0.96}{0.04}\right)$$

$$\Rightarrow \quad 3I_2^2 r_2 = 625 \text{ W}$$

48. (b)

Copper loss : rotor output : rotor input

$= sP_g : (1 - s)P_g : P_g = s : (1 - s) : 1$

49. (c)

Rotor losses ≅ rotor copper / ohmic losses

Rotor losses = airgap power – mech developed power

50. (d)

Core losses are constant as V_t and f are treated as constant.

51. (c)

$$f_r = \frac{100}{60} = \frac{5}{3}$$

and $\quad f_r = sf$

$$\Rightarrow \quad \frac{5}{3} = S \times 50$$

$$\Rightarrow \quad S = \frac{1}{30}$$

rotor copper loss = SP_g

$$= \frac{1}{30}(50 - 2) = 1.6 \text{ kW}$$

65. (b)

Refer rotor-resistance speed control of IM

66. (b)

At max^m torque, $s = \frac{r_2}{x_2}$.

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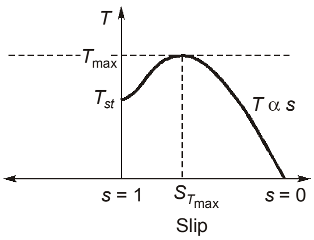
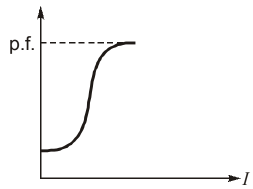
67. (b)

$$T_{st} \propto V^2$$

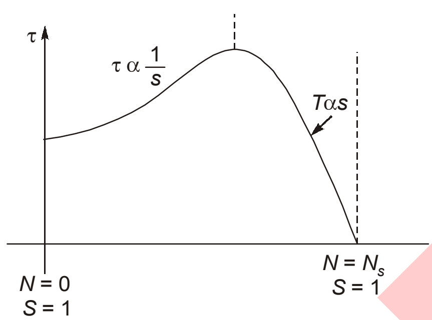
70. (b)





It is clear from the above shown diagram.

72. (c)



For power factor $\cos\theta_2 = \frac{R_2}{Z_2} = \frac{R_2}{R_2 + jsX_2}$

At starting $(\cos\theta_2)_{starting} = \frac{R_2}{R_2 + X_2}$

Order of R_2/phase = 0.1 to 0.2Ω

Order of X_2/phase = 1.5Ω to 2Ω

$$R_2^2 <<< X_2^2$$

So $R_2^2 \to$ neglected

$$\cos\theta_2 = \frac{R_2}{X_2}$$

As $R_2 \uparrow$ so power factor increases.

Hence option (a) is wrong.

$$T_s = \frac{180}{2\pi N_s} \times \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

So, R_2^2 term is neglected

$$T_s = \frac{180}{2\pi N_s} \frac{E_2^2 R_2}{X_2^2},$$

So, starting torque increases as it is directly proportional to rotor resistance.

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73. (39.56)

$$P_{out} = 60 \text{ W}$$
$$I = 0.3125 \text{ A}$$
$$V = 230 \text{ V}$$
$$VI\cos\phi = P_{out}$$
$$\cos\phi = 0.8347 \qquad \left[\because \cos\phi = \frac{P_{out}}{VI}\right]$$
$$\phi = 33.406$$
$$Q = P\tan\phi$$
$$Q = 39.56 \text{ VAr}$$

74. (a, b, d)

In induction motor,

speed or rotor $(N_r) = N_s(1 - s)$ rpm

⇒ Speed of rotor $= N_s(1 - s)$ rpm

⇒ Speed of stator magnetic field $= N_s$ rpm

⇒ Speed of rotor magnetic field $= N_s$ rpm

⇒ Speed of rotor w.r.t. stator

= rotor speed – stator speed

$= N_s(1 - s) - 0$

Speed of rotor w.r.t. stator $= N_s(1 - s)$ rpm

⇒ Speed of stator w.r.t. rotor RMF

= Stator speed – Speed of rotor RMF

$= 0 - N_s$

$= -N_s$ rpm

⇒ Speed of rotor RMF w.r.t. stator

=rotor RMF speed – stator speed

$= N_s - 0$

$= N_s$ rpm

⇒ The speed of stator magnetic field w.r.t. to rotor

= (Stator RMF) – rotor speed

$= N_s - N_s(1 - s)$

$= sN_s$ rpm

75. (c, d)

In blocked rotor test,

$N_r = 0,$

So, Slip = 1

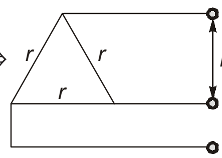
⇒ Power input at 220 Volt = 6 kW

⇒ Power input @ rated voltage

$$= \left(\frac{440}{220}\right)^2 \times 6 \text{ kW} = 24 \text{ kWatt}$$

$\Rightarrow$ Input current at rated voltage

$$= \frac{440}{220} \times 25 = 50 \text{ Amp}$$

$\Rightarrow$ 

$R = 2r \,||\, r = \frac{2r}{3}$

$$0.8 = \frac{2r}{3}$$

$$r = 1.2\ \Omega/\text{phase}$$

$\Rightarrow$ Air gap power

$$= \text{Input power} - 3 \times \left(\frac{I_L}{\sqrt{3}}\right)^2 \times r - 400$$

$$= 24000 - 3 \times \frac{50^2}{3} \times 1.2 - 400$$

$$P_{ag} = 20600 \text{ Watt}$$

$$\text{Starting torque} = \frac{P_{ag}}{\omega_s} = \frac{20600 \times 6}{4\pi \times 50}$$

$$= 196.7 \text{ N-m}$$

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