Number of Questions: 25 **Section Marks: 90**

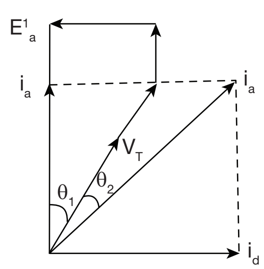
Directions for questions 1 to 25: Select the correct alternative from the given choices.

1. A three phase Y connected 50Hz two pole synchronous machine has a stator with 2000 turns/phase. What rotor flux is required to produce line to line voltage of 5kV?
(A) 1.2×10^{-2}Wb (B) 1.95×10^{-2}Wb
(C) 6.5×10^{-3}Wb (D) 3.75×10^{-3}Wb

2. A location requires 300kW of 60Hz ac power. Power sources are available only at 50Hz. Power is to be generated using synchronous motor - alternator set. How many poles should each of the machines have to convert 50Hz power to 60Hz power?
(A) 10 pole motor, 12 pole generator
(B) 12 pole motor, 10 pole generator
(C) 10 pole motor, 10 pole generator
(D) 12 pole motor, 12 pole generator

3. If the frequency of an alternator is changed form f_1 to f_2 its synchronous reactance (X_S) becomes _______.
(A) $(f_1/f_2)\, X_S$ (B) $(f_2/f_1)\, X_S$
(C) X_S (D) X_S/f_2

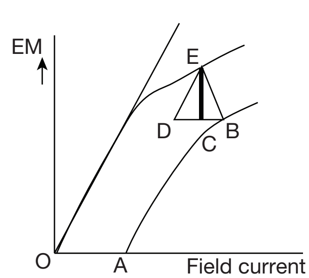
4. Given synchronous generator phasor diagram



θ_1, θ_2 indicate (respectively)
(A) torque angle, power factor angle
(B) power factor angle, torque angle
(C) power factor angle, internal voltage angle
(D) internal voltage angle, torque angle

5. _______ torque of synchronous motor can cause the motor to slip and step out of synchronism.
(A) accelerating (B) Pull - in
(C) pull - out (D) load

6. In the following characteristics of an alternator BC represents.



(A) field current necessary to overcome demagnetizing effect of armature reaction at full load.
(B) armature reaction drop at full load.
(C) field current necessary to overcome cross magnetizing effect of armature reaction at full load.
(D) armature resistance drop at full load.

7. Which of the following equation represent the maximum mechanical power developed in synchronous motor?
(A) $\dfrac{E_b V}{Z_s} - \dfrac{E_b^2}{Z_s}$ (B) $\dfrac{E_b V}{Z_s} - \dfrac{E_b^2}{Z_s}\sin\theta$
(C) $\dfrac{E_b V}{Z_s} - \dfrac{E_b^2}{Z_s}\cos\theta$ (D) $\dfrac{E_b V}{Z_s}\cos\theta$

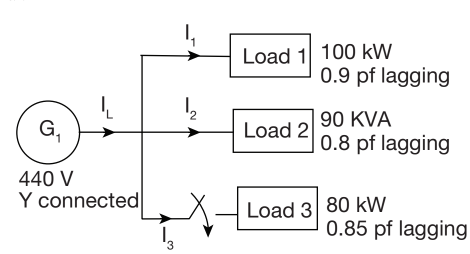
8. In an alternator chording angle for fundamental flux wave is α. Then its value for 7th harmonic is
(A) $\dfrac{\alpha}{7}$ (B) 7α
(C) $\dfrac{6\alpha}{7}$ (D) $\dfrac{8\alpha}{7}$

9. Synchronous motors are :
(A) self starting
(B) started manually
(C) started with a squirrel cage
(D) started with a capacitor

10. A 40 MVAr synchronous condenser operates on a 34.5 kV bus. Synchronous reactance is 150%. Estimate the field excitation required to get 40 MVAr power.
(A) 100% (B) 200%
(C) 250% (D) 50%

11. A 480V, 60Hz six pole synchronous motor draws 80A form the line at UPF, full load. Assuming that motor is lossless. Then what is the output torque?
(A) 629 Nm (B) 429 Nm
(C) 529 Nm (D) 729 Nm

12. For the circuit given below, what real and reactive power are provided by the generator when the switch is closed?



(A) 180 kW, 90kVAr (B) 252 kW, 52.8kVAr
(C) 252 kW, 152kVAr (D) 108 kW, 52.8kVAr

13. A 100MVA, 11.5kV, 0.75pf lagging, 50Hz two pole Y – connected synchronous generator has a per unit reactance of 0.9 and a per unit armature resistance of 0.012. The magnitude of internal generated voltage at rated conditions is ____ and the torque angle is _____

(A) 10750, 23° (B) 11556, 37°
(C) 10750, 37° (D) 11556, 23°

14. A three phase synchronous generator has negligible armature resistance and synchronous reactance X_d = 1.5P.u. This machine is connected to an infinite bus at voltage $1\angle 0°$P.u. what is the internal voltage of the machine when it delivers a current of $1\angle 30°$P.u to the infinite bus

(A) $1.44\angle 83°$ (B) $1.23\angle 82°$
(C) $1.32\angle 79°$ (D) None of the above

15. A three phase two pole winding is installed in six slots on a stator. There are 80 turns of wire in each slot of the windings. The three phases are Δ connected, all coils in each phase are connected in series. What is the frequency of voltage produced by this winding? (N = 3600rm)

(A) 50 Hz (B) 60 Hz
(C) 80 Hz (D) 48 Hz

16. What may be the highest speed at which two generators mounted on the same shaft be driven, if frequency of one generator is 25 Hz and that of the other is 60 Hz? They cannot have more than 26 poles.

(A) 120 rpm (B) 360 rpm
(C) 300 rpm (D) 3000 rpm

17. A 50 kVA, 200 V, 50 Hz, 1 – Φ alternator has an effective armature resistance of 0.02 ohm and an armature leakage of 0.08 ohm. Compute the voltage induced in the armature, when the alternator is delivering rated current at a load power factor of 0.8 leading.

(A) 216.39 V (B) 192.93 V
(C) 468.25 kV (D) 372.25 kV

18. A 3-phase alternator has a direct axis synchronous reactance of 0.6 p.u and a quadrature axis synchronous reactance of 0.3 p.u. Calculate the direct axis current when the alternator delivers a full load current at 0.7 p.f lagging.

(A) 0.71 (B) 0.58
(C) 0.82 (D) 0.17

19. A 600 kVA, 11 kV, 6-pole, 3 – Φ star connected alternator has percentage resistance and reactance of 2 and 10 respectively. Calculate the synchronizing power per mechanical degree of displacement at full load 0.9 power factor lagging.

(A) 111.50 W/phase (B) 111.50 kW/phase
(C) 334.5 W/phase (D) 334.5 kW/phase

20. Two alternators A and B operate in parallel and supply a load of 20 MW at 0.75 p.f lagging. Calculate the power factor of alternator B when alternator A supplies 14,000 kW at 0.9 lagging power factor.

(A) 0.48 lagging (B) 0.77 lagging
(C) 0.62 lagging (D) 0.53 lagging

21. Calculate the power angle when a2000 kVA, 11 kV, 3-phase, Y-connected alternator having a resistance of 0.5 ohm and a reactance of 5 ohm per phase delivers full load current at normal rated voltage and 0.8 p.f lagging.

(A) 6.60° (B) 40.16°
(C) 3.30° (D) 36.24°

22. A 2000V star connected synchronous motor has a resistance of 0.4 ohm per phase and a synchronous reactance of 3.0 ohm per phase. The motor is operating at 0.8 power factor leading with a line current of 300 A. Calculate the value of the generated e.m.f per phase.

(A) 692.89 V/phase
(B) 1370.19 V/phase
(C) 1782.36 V/phase
(D) 1200.12 V/phase

23. A 1500 V, 3-phase, 6-pole, Y-connected synchronous motor runs at 1000 rpm. The excitation is constant and corresponds to an open-circuit terminal voltage of 1500 V. The resistance is negligible as compared with synchronous reactance of 4 Ω per phase. Calculate the torque developed for an armature current of 300 A.

(A) 5627.44 N-m (B) 5374.21 N-m
(C) 562.74 N-m (D) 537.42 N-m

Common data questions for 24 and 25:

24. A 480V, 200kW, two pole, three phase, 50 Hz synchronous generators prime mover has the no load speed of 3040rpm and full load speed of 2975rpm. It operates in parallel with a 480 V, 180 kW, four pole, 50 Hz synchronous generator whose prime mover has a no load speed of 1500rpm and full load speed of 1485rpm. Together, they supply 200kW at 0.85PF lagging. Speed drops of generator 1 and generator 2 are respectively. (in percent)

(A) 2.18, 1.01 (B) 1.01, 2.18
(C) 0.218, 0.101 (D) 0.101, 0.218

25. What is the power given by generator 2?

(A) 128 kW (B) 72 kW
(C) 100 kW (D) 200 kW

Answer Keys

1. C	**2.** A	**3.** B	**4.** A	**5.** C	**6.** A	**7.** C	**8.** B	**9.** C	**10.** C
11. C	**12.** B	**13.** D	**14.** C	**15.** B	**16.** C	**17.** B	**18.** C	**19.** B	**20.** A
21. C	**22.** C	**23.** B	**24.** A	**25.** B					

Hints and Explanations

1. $V_{\text{phase}} = \dfrac{5000}{\sqrt{3}} = 2886.8$

$E = \sqrt{2}\pi N_c \varphi f$

$\Rightarrow \phi = \dfrac{E}{\sqrt{2}\pi N_C f} = \dfrac{2886.8}{\sqrt{2}\pi \times 2000 \times 50} \approx 6.5 \times 10^{-3}$ Wb

Choice (C)

2. $N_s = \dfrac{120 f}{p}$

But since shafts are coupled, mechanical speed of motor and generator should be equal.

Hence, $\dfrac{120 \times 50}{P_1} = \dfrac{120 \times 60}{P_2}$

$\Rightarrow \dfrac{P_2}{P_1} = \dfrac{6}{5}$

Hence 12 pole generator, 10 pole motor will be suitable. Choice (A)

3. Since armature reaction αf

$\therefore \quad X_s \, \alpha f$ Choice (B)

4. Choice (A)

5. Choice (C)

6. Choice (A)

7. Choice (C)

8. Choice (B)

9. Choice (C)

10. $V_t = E + j I_a X_S$

$1\angle 0° = E\angle 0° + j I_a(1.5)$

$1 - E = 1.5 I_a \angle(90° + 90°)$

At $|I_a| = 1$

$1 - E = -1.5$

$|E| = 2.5$

$\therefore$ Field excitation should be 250% Choice (C)

11. For lossless motor, $P_{\text{OUT}} = P_{\text{IN}}$

$\tau = \dfrac{p}{\omega} = \dfrac{\sqrt{3}\, V_T I_L \cos\theta}{\left(\dfrac{120 \times 60}{6}\right)\dfrac{2\pi}{60}}$

$= \dfrac{66.5 \times 1000}{\left(\dfrac{1200 \times 2\pi}{60}\right)} \approx 529$ Nm Choice (C)

12. $P_3 = 80$kW

$Q_3 = P \tan\theta = P \tan(\cos^{-1}(.85)) = 80 \text{ kW} \times \tan(-31.79°)$

$= -49.6$KVAr

$P_2 = S\cos\theta = 90\text{KVA} \times 0.8 = 72$kW

$Q_2 = \sin\theta = 90\text{KVA} \times 0.6 = 54$KVAr

$P_1 = 100$kW

$Q_1 = P\tan\theta = 100 \text{ kW}(\tan(\cos^{-1}0.9))$

$= 100\tan(25.8) = 48.4$KVAr

$\therefore$ Total real power = 252kW

Total reactive power = 52.8KVAr Choice (B)

13. $V_{\text{phase}} = \dfrac{11500}{\sqrt{3}} = 6640$V

$Z_{\text{base}} = \dfrac{3(6640)^2}{100 \times 10^6} = 1.32\Omega$

$R_A = 0.012 \times 1.32 = 0.0158\Omega$

$X_S = 0.9 \times 1.32 = 1.188\Omega$

Rated armature current $= \dfrac{S}{\sqrt{3}V_T} = \dfrac{100 \times 10^6}{\sqrt{3} \times 11.5 \times 10^3}$

$= 5020$A

$Pf = 0.75$ lagging, $\therefore I_A = 5020\angle -41.41°$

$\therefore \quad E_A = V_{\text{phase}} + R_A I_A + j X_S I_A$

$= 6640\angle 0° + (0.0158)(5020\angle -41.41°) + j\,1.188(5020\angle -41.41°)$

$= 6640 + 79.316 + j\,[4472.82 - j3936]$

$= 6640 + 79.316 + 3936 + j4472.82$

$= 10655.316 + j4472.82$

$\therefore \quad E_A = 11556.03\angle 22.73° \approx 11556\angle 23°$ Choice (D)

14. $E\angle\delta = V_a\angle 0° + I_a \angle\theta\, X_d\angle 90°$

$= 1\angle 0° + 1.5\angle(90 + 30°)$

$= 1 + (-0.75) + j1.3$

$= 1.324\angle 79.1° \approx 1.32\angle 79°$ Choice (C)

15. $f = \dfrac{np}{120} = \dfrac{3600 \times 2}{120} = 60$Hz Choice (B)

16. $N = \dfrac{120 f_1}{P_1} = \dfrac{120 f_2}{P_2}$

$= \dfrac{120 \times 60}{P_1} = \dfrac{120 \times 25}{P_2}$

$P_1/P_2 = \dfrac{60}{25}$

$P_1, P_2 \le 26$

$\therefore \quad P_1, P_2 = 24, 10$

$\therefore \quad N = \dfrac{120 \times 60}{24} = 300$ rpm

$= \dfrac{120 \times 25}{10} = 300$ rpm Choice (C)

17. $I = 50000/200 = 250$A

$E = [(V\cos\Phi + IR_a)^2 + (V\sin\Phi - IX_L)^2]^{11/2}$

$= [(200 \times 0.8 + 250 \times 0.02)^2 + (200 \times 0.6 - 250 \times 0.08)]^{1/2} = 192.93$V Choice (B)

18. $V = 1$ p.u

$X_d = 0.6$ p.u

$X_q = 0.3$ p.u

$\cos\phi = 0.7 \Rightarrow \phi = \cos^{-1}(0.7) = 45.57^\circ$
$\sin\phi = 0.7$
$I_a = 1$ p.u

$$\tan\delta = \frac{I_a X_q \cos\varphi}{V + I_a X_q \sin\varphi} = \frac{1\times0.3\times0.7}{1+1\times0.37+0.7} = 0.173$$

$\delta = 9.81^\circ$
$I_d = I_a \sin[\Phi + \delta] = 1 \times \sin(45.57^\circ + 9.81^\circ) = 0.82$

Choice (C)

19. Full load current $I = \dfrac{600\times10^3}{\sqrt{3}\times11\times10^3} = 31.5\text{A}$

$$V_{ph} = \frac{11000}{\sqrt{3}} = 6350\text{V}$$

$I R_a = 0.02 \times 6350 = 127\text{V}$
$I X_s = 0.1 \times 6350 = 635 \text{ V} \Rightarrow X_s = 20.15\ \Omega$
$E = [(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_s)^2]^{1/2}$
$= [(6350 \times 0.9 + 127)^2 + (6350 \times 0.435 + 635)^2]^{1/2}$
$= 6757.97\text{V}$

$\alpha\text{ (mech)} = 1^\circ \Rightarrow \alpha\text{ (elect)} = 1 \times \dfrac{6}{2} = 3^\circ$

$\alpha = 3\pi/180 = \pi/60$ elect.radi

$$P_{sy} = \frac{\frac{\pi}{60}\times6757.97\times6350}{20.15} = 111.50 \text{ kW/phase}$$

Choice (B)

20. $\cos\phi = 0.75 \Rightarrow \phi = 41.40^\circ$
Load kW = 20000 kW
Load KVAR = 20000 $\tan\Phi$
= 17632.37 KVAR
Load kw supplied by alternator A, $kw_1 = 14000$ kW
Load kw supplied by alternator B, $kw_2 = 6000$ kW
Load KVAR supplied by alternator A $KVAR_1$
$= kw_1 \times \tan\phi_1$
$\cos\phi_1 = 0.9 \Rightarrow \phi_1 = 25.84^\circ$
$KVAR_1 = 14000 \times \tan(25.84)$
$= 6779.92$ KVAR
Load $KVAR_2$ supplied by alternator B $KVAR_2$
$= 17632.37 - 6779.92$
$= 10852.45$ KVAR
$KVA_2 = 6000 - {}_j10852.45$
$= 12400\angle{-61.06^\circ}$
$\cos\phi_2 = 0.48$ lagging

Choice (A)

21. $\cos\Phi = 0.8 \Rightarrow \Phi = 36.86^\circ$

$$I = \frac{2000\times10^3}{\sqrt{3}\times11\times10^3} = 104.97\text{A}$$

$IR_a = 104.97 \times 0.5 = 52.48\text{V}$
$IX_s = 104.97 \times 5 = 524.85\text{V}$
$V/\text{phase} = 11000/\sqrt{3} = 6350.85\text{V}$

$$\tan(\phi+\delta) = \frac{V\sin\varphi + I X_s}{V\cos\varphi + IR_a} = \frac{6350.85\times0.6+524.85}{6350.85\times0.8+52.48}$$

$\tan(\phi + \delta) = 0.844$

$\phi + \delta = 40.16 \Rightarrow \delta = 40.16 - 36.86^\circ$
$\Rightarrow\ \delta = 3.30^\circ$

Choice (C)

22. $\phi = \cos^{-1}(0.8) = 36.86^\circ$

$$\theta = \tan^{-1}\left(\frac{3}{0.4}\right) = 82.40^\circ$$

$\theta + \phi = 82.40 + 36.86 = 119.26^\circ$

$$V = \frac{2000}{\sqrt{3}} = 1154.70\text{V}$$

$$Z_S = \sqrt{0.4^2+3^2} = 3.02\ \Omega$$

$IZ_s = 300 \times 3.02 = 906\ \Omega$

$$E_b = \sqrt{V^2 + E_R^2 - 2V\,E_R\cos(\theta+\varphi)}$$

$$= \sqrt{(1154.70)^2 + (906)^2 - 2\times1154.70\times906\times\cos(119.26)}$$

$= 1782.36$ volt/phase

Choice (C)

23. Voltage/phase $= \dfrac{1500}{\sqrt{3}} = 866.02\text{V}$

Induced e.m.f = 866.02V
Impedance drop = 300 × 4 = 1200V
$866^2 = 866^2 + 1200^2 - 2 \times 866 \times 1200 \times \cos(90 - \Phi)$
$\sin\phi = 0.692 \Rightarrow \phi = 43.78^\circ$
Power input $= \sqrt{3} \times 1500 \times 300 \times \cos(43.78^\circ)$
$= 562.74$kW

$$\text{Torque } T = \frac{9.55\times562.74}{1000} = 5374.21 \text{ N-m}$$

Choice (B)

24. $F_{nl1} = \dfrac{n_m P}{120} = \dfrac{3040\times2}{120} = 50.67\text{Hz}$

$$F_{fl1} = \frac{2975\times2}{120} = 49.58\text{Hz}$$

$$F_{nl2} = \frac{1500\times4}{120} = 50\text{Hz}$$

$$F_{fl2} = \frac{1485\times4}{120} = 49.5\text{Hz}$$

$$SD_1 = \frac{n_{nl}-n_{fl}}{n_{fl}}\times100\% = \frac{3040-2975}{2975}\times100 = 2.18\%$$

$$SD_2 = \frac{1500-1485}{1485}\times100 = 1.01\%$$

Choice (A)

25. $P_2 = S_{P2}(f_{nl2} - f_{sys}) = 360[50 - 49.8] = 72\text{kW}$

$$S_{P2} = \frac{P}{f_{nl}-f_{fl}} = \frac{180\text{kW}}{50-49.5} = 360\text{kW/Hz}$$

$(S_{pl} = 183.48\text{KW/Hz})$
$P_{Load} = S_{p1}(f_{nL} - f_{sys}) + S_{p2}(f_{nl} - f_{sys})$
$\Rightarrow\ 200 = 183.48(50.67 - f_{sys}) + 360(50 - f_{sys})$
$\Rightarrow\ f_{sys} = 49.8$

Choice (B)