CLASS TEST

S.No.: 02SK_ABCDEFGHI_26725

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# SYNCHRONOUS MACHINE

## ELECTRICAL ENGINEERING

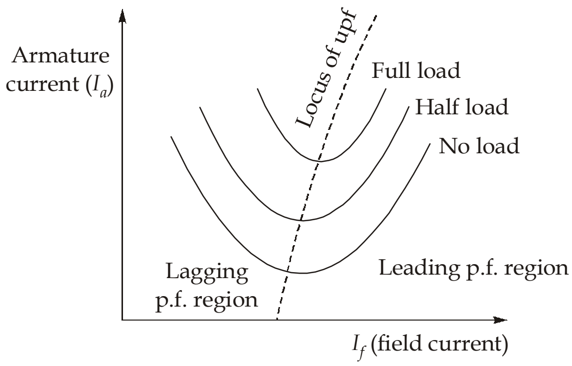
Date of Test : 26/07/2025

## ANSWER KEY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | (d) | 7. | (c) | 13. | (c) | 19. | (b) | 25. | (b) |
| 2. | (d) | 8. | (b) | 14. | (b) | 20. | (b) | 26. | (a) |
| 3. | (c) | 9. | (b) | 15. | (a) | 21. | (c) | 27. | (b) |
| 4. | (b) | 10. | (a) | 16. | (d) | 22. | (a) | 28. | (b) |
| 5. | (c) | 11. | (c) | 17. | (a) | 23. | (b) | 29. | (a) |
| 6. | (b) | 12. | (c) | 18. | (a) | 24. | (d) | 30. | (a) |

## DETAILED EXPLANATIONS

**1.** **(d)**




∴ As we go right of the unity power factor locus of $V$-curve we obtain over excitation and leading current input.

**2.** **(d)**

**3.** **(c)**

For short circuit current, $I_{sc} = \dfrac{E}{X_s}$

$$E \propto f\phi$$

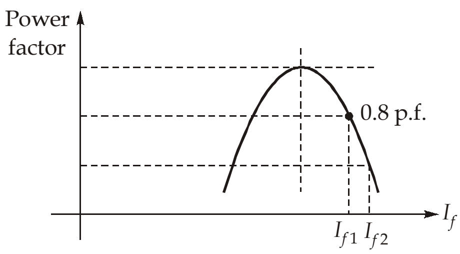
$$X_s \propto f$$

So, $I_{sc} \propto \phi$

Hence short circuit current is only a function of excitation.

**4.** **(b)**

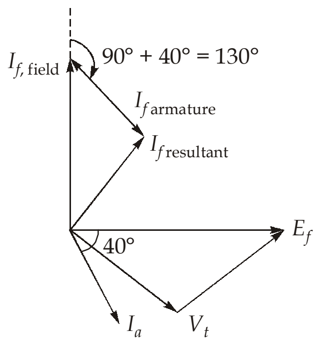
Inverted $V$ curve is the curve between power factor and field current.




Power factor reduces. Thus it is obvious power factor angle will increase.

**5.** **(c)**

**6.** **(b)**



**7.** **(c)**

Both the statements are correct.

**8.** **(b)**

$$E_f^2 = (V_E \cos\phi)^2 + (V_t \sin\phi + I_a X_s)^2$$

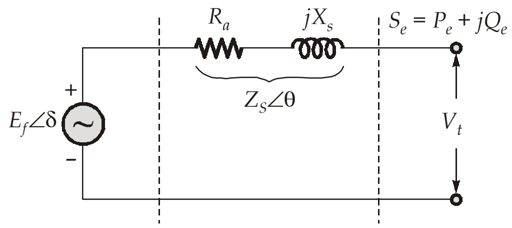
$$E_f^2 = V_t^2\left[0.8^2 + \left(0.6 + \frac{I_a X_s}{V_t}\right)^2\right]$$

$$E_f^2 = V_t^2\left[0.8^2 + (0.6 + 0.2)^2\right]$$

$$E_f = 1.13\ V_t$$

$$\text{Voltage regulation} = \frac{E_f - V_t}{V_t} \times 100 = \frac{1.13V_t - V_t}{V_t} \times 100 = 13\%$$

**9.** **(b)**




$$Z_s\angle\theta = (0.8 + j8) = 8.039\angle 84.25° \text{ ohm}$$

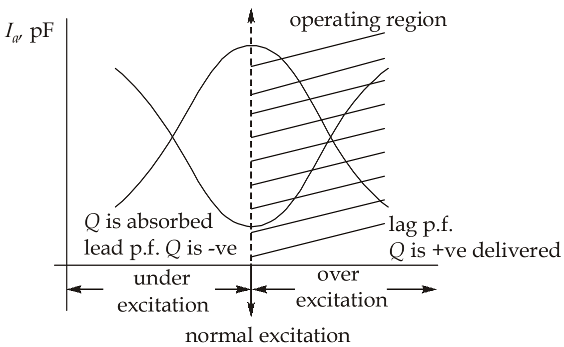
The output power can be written as

$$P_{e\,(out)} = \frac{V_t E_f}{Z_s}\cos(\theta - \delta) - \frac{V_t^2}{Z_s}\cos\theta$$

The $P_{e(out)}$ is maximum, if $\Rightarrow \delta = \theta$

So, $\delta = 84.25°$

**10.** **(a)**




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

**11.** **(c)**

Speed of alternator, $N_s = \dfrac{120f}{P}$

$$N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Phase voltage, $E_1 = \dfrac{3300}{\sqrt{3}}\text{V} = 1905.256 \text{ V}$

Electrical degree change, $\Delta\delta = \frac{P}{2}\theta_m$ where $\theta_m = 1°$

$$\Delta\delta = 3°, \text{ i.e., } \Delta\delta = \frac{\pi}{60} \text{ rad}$$

Full load current, $I = \frac{3 \times 10^6}{\sqrt{3} \times 3.3 \times 1000} = 524.86 \text{ A}$

Base impedance, $Z_s = \frac{V^2}{\text{MVA}} = 3.63\ \Omega$

Synchronous reactance, $X_s = 0.25 \times 3.63\ \Omega = 0.9075\ \Omega$

Synchronous power, $P_{syn} = \frac{3E^2}{X_s}\Delta\delta$

$$P_{syn} = \frac{3 \times 1905.256^2}{0.9075} \times \frac{\pi}{60} = 628.3186 \text{ kW}$$

Synchronizing torque, $T_{syn} = \frac{P_{syn} \times 60}{2\pi N}$

$$T_{syn} = \frac{628.3186 \times 60}{2\pi \times 1000} \text{ Nm}$$

$$T_{syn} = 6 \text{ Nm}$$

**12. (c)**

Power angle can be calculated as,

$$\vec{E}'_f = \vec{V}_t + j\vec{I}_a X_q$$

As rated load is being supplied at unity power factor,

$$\therefore \quad \vec{I}_a = 1\angle 0° \text{ p.u.}$$

$$\vec{E}'_f = 1.0\angle 0° + j1.0\angle 0°\ (0.8)$$

$$= 1.28\angle 38.65° \text{ p.u.}$$

$$\therefore \quad \text{Power angle, } \delta = 38.65°$$

**13. (c)**

$$\vec{E}' = \vec{V}_t - j\vec{I}_a X_q$$

$$X_q = 7\ \Omega$$

$$\text{p.u. value of } X_q = \frac{\text{ohmic value}}{\text{base value}}$$

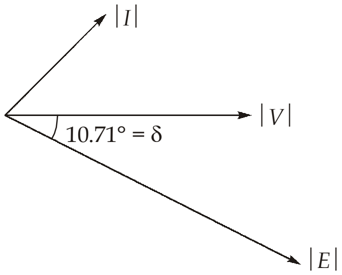
$$\text{Base ohms} = \frac{\left(\frac{440}{\sqrt{3}}\right)}{10} = 25.4\ \Omega$$

$$\text{p.u. value of } X_q = \frac{7}{25.4} = 0.2756 \text{ p.u.}$$

$$\vec{E} = 1 - ((j0.2756) \times 1\angle\cos^{-1}(0.8))$$

$$= 1.18\angle -10.71° \text{ p.u.}$$

$$\therefore \quad \text{Torque angle, } \delta = 10.71°$$




**Alternative method:**

$$\text{Torque angle, } \delta = \tan^{-1}\left[\frac{IX_q\cos\theta}{V + IX_q\sin\theta}\right] = \tan^{-1}\left[\frac{10\times 7\times\cos(36.87°)}{254 + (10\times 7\sin(36.87°))}\right]$$

$$\delta = 10.71°$$

**14. (b)**

$$\text{Power (P)} = \frac{VE_f}{X_s}\sin\delta$$

$$0.75 = \frac{1\times 1.25}{0.7}\sin\delta$$

$$\delta = 24.83°$$

Current is given by,

$$\vec{I} = \frac{\vec{E}_f - \vec{V}}{jX} = \frac{1.25\angle 24.83° - 1\angle 0°}{j0.7}$$

$$I = 0.77\angle -14.36°$$

$$\text{Phase angle, } \phi = 14.36°$$

$$\text{Power factor} = \cos\phi = 0.9688 \text{ (lagging)}$$

**15. (a)**

$$\text{Excitation emf, } (\vec{E}_f) = \vec{V} + \vec{I}_a Z_s$$

Armature current,
$$I_a = \frac{20\times 10^3}{\sqrt{3}\times 400} = 28.87 \text{ A}$$

$$\vec{E}_f = \frac{400}{\sqrt{3}} + (28.87\angle 36.87°)\times(0.5 + j3)$$

$$\vec{E}_f = 205.85\angle 22.25° \text{ V}$$

$$\text{Voltage regulation} = \frac{|E_f| - |V|}{|V|}\times 100$$

$$= \frac{205.85 - \left(\frac{400}{\sqrt{3}}\right)}{\left(\frac{400}{\sqrt{3}}\right)}\times 100 = -10.86\%$$

**16. (d)**

$$\text{Base impedance } (Z_B) = \frac{V_B^2}{S_B} = \frac{400^2}{50000} = 3.2\ \Omega$$

Synchrnous reactance,

$$(X_s)_{pu} = \frac{7.5}{3.2} = 2.34375 \text{ p.u.}$$

When motor is operating at 75% load with 0.8 p.f. leading

$$\vec{E}_{f1} = \vec{V} - j\vec{I}_{a1}X$$
$$= 1\angle 0° - j(0.75\angle\cos^{-1}(0.8)) \times (2.34375)$$
$$= 2.49\angle{-34.4°} \text{ p.u.}$$

Now excitation emf is decreased by 5%

$$E_f \sin\delta = \text{constant}$$
$$E_{f1}\sin\delta_1 = E_{f2}\sin\delta_2$$
$$E_{f2} = 0.95 \times 2.49 = 2.37$$
$$\delta_2 = \sin^{-1}\left(\frac{E_{f1}}{E_{f2}} \times \sin\delta_1\right)$$
$$\delta_2 = \sin^{-1}(0.594)$$
$$\delta_2 = 36.44°$$
$$\text{Current, } \vec{I}_{a2} = \frac{\vec{V} - \vec{E}_{f2}}{jX_s} = \frac{1 - 2.37\angle - 36.44°}{j2.34375}$$
$$\vec{I}_a = 0.7144\angle 32.78°$$
$$\text{Power factor} = \cos 32.78° = 0.8407 \text{ lagging}$$

**17. (a)**

$$\text{Full load current} = \frac{25 \times 10^3}{\sqrt{3} \times 400 \times 0.8} = 45.11 \text{ A}$$
$$\text{Excitation emf } \vec{E}_f = \vec{V} - j\vec{I}_a X$$
$$= \frac{400}{\sqrt{3}} - (45.11\angle 36.87°)(j7)$$
$$= 490.5\angle{-31°} \text{ V}$$

Rotor angle slip by 0.25 mechanical degree,

$$\theta_e = \frac{P}{2}\theta_m$$
$$\Delta\delta = \frac{4}{2} \times 0.25 = 0.5°$$
$$\text{Synchronizing emf} = 2E_f \sin\frac{\Delta\delta}{2}$$
$$= 2 \times 490.5 \sin\left(\frac{0.5}{2}\right) = 4.28 \text{ V}$$

$$\text{Synchronizing current} = \frac{4.28}{7} = 0.611 \text{ A}$$

**18. (a)**

$$\text{Reluctance power, } P = V^2\left(\frac{X_d - X_q}{2X_dX_q}\right)\sin 2\delta$$

$$\text{Excitation emf, } \vec{E}_f = \vec{V} + j\vec{I}_a X_q$$

$$\text{Armature current, } I_a = \frac{4\times 10^6}{\sqrt{3}\times 6600} \approx 350 \text{ A}$$

$$\vec{E}_f = \frac{6600}{\sqrt{3}} + j(350\angle -\cos^{-1}(0.8))\times 4 = 4783.48\angle 13.54° \text{ V}$$

$$\text{Load angle } \delta = 13.54°$$

$$\text{Reluctance power, } P = (6600)^2\left[\frac{10-4}{2\times 10\times 4}\right]\sin(2\times 13.54)$$

$$P = 1.487 \text{ MW}$$

**19. (b)**

Reactive power supplied by generator is given by,

$$Q = \frac{VE\cos\delta}{X} - \frac{V^2}{X}$$

$$\text{Excitation emf, } \vec{E} = \vec{V} + j\vec{I}_a X$$

$$\vec{I}_a = 1\angle\cos^{-1}(0.95)$$

$$\vec{E} = 1.0\angle 0° + j1(\angle\cos^{-1}(0.95)) \times (1.5 + 0.5)$$

$$\vec{E} = 1.937\angle 78.82° \text{ p.u.}$$

$$\text{Reactive power, } Q = \frac{(1)(1.937)}{2}\cos 78.82° - \frac{1}{2}$$

$$Q = -0.312 \text{ p.u.}$$

Reactive power absorbed by generator is 0.312 p.u.

**20. (b)**

$$\text{Synchronous impedance, } Z_s = (0.5 + j5)\Omega = 5.025\angle 84.29° \ \Omega$$

$$I_a = \frac{V\angle 0° - E\angle -\delta}{Z_s\angle\theta}$$

$$S = VI_0^* = V\angle 0\left[\frac{V\angle 0 - E\angle -\delta}{Z_s\angle\theta}\right]^*$$

$$S = \frac{V^2}{Z_s}\angle\theta - \frac{EV}{Z_s}\angle\theta + \delta$$

So from above equation,

$$P = \frac{V^2}{Z_s}\cos\theta - \frac{EV}{Z_s}\cos(\theta + \delta)$$

$$900 \times 10^3 = \frac{2000^2}{5.025}(\cos 84.29°) - \frac{2000 \times 3000}{5.025}\cos(84.29° + \delta)$$

$$84.29° + \delta = 133.426°$$

$$\text{Power angle, } \delta = 49.13°$$

**21. (c)**

Take, $V_t = 1\angle 0°$ p.u.

So, $I_a = 1\angle{-\cos^{-1}(0.8)}$ p.u.

Alternator excitation emf, $\vec{E}_f = \vec{V}_t + \vec{I}_a \vec{Z}_s$

$$\vec{E}_f = 1\angle 0° + [1\angle{-\cos^{-1}}(0.8)] \times 1.25\angle 90°$$

$$\vec{E}_f = 1 + 1.25\angle 53.13°$$

$$|\vec{E}_f| = \sqrt{(1 + 1.25\cos 53.13°)^2 + (1.25\sin 53.13°)^2}$$

$$= 2.01 \text{ p.u.}$$

When motor just fall out of step,

$$\delta \approx 90$$

Now for same excitation,

$$2.01\angle 90° = 1\angle 0° + I_a \times 1.25\angle 90°$$

$$\vec{I}_a = \frac{j2.01 - 1}{j1.25} = 1.608 + j0.8$$

$$\vec{I}_a = 1.8\angle 26.45° \text{ p.u.}$$

$$\text{Power factor} = \cos(26.45°) = 0.895 \text{ leading}$$

**22. (a)**

$$S_{load} = 1200\angle{-\cos^{-1}}(0.8) = 960 - j720$$

$$S_A = 750\angle{-\cos^{-1}}(0.9) = 675 - j326.9$$

Now, $S_A + S_B = S_{load}$

∴ $S_B = S_{load} - S_A$

$$= 960 - j720 - 675 + j326.9$$

$$= 285 - j393.1$$

$$S_B = 485.54\angle{-54.05°}$$

$$\cos\phi_B = \cos(-54.05) = 0.587 \text{ (lagging)}$$

**23. (b)**

For leading power factor, $(E_f)^2 = (V\cos\phi - I_a R_a)^2 + (V\sin\phi + I_a X_s)^2$

$$= \left(\frac{400}{\sqrt{3}} \times 0.8 - 52.5 \times 0.25\right)^2 + \left(\frac{400}{\sqrt{3}} \times 0.6 + 52.5 \times 3.2\right)^2$$

$$= (171.6)^2 + (306.57)^2$$

$$E_f = 351.3 \text{ V}$$

$$E_f \text{ (line to line)} = 351.3 \times \sqrt{3} = 608.5 \text{ Volts}$$

**24. (d)**

Total real power, $P = S_P\left(f_{nl} - f_{sys}\right)$

$$f_{sys} = f_{nl} - \frac{P}{S_P} = 61 - \frac{1800\text{ kW}}{1\text{ MW/Hz}}$$

Operating system frequency,

$$f_{sys} = 59.2\text{ Hz}$$

**25. (b)**

$$E_f^2 = (V_t\cos\theta + I_a r_a)^2 + (V_t\sin\theta \pm I_a X_a)^2$$

$$= (1600 + 80)^2 + (1200 - 494)^2$$

$$E_f = 1822.31\text{ V}$$

$$\%\,R = \frac{1822.31 - 2000}{2000}\times 1000 = -8.9\%$$

**26. (a)**

Let,synchronous speed of motor = $N_{sm}$

Also, $N_{sm} = \frac{120\times f_m}{P_m}$

$\therefore$ $N_{sm} = \frac{120\times 60}{P_m}$

Synchronous speed of alternator,

$$N_{sg} = \frac{120\times f_g}{P_g} = \frac{120\times 25}{20} = 150\text{ rpm}$$

Since alternator and motor are directly coupled

$$N_{sg} = N_{sm}$$

(or) $150 = \frac{120\times 60}{P_m}$

$\Rightarrow$ $P_m = 48$

**27. (b)**

Given, $V = \frac{11\times 10^3}{\sqrt{3}} = 6350.853\text{ V}$

$$R = 1.2\ \Omega,$$

$$jX = j25\ \Omega$$

$$|I| = \frac{1.4375\times 10^6}{3\times 6350.853} = 75.45\text{ A}$$

$$I = 75.45\angle -36.87^\circ$$

$$E = 6350.853 + (1.2 + j25)\,(75.45\angle -36.87^\circ)$$

$$= 7693.807\angle 10.898^\circ\text{ V}$$

$$\text{Voltage regulation} = \frac{|E| - |V|}{|V|}\times 100 = \frac{7693.807 - 6350.853}{6350.853}\times 100 = 21.14\%$$

**28. (b)**

The generator described above is $Y$-connected, so the direct current in the resistance test flows through two windings

$$2R_A = \frac{V_{DC}}{I_{DC}}$$

$$R_A = \frac{10}{2 \times 25} = 0.2\ \Omega$$

Internal generated voltage,

$$E_A = V_{\text{ph O.C.}} = \frac{V_T}{\sqrt{3}}$$

$$E_A = \frac{540}{\sqrt{3}} = 311.77\ \text{V}$$

The short circuit is equal to line current, since generator is Y-connected,

$$I_{A,\,SC} = I_L = 300\ \text{A}$$

$$\frac{E_A}{I_A} = \sqrt{R^2 + X_S^2}$$

$$X_S = \sqrt{\left(\frac{311.77}{300}\right)^2 - (0.2)^2}$$

$$X_S = 1.02\ \Omega$$

**29. (a)**

$$P_{\text{input}} = V\angle 0 I_a^*$$

$$= R_e\left[V\angle 0^\circ\left(\frac{V\angle 0^\circ - E_f\angle -\delta}{Z_s\angle\theta_s}\right)^*\right]$$

$$= \frac{V^2}{Z_s}\cos\theta_s - \frac{VE_f}{Z_s}\cos(\theta_s + \delta)$$

$\because$ $$Z_s = 5.87\angle 81.18\ \Omega$$

$\therefore$ $$760 \times 10^3 = \frac{(3.3)^2 \times 10^6}{5.87}\cos 81.18 - \frac{(3.3) \times 4.3 \times 10^6}{5.87}\cos(81.18 + \delta)$$

On solving, $$\delta = 20.165^\circ$$

Now, $$I_a = \frac{\frac{3.3 \times 10^3}{\sqrt{3}}\angle 0^\circ - \frac{4.3 \times 10^3}{\sqrt{3}}\angle -20.165}{(0.9 + j5.8)}$$

$$I_a = 162.81\angle 35.29^\circ\ \text{A}$$

$\therefore$ Power factor $= \cos(35.29) = 0.8162$ leading

**30.** **(a)**

For double layer winding,

$$\text{No. of slots} = \text{No. of coils}$$

$$\text{Total number of turns} = 60 \times 10 = 600$$

$$\text{Turns per phase} = \frac{600}{3} = 200$$

$$\text{Pitch factor } (K_c) = \cos 18° = 0.951$$

$$\text{Distribution factor } (K_d) = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}$$

$$m = \frac{60}{4} \times \frac{1}{3} = 5$$

$$\beta = \frac{180}{60/4} = 12°$$

$$K_d = \frac{\sin\frac{5 \times 12}{2}}{5\sin\frac{12}{2}} = 0.9567$$

$$\text{Induced emf, } E_{\text{ph}} = \sqrt{2}\pi K_w \phi f T_{ph}$$

$$E_{\text{ph}} = \sqrt{2}\pi \times 0.9567 \times 0.95 \times 0.015 \times 50 \times 200$$

$$E_{\text{ph}} = 606.33 \text{ V}$$

$$E_{\text{L-L}} = 1.05 \text{ kV}$$

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