CLASS TEST

S.No. : 01 SK_EE_ABCD_190822

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SYNCHRONOUS MACHINES

ELECTRICAL ENGINEERING

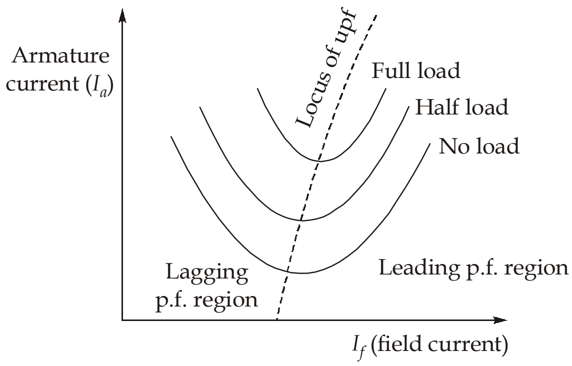
Date of Test :19/08/2022

ANSWER KEY

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

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)

$$\text{Reactive power output, } Q_{out} = \frac{EV}{X_d}\cos\delta - \frac{V^2}{X_d}$$

The maximum reactive power occurs at $\delta = 0°$.

4. (c)

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

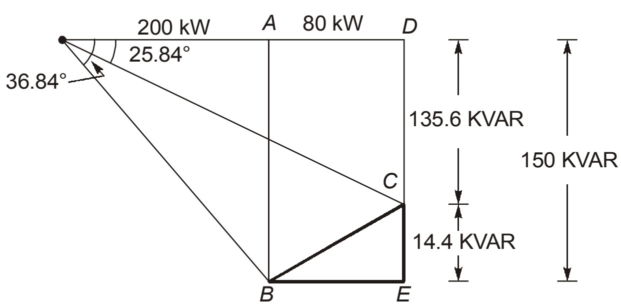
$$E \propto f\phi$$
$$X_s \propto f$$

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

Hence short circuit current is only a function of excitation.

5. (a)

$$\theta_1 = \cos^{-1}(0.8) = 36.87°$$
$$\theta_2 = \cos^{-1}(0.9) = 25.84°$$



Leading kVAR taken by motor $= CE$

$$CE = AB - DC$$
$$= 200\tan(36.87°) - 280\tan(25.84°)$$
$$CE = 14.4 \text{ kVAR}$$

6. (a)

On a per-phase basis :

$$\vec{E}_{a1} = 120\angle 10° \text{ V}$$

$$\vec{E}_{a2} = 120\angle 20° \text{ V}$$

$$\vec{Z}_{s1} = j5\ \Omega \quad ; \quad \vec{Z}_{s2} = j8\ \Omega$$

$$\vec{Z}_L = 4 + j3 = 5\angle 36.87°\ \Omega$$

$$\vec{V}_a = \vec{I}_L \vec{Z}_L$$

$$= \frac{\vec{E}_{a1}\vec{Z}_{s2} + \vec{E}_{a2}\vec{Z}_{s1}}{\vec{Z}_L(\vec{Z}_{s1} + \vec{Z}_{s2}) + \vec{Z}_{s1}\vec{Z}_{s2}}\vec{Z}_L$$

$$\Rightarrow \quad \vec{V}_a = \frac{(120\angle 10°)(j8) + (120\angle 20°)(j5)}{(4+j3)(j5+j8)+(j5)(j8)} \times (4+j3)$$

$$= 82.17\angle -5.93° \text{V}$$

7. (b)

Since there are as many coils as there are slots in the armature for a double layer winding, the number of coils in a phase group is

$$n = \frac{144}{16 \times 3} = 3$$

The number of slots per pole:

$$S_p = \frac{144}{16} = 9$$

Thus, the slot span: $\gamma = \dfrac{180°}{9} = 20°$ electrical. Since there are 9 slots per pole and 3 coils in a phase group, each coil must span 7 slots. Hence, the coil pitch is 20 × 7 = 140° electrical

We can now compute the pitch factor, the distribution factor and the winding factor as

Pitch factor, $$K_p = \sin\left(\frac{140°}{2}\right) = 0.94$$

Distribution factor, $$K_d = \frac{\sin\left(3 \times \dfrac{20°}{2}\right)}{3 \times \sin\left(\dfrac{20°}{2}\right)} = 0.96$$

$$K_w = 0.94 \times 0.96 = 0.902$$

The effective turns per phase are

$$N_e = \frac{16 \times 3 \times 10 \times 0.902}{2} = 216.48$$

The frequency of generated voltage is

$$f = \frac{375 \times 16}{120} = 50 \text{ Hz}$$

RMS value of the generated voltage per phase is

$$E_a = 4.44 \times 50 \times 216.48 \times 0.025$$

$$= 1201.46 \text{ V}$$

RMS value of line voltage is

$$E_L = \sqrt{3} \times 1201.46 = 2081 \text{ V}$$

8. (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,

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

$$I = 0.77\angle{-14.36°}$$

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

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

9. (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,

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

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

$$= 1.28\angle 38.65° \text{ p.u.}$$

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

10. (b)

In a synchronous machine if the main field flux is ahead of armature field flux axis in the direction of rotation, the machine is acting like a synchronous generator.

11. (a)

Given;

$$E_f = 1.5 \text{ p.u.} \qquad X_s = 1.3 \text{ p.u.}$$

$$\therefore \quad P = 0.6 \text{ p.u,} \qquad V_t = 1.0 \text{ p.u.}$$

$$\because \text{ Synchronous power; } P = \frac{E_t V_t}{X_s}\sin\delta$$

$$0.60 = \frac{1.5 \times 1}{1.3}\sin\delta$$

$$\sin\delta = 0.52;$$

$$\text{or,} \quad \delta = 31.33°$$

Considering the cylindrical rotor machine;

the reactive power is;

$$Q = \frac{E_t V_t}{X_s}\cos\delta - \frac{V_t^2}{X_s}$$

$$\frac{dQ}{d\delta} = \frac{-E_f \cdot V_t \sin\delta}{X_s} \quad ...(i)$$

and
$$\frac{dP}{d\delta} = \frac{E_f \cdot V_t}{X_s}\cos\delta \quad ...(ii)$$

From equation (i) and (ii),

$$\frac{dQ}{dP} = -\tan\delta = -\tan 31.33°$$

$$= -0.6087$$

As given, with 2% increase in prime mover input; the active power is increased by 2%.

Then, $dQ = 2\% \times -0.6087$

$dQ = -1.2174\%$

12. **(a)**

Load 12 kW, 0.8 pf leading

Armature current, $I_a = \frac{12 \times 10^3}{\sqrt{3} \times 400 \times 0.8} = 21.65$ A,

Phase angle, $\phi = 36.9°$ leading

Terminal voltage, $V_t = \frac{400}{\sqrt{3}} = 231$ V,

Synchronous reactance,

$X_s = 2.5\ \Omega$

Induced emf, $E_f = 231\angle 0° - j \times 21.65\angle 36.9° \times 2.5$

$= 267\angle -9.3°$ V

$E_f = 267$ V,

$\delta = 9.3°$ elect

Mechanical disturbance,

$\Delta\delta = 1$ deg mech $= 1 \times 4 = 4°$ elect

$$E_s = 2E_f \sin\left(\frac{\Delta\delta}{2}\right) = 2 \times 267 \sin 2°$$

$$= 18.6 \text{ V (phase)}$$

$$I_S = \frac{18.6}{2.5} = 7.45 \text{ A}$$

$$P_S = 3V_t I_s \cos\left(\delta + \frac{\Delta\delta}{2}\right)$$

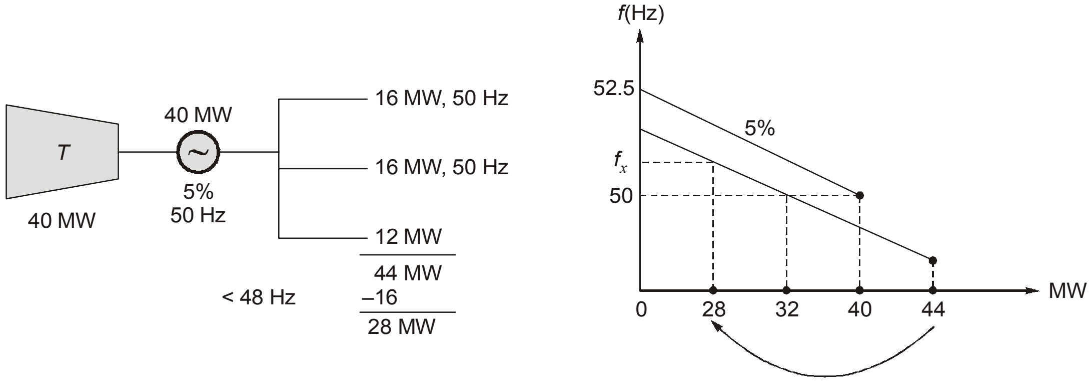
$$= 3 \times 231 \times 7.45 \cos(9.3° + 2°)$$

$$= 5.063 \text{ kW}$$

$$n_s' = 25\pi \text{ rad mech/s}$$

$$T_s = \frac{5.063}{25\pi} = 64.46 \text{ N-m}$$

13. (d)



From drop characteristics,

$$\frac{\Delta f_1}{\Delta P_1} = \frac{\Delta f_2}{\Delta P_2}$$

$$\frac{2.5}{40} = \frac{\Delta f_2}{4}$$

$$\Delta f_2 = \frac{2.5 \times 4}{40} = 0.25$$

$\therefore$ $$f_x = 50 + 0.25 = 50.25 \text{ Hz}$$

14. (c)

Power equation for salient pole alternator is,

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

Putting values in power equations,

$$P = \frac{1.12 \times 1.0}{0.5}\sin\delta + \frac{(1.0)^2}{2}\left(\frac{1}{0.25} - \frac{1}{0.5}\right)\sin 2\delta$$

$$= 1.12 \times 2 \sin\delta + 0.5\left(\frac{1}{0.5}\right)\sin 2\delta$$

$$P = 2.24 \sin\delta + \sin 2\delta$$

For, P_{max} $$\frac{dP}{d\delta} = 0;$$

$$\frac{dP}{d\delta} = 2.24 \cos\delta + 2\cos 2\delta = 0$$

or, $2.24 \cos\delta + 2(2\cos^2\delta - 1) = 0$

or, $2.24 \cos\delta + 4\cos^2\delta - 2 = 0$

or, $2\cos^2\delta + 1.12\cos\delta - 1 = 0$

Solving we get;

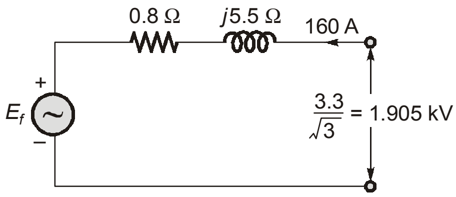
$$\cos\delta = 0.48; -1.04 \text{ (invalid)}$$

or, $\cos\delta = 0.48$

or, $\delta = \cos^{-1}(0.48) = 61.32°$

15. **(a)**

Consider the following circuit;



Full load current $= 160\angle{-36.86°}$ A

Synchronous impedance; $Z_s = (0.8 + j\,5.5)\ \Omega$

$= 5.56\angle 81.724°\ \Omega$

From circuit diagram we can write;

$$\vec{E}_f = 1.905 \times 10^3\angle 0° - 5.56\angle 81.724° \times 160\angle{-36.86°}$$

$$E_f = 1.42\angle{-26.22°}\text{ kV}$$

Now $P_{\text{mech (dev)}} = 3 \times 1.42 \times 160 \cos(-36.86° + 26.22°)$

$= 669.88$ kW

shaft output $= 669.88 - 30 = 639.88$ kW

Power input $= \sqrt{3} \times 3.3 \times 160 \times 0.8$

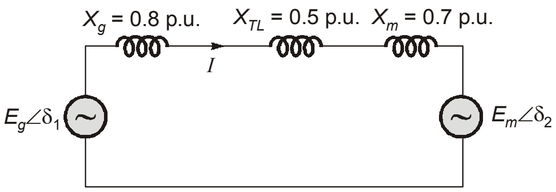
$= 731.62$ kW

$$\eta_{\text{full load}} = \frac{\text{Output}}{\text{Input}} \times 100 = \frac{639.88}{731.62} \times 100$$

$= 87.46\%$

16. **(b)**

Consider the following circuit diagram:



from the +ve sequence circuit, we can write

$$X_{eq} = X_g + X_{TL} + X_m$$

$= 0.8 + 0.5 + 0.7$

$= 2.0$ p.u.

As $E_g = 1.5$ p.u.

and $E_m = 1.1$ p.u.

Power transferred from generator to motor,

$$P = \frac{E_g \times E_m}{X_{eq}} \sin(\delta')$$

Where, $\delta' = \delta_1 - \delta_2$

then; $$0.6 = \frac{1.5 \times 1.1}{2.0} \sin(\delta_1 - \delta_2)$$

$$\sin(\delta_1 - \delta_2) = \frac{1.2}{1.5 \times 1.1} = 0.7272$$

$$(\delta_1 - \delta_2) = 46.66° \text{ (electrical)}$$

17. (c)

Given,

$$V_t = 6.6 \text{ kV (line)} = 3810.6 \text{ V (phase)}$$

$$\text{Rated load} = 1000 \text{ kVA}$$

$$I_{a\,(\text{rated})} = \frac{1000}{\sqrt{3} \times 6.6} = 87.48\angle -36.86° \text{ A}$$

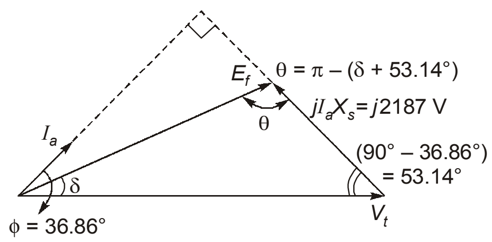
Operation at 0.8 lagging p.f. at rated terminal voltage

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

$$= 3.8106 \times 10^3\angle 0° + j\,87.48\angle -36.86° \times (25)$$

$$\vec{E}_f = 5413.12\angle 18.86° \text{ V}$$

Operation at 0.8 leading p.f. excitation remaining unchanged. Consider the phasor diagram shown below.



From diagram; we can write

$$\frac{5413.12}{\sin 53.14°} = \frac{2187}{\sin\delta}$$

Solving we get; $\sin\delta = 0.323$

$$\delta = 18.84°$$

Here, $\theta = \pi - (\delta + 53.14)$

$$= 108.02°$$

Again, we can write,

$$\frac{V_t}{\sin 108.02°} = \frac{2187.5}{0.323}$$

or, $V_t = 6438.77$ V (phase)

or, $V_{t\,(\text{line})} = 11.15$ kV

18. (b)

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,

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

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

$$84.29° + \delta = 133.426°$$

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

19. **(c)**

Take, $V_t = 1\angle 0°$ p.u.

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

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

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

$$\vec{E}_f = 1 + 1.25\angle 53.13°$$

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

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

When motor just fall out of step,

$$\delta \approx 90$$

Now for same excitation,

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

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

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

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

20. **(d)**

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

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

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

$\therefore$ $S_B = S_{load} - S_A$

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

$$= 285 - j393.1$$

$$S_B = 485.54\angle{-54.05°}$$

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

21. **(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,

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

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

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

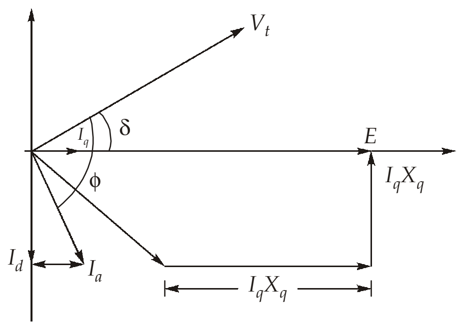
$$X_S = 1.02\ \Omega$$

22. **(c)**

With no field excitation,

$$P_{in} = \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

For maximum P_{in} $\quad \delta = 45°$



$$|I_d X_d| = |I_q X_q| = V_t \cos 45°$$

$$I_d = \frac{1}{\sqrt{2}} \times \frac{1}{1.2} = 0.589\ \text{p.u.}$$

$$I_q = \frac{1}{\sqrt{2}} \times \frac{1}{0.6} = 1.178\ \text{p.u.}$$

$$\psi = \tan^{-1}\left(\frac{I_d}{I_q}\right) = \tan^{-1}\left(\frac{0.589}{1.178}\right) = 26.56°$$

$$\text{power factor} = \cos\phi = \cos(26.56° + 45°) = 0.316\ \text{(lagging)}$$

23. **(b)**

$$P_{in} = \sqrt{3} \times VI_a$$

$$P_{in} = \sqrt{3} \times 460 \times I_a$$

$$P_{in} = P_{out} + P_{loss}$$

$$= 125 \times 746 + 3 \times I_a^2 \times 0.078$$

$$\sqrt{3} \times 460 \times I_a = 93250 + 0.234\, I_a^2$$

$$0.234\, I_a^2 - 796.74\, I_a + 93250 = 0$$

$$I_a = 121.4 \text{ A}$$

24. **(c)**

Connected load, $P_1 + P_2 = 50$ MW

No load frequency, $f_0 = 50$ Hz

drop in frequency for a drop of 50 MW

$$= 3\% \text{ of } f_0$$

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

For load of P_1 MW $= \dfrac{1.5}{50} \times P_1$

Operating frequency of generator A,

$$f_A = \left(50 - \frac{1.5}{50} P_1\right)$$

Operating frequency of generator B,

$$f_B = f_0 - \left(\frac{3.5}{100} \times 50\right)\frac{P_2}{25} = \left(50 - \frac{3.5}{50} P_2\right)$$

For parallel operation,

$$f_A = f_B$$

$$50 - \frac{1.5}{50} P_1 = 50 - \frac{3.5}{50} P_2$$

$$1.5\, P_1 = (3.5)\,(50 - P_1)$$

$$P_1 = 35 \text{ MW}$$

25. **(a)**

Synchronous speed, $N_s = \dfrac{120 \times 50}{8} = 750$ rpm

Synchronizing power, $P_{syn} = \dfrac{3V_P E_f}{X_s} \cos\delta \times \dfrac{\pi}{180} \times \dfrac{P}{2}$

$$= 3 \times \left(\frac{6000}{\sqrt{3}}\right) \times \frac{6000}{\sqrt{3}} \times \frac{1}{4} \times 1 \times \frac{\pi}{180} \times \frac{8}{2}$$

$$= 628.318 \text{ kW/mech degree}$$

Synchronizing torque, $T_{syn} = \frac{628.318\times 10^3}{2\pi\times 750}\times 60 = 8000$ Nm/mech degree

26. (b)

Reactive power, $Q = \frac{E_f V}{X_s}\cos\delta - \frac{V^2}{X_s}$

$$\frac{dQ}{d\delta} = \frac{-E_f V}{X_s}\sin\delta$$

Real power, $P = \frac{E_f V}{X_s}\sin\delta$

$$0.6 = \frac{1.5\times 1}{1.2}\sin\delta$$

$$\delta = 26.68°$$

$$\frac{dP}{d\delta} = \frac{E_f V}{X_s}\cos\delta$$

$$\frac{dQ}{dP} = -\tan\delta = -\tan 26.68°$$

Change in reactive power,

$$dQ = -(0.547)\times(1\%)$$
$$= -0.547\%$$

27. (d)

$$N_{ph} = \frac{4\times 54}{2\times 3} = 36$$

$$m = \frac{54}{2\times 3} = 9$$

$$\beta = \frac{180°}{\left(\frac{54}{2}\right)} = \frac{20°}{3}$$

$$K_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}} = \frac{\sin(30°)}{9\sin\frac{10}{3}} = 0.955$$

$$\text{coil span} = 180° - 2\times\frac{20°}{3} = 166.67°$$

$$\alpha = 2\times\frac{20°}{3} = \frac{40°}{3}$$

$$K_C = \cos\frac{\alpha}{2} = \cos\frac{20°}{3} = 0.993$$

$$E_{ph} = \frac{3300}{\sqrt{3}} = \sqrt{2}\pi f\times 0.993\times 0.955\times 36\times\phi$$

$$\phi = 0.2512 \text{ Wb}$$

28. (a)

Given, efficiency, $\eta = 0.95$

$$\text{Input} = \frac{800\text{ kW}}{0.95} = 842.10\text{ kW}$$

$$I_a = \frac{842.10}{\sqrt{3}\times 11\times 0.8} = 55.25\text{ A at 0.8 p.f. leading}$$

$$V_t = \frac{11000}{\sqrt{3}} = 6351\text{ V}$$

$$\vec{E}_f = \vec{V}_t - j\vec{I}_a X_s$$

$$= 6351 - j35 \times 55.25\angle\cos^{-1} 0.8$$

$$= 7668.90\angle -11.637$$

$$|E_f| = 7.668\text{ kV}$$

29. (b)

$$\text{Load kVA} = \frac{1280\times 1000}{0.8} = 1600\text{ kVA}$$

$$I_L = \frac{\text{kVA}}{\sqrt{3}V_L} = \frac{1600\times 1000}{\sqrt{3}\times 13500} = 68.43\text{ A}$$

$$V_{\text{ph}} = \frac{V_t}{\sqrt{3}} = \frac{13500\text{ V}}{\sqrt{3}} = 7794.23\text{ V}$$

$$E_{ph}^2 = (V_{ph}\cos\phi + I_a r_a)^2 + (V_{ph}\sin\phi - I_a X_s)^2$$

$$E_{ph}^2 = (7794.23 \times 0.8 + 68.43 \times 1.5)^2 + (7794.23 \times 0.6 - 68.43 \times 30)^2$$

$$E_{\text{ph}} = 6859.63\text{ V}$$

$$\%VR = \frac{E_{\text{ph}} - V_{\text{ph}}}{V_{\text{ph}}}\times 100 = \frac{6859.63 - 7794.23}{7794.23}\times 100 = -11.99\%$$

30. (d)

Given,
$$V_t = 1.0 \text{ p.u.}$$
$$I_a = 1.0 \text{ p.u. at 0.8 p.f. lagging}$$
$$\phi = \cos^{-1} 0.8 = 36.86°$$
$$X_d = 0.8 \text{ p.u.}$$
$$X_q = 0.5 \text{ p.u.}$$

As we can use the relation,

$$\tan\psi = \frac{V_t \sin\phi + I_a X_q}{V_t \cos\phi + I_a r_a} \qquad [\because \text{ Here } r_a = 0]$$

$$\tan\psi = \frac{1\times 0.6 + 1\times 0.5}{1\times 0.8 + 0}$$

or
$$\tan\psi = 1.375$$
$$\psi = 53.97°$$

$\because$ Power angle; $\delta = \psi - \phi$ [for generator]
$$= 53.97° - 36.86°$$
$$= 17.11°$$

We can write,

No load voltage; $E_f = V_t \cos\delta + I_d X_d$
$$= V_t \cos\delta + (I_a \sin\psi)X_d$$
$$= 1 \times \cos 17.11° + (1 \times \sin 53.97°) \times 0.8$$
$$= 1.602 \text{ p.u.} \approx 1.60 \text{ p.u.}$$

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