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Synchronous Machine

ELECTRICAL ENGINEERING

Date of Test : 20/10/2026

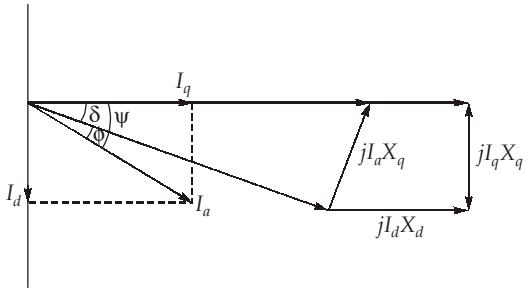
ANSWER KEY ➤

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

DETAILED EXPLANATIONS

1. (b)

Let V_p be the reference phasor



$$\therefore \quad V_p = 1\angle 0° = 1 + j0 \text{ p.u.}$$

I_a = 1 p.u. at 0.8 lagging power factor

$$\therefore \quad I_a = 1\angle -\cos^{-1} 0.8 = 1\angle -36.9° \text{ p.u.}$$

$$I_aX_d = 0.8 \text{ p.u.}$$

$$I_aX_q = 0.5 \text{ p.u.}$$

$$E'' = V_p + jI_aX_q$$
$$= 1 + j0 + j1\angle -36.9° \times 0.5$$
$$= 1 + 0.5\angle(90° - 36.9°)$$
$$= 1 + 0.5\angle 53.1°$$
$$= 1 + 0.3 + j0.4$$
$$= 1.36\angle 17.1° \text{ V}$$
$$I_d = I_a \sin(36.9° + 17.1°)$$
$$= 1 \times \sin 54° = 0.809$$
$$\therefore \quad E_f = E'' + (X_d - X_q)I_d$$
$$= 1.36 + (0.8 - 0.5) \times 0.805$$
$$= 1.60 \text{ p.u.}$$

2. (b)

$$E_f^2 = (V_t \cos\theta + I_a r_a)^2 + (V_t \sin\theta \pm I_a X_a)^2$$
$$= (1600 + 80)^2 + (1200 - 494)^2$$
$$E_f = 1822.31 \text{ V}$$
$$\% R = \frac{1822.31 - 2000}{2000} \times 1000$$
$$= -8.9\%$$

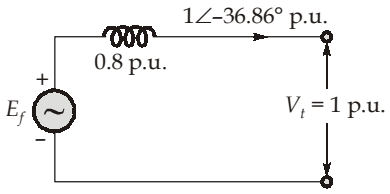
3. (c)

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. (a)

Consider the circuit diagram drawn below:



From circuit diagram we can write,

$$\vec{E}_f = 1 + j\,0.8\ (1\angle -36.86°)$$

$$\vec{E}_f = 1.61\angle 23.4°\ \text{p.u.}$$

Here, power angle, $\delta = 23.4°$

$$\text{Real power; } P_e = \frac{V_t E_f}{X_s}\sin\delta$$

$$\text{Synchronizing power, } \frac{dP_e}{d\delta} = \frac{V_t E_f}{X_s}\cos\delta = \frac{1\times 1.61}{0.8}\cos(23.4°)$$

$$\frac{dP_e}{d\delta} = 1.847\ \text{p.u./electrical radian}$$

or,
$$\frac{dP_e}{d\delta} = 1.847\times 10^3 \times \frac{\pi}{180}\ \text{kW/electrical degree}$$
$$= 32.236\ \text{kW/electrical degree}$$

or, 1 electrical degree $= \frac{P}{2}$ mechanical degree

then;
$$\frac{dP_e}{d\delta} = 32.236 \times 4\ \text{kW/mechanical degree}$$
$$\frac{dP_e}{d\delta} = 128.944\ \text{kW/mechanical degree}$$

5. (b)

Given, Load = 600 kW at 0.75 p.f. lagging

$$\text{Load kVA} = \frac{600}{0.75} = 800\ \text{kVA}$$

$$\text{Load kVAR} = \text{Load kVA} \times \sin\phi$$
$$= 800\times\sqrt{1-(0.75)^2}$$
$$= 529.15\ \text{kVAR}$$

When a synchronous motor is connected to improve the power factor it is over excited. As there is reactive power required from motor so it will operate at zero power factor leading. Which supplied 529.15 kVAR to load.

6. (a)

$$P_{\text{input}} = V\angle 0 I_a^*$$
$$= R_e\left[V\angle 0°\left(\frac{V\angle 0° - E_f\angle -\delta}{Z_s\angle\theta_s}\right)^*\right]$$

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

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

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

On solving, $\delta = 20.165°$

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

$I_a = 162.81\angle 35.29°$ A

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

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: $\gamma = \frac{180°}{9} = 20°$ 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, $K_d = \frac{\sin\left(3 \times \frac{20°}{2}\right)}{3 \times \sin\left(\frac{20°}{2}\right)} = 0.96$

$K_w = 0.94 \times 0.96 = 0.902$

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

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

$= 1201.46$ 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,

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

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

$$= 1.28\angle 38.65° \text{ p.u.}$$

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

10. (b)

$$P_{sy} = \frac{EV}{X_s}\cos\delta$$

where P_{sy} = symmetrical power coefficient

$$P_{sy} \propto \text{stability} \propto \text{excitation}$$

At 'Q' the excitation is more than at 'P'.

So it is more stable at Q.

11. (b)

Emf equation synchronous motor is given as

$$\vec{E} = \vec{V}_t - \vec{I}_a\vec{Z}_s$$

Given that, $\vec{V}_t = 1\angle 0°$ p.u., $\vec{I}_a = 1\angle 90°$ p.u., $\vec{Z}_s = 0.5\angle 90°$ p.u.

$$\vec{E} = 1\angle 0° - (1\angle 90°) \times (0.5\angle 90°)$$

$$= 1 - 0.5\angle 180°$$

$$\vec{E} = 1 + 0.5\angle 0° = 1.5 \text{ p.u.}$$

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12. (d)

The flux in this machine is given by,

$$\phi = dlB \qquad \text{[where } d \text{ is diameter and } l \text{ is length of the coil]}$$
$$\phi = (0.5)\ (0.3)\ (0.2)$$
$$= 0.03 \text{ Wb}$$

speed of the rotor is given by,

$$\omega = 3600 \times \frac{2\pi}{60} = 377 \text{ rad/sec}$$

The magnitude of peak phase voltage,

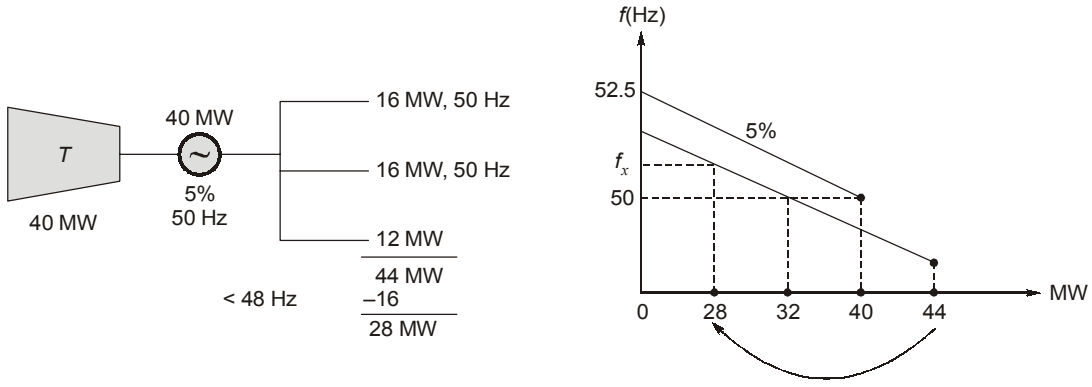
$$E_{max} = N_c\, \phi\, \omega$$
$$= 15 \times 0.03 \times 377$$
$$= 169.65 \text{ V}$$

Rms phase voltage, $E_{rms} = \frac{E_{max}}{\sqrt{2}} = \frac{169.65}{\sqrt{2}} = 120 \text{ V}$

Since generator is Y-connected,

$$V_{terminal} = \sqrt{3}(120) = 208 \text{ V}$$

13. (d)



From drop characteristics,

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

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

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

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

14. (b)

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

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

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

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

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

Full load current, $I = \frac{3\times10^6}{\sqrt{3}\times3.3\times1000} = 524.86$ 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, $P_{syn} = \frac{3E^2}{X_s}\Delta\delta$

$P_{syn} = \frac{3\times1905.256^2}{0.9075}\times\frac{\pi}{60} = 628.3186$ kW

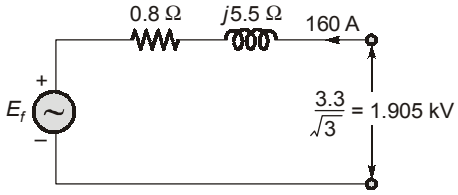
Synchronizing torque, $T_{syn} = \frac{P_{syn}\times60}{2\pi N}$

$T_{syn} = \frac{628.3186\times60}{2\pi\times1000}$ Nm

$T_{syn} = 6$ Nm

15. (a)

Consider the following circuit;



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

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

= $5.56\angle81.724°\ \Omega$

From circuit diagram we can write;

$\vec{E}_f = 1.905\times10^3\angle0° - 5.56\angle81.724°\times160\angle-36.86°$

$E_f = 1.42\angle-26.22°$ kV

Now $P_{mech\ (dev)} = 3\times1.42\times160\cos(-36.86° + 26.22°)$

$= 669.88$ kW

shaft output = $669.88 - 30 = 639.88$ kW

Power input = $\sqrt{3}\times3.3\times160\times0.8$

= 731.62 kW

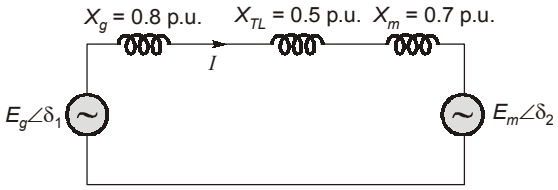
$\eta_{full\ load} = \frac{\text{Output}}{\text{Input}}\times100 = \frac{639.88}{731.62}\times100$

= 87.46%

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16. (b)

Consider the following circuit diagram:



from the +ve sequence circuit, we can write

$$X_{eq} = X_g + X_{TL} + X_m$$
$$= 0.8 + 0.5 + 0.7$$
$$= 2.0 \text{ p.u.}$$

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. (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,

$$\theta_e = \frac{P}{2}\theta_m$$

$$\Delta\delta = \frac{4}{2} \times 0.25 = 0.5°$$

$$\text{Synchronizing emf} = 2E_f \sin\frac{\Delta\delta}{2}$$

$$= 2 \times 490.5 \sin\left(\frac{0.5}{2}\right) = 4.28 \text{ V}$$

18. (b)

Synchronous impedance, $Z_s = (0.5 + j5)\Omega = 5.025\angle 84.29^\circ\ \Omega$

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

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

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

So from above equation,

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

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

$$84.29^\circ + \delta = 133.426^\circ$$

$$\text{Power angle, } \delta = 49.13^\circ$$

19. (c)

Take, $V_t = 1\angle 0^\circ$ p.u.

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

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

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

$$\vec{E}_f = 1 + 1.25\angle 53.13^\circ$$

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

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

When motor just fall out of step,

$$\delta \approx 90$$

Now for same excitation,

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

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

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

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

20. (d)

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

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

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

$\therefore$ $S_B = S_{load} - S_A = 960 - j720 - 675 + j326.9$

$$= 285 - j393.1$$

$$S_B = 485.54\angle -54.05^\circ$$

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

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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,

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

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

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

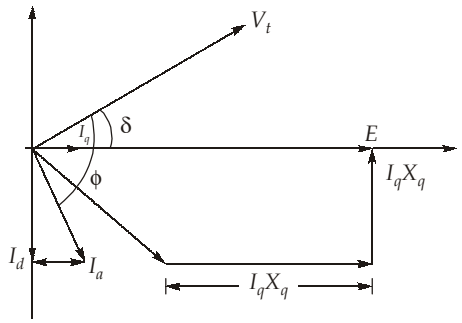
$$X_S = 1.02\ \Omega$$

22. (c)

With no field excitation,

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

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



$$|I_dX_d| = |I_qX_q| = V_t \cos 45°$$

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

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

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

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

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

$= 3\%$ of $f_0 = 0.03 \times 50 = 1.5$ Hz

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

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

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

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

$= 628.318$ kW/mech degree

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

26. (c)

The undesirable phenomenon of hunting, can be guarded against in three ways:

- by using a flywheel
- by designing the synchronous machine with suitable synchronizing power coefficient.
- by the employment of damper winding.

27. (d)

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

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

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

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

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

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

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

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

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

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)

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

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

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

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

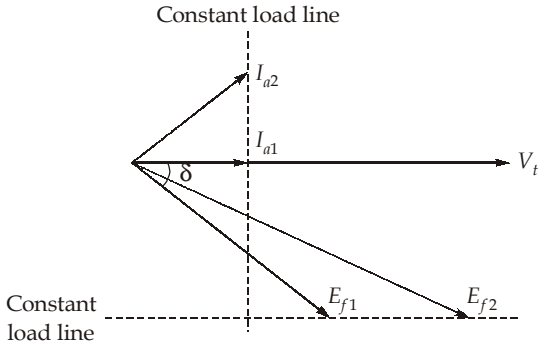
$$E_{ph}^2 = (7794.23 \times 0.8 + 68.43 \times 1.5)^2 + (7794.23 \times 0.6 - 68.43 \times 30)^2$$

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

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

30. (d)

The power factor will decrease if excitation will be increased.



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