DETAILED SOLUTIONS

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ESE 2025 : Prelims Exam
CLASSROOM TEST SERIES

ELECTRICAL ENGINEERING

Test 8

Section A : Power Systems [All Topics]

Section B : Electrical Machines-1 [Part Syllabus]

Section C : Control Systems-2 [Part Syllabus] + Engineering Mathematics-2 [Part Syllabus]

ANSWER KEY

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

DETAILED EXPLANATIONS
Section A : Power Systems

1. (d)

Area under load curve = Energy produced in total hours

$= (30 \times 4 + 45 \times 6 + 60 \times 4 + 15 \times 6 + 0 \times 4)$ kWhr

$= 720$ kWhr

Rectangular area corresponding to P_{max} in 24 hours

$= 60 \times 24 = 1440$ kWhr

Plant load factor, $$P_{Lf} = \frac{\text{Area under load curve}}{\text{Rect. Ar. corresponding to } P_{max}} = \frac{720}{1440} = 0.5$$

Plant capacity factor, $$P_{Cf} = \frac{\text{Area under load curve}}{\text{Rect. Ar. corresponding to } P_C}$$

$$\Rightarrow \quad P_{Cf} = \frac{720}{80 \times 24} = 0.375$$

∴ Reserve capacity, $R_C = P_C - P_{max}$

$$= P_{max}\left[\frac{P_{Lf} - P_{Cf}}{P_{Cf}}\right] = 60\left[\frac{0.5 - 0.375}{0.375}\right] = 20 \text{ kW}$$

2. (b)

Diameter of the conductor,

$d = 3$ cm

∴ Radius of the conductor,

$$r = \frac{d}{2} = \frac{3}{2} = 1.5 \text{ cm}$$

Spacing between the conductor,

$D = 1.1682$ m $= 116.82$ cm

The total inductance of the circuit is

$$L = \frac{\mu_0}{\pi}\ln\left[\frac{D}{0.7788r}\right] = \frac{4\pi \times 10^{-7}}{\pi}\ln\left[\frac{116.82}{0.7788 \times 1.5}\right]\text{H/m}$$

$$= 4 \times 10^{-7}\ln\left[\frac{116.82}{1.1682}\right] = 4 \times 10^{-7}\ln(100) \text{ H/m}$$

$L = 4 \times 10^{-7} \times 2\ln(10)$ H/m

$= 8 \times 10^{-7} \times 2.30$ H/m

$= 18.4 \times 10^{-7}$ H/m

∴ Inductive reactance, $X = 2\pi f L\, l$

$= 2\pi \times 50 \times 18.4 \times 10^{-7} \times (50 \times 1000)$

$= 28.903\ \Omega$

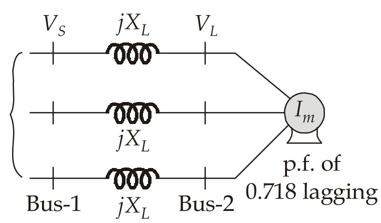
3. (c)

$$\%\eta = 80\% = 0.8$$

Rated output of motor, $P_0 = 16 \text{ hp} = 16 \times 746$

Rated input power, $P_i = \frac{16 \times 746}{0.8} = 14920 \text{ W}$

P.f. of the motor, $\cos\phi = \frac{P_i}{\sqrt{3} \times V_L I_L} = \frac{14920}{\sqrt{3} \times 400 \times 30} = 0.718$ lagging



Addition of reactance per phase will always decrease the power factor i.e. $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X^2}}$

as $X \uparrow Z \uparrow \cos\phi \downarrow$

$\therefore$ For some value of X_L p.f. must be less than 0.718 lagging.

Thus, available option is (c) 0.443 lagging

4. (d)

$$K = \frac{C_m}{C_s} = \frac{\frac{1}{20}C_s}{C_s} = \frac{1}{20} = 0.05$$

No. of insulator disc, $n = 3$

Line voltage, $V_L = 20 \text{ kV}$

Phase voltage, $V_{ph} = \frac{20}{\sqrt{3}} \text{kV}$

%efficiency, $\%\eta = \frac{V_{ph}}{3V_3} \times 100 = \frac{(K^2 + 4K + 3)}{3(K^2 + 3K + 1)} \times 100$

$$= \frac{(0.05^2 + 4 \times 0.05 + 3)}{3(0.05^2 + 3 \times 0.05 + 1)} \times 100 = 92.62\%$$

and $V_3 = (K^2 + 3K + 1)V_1$

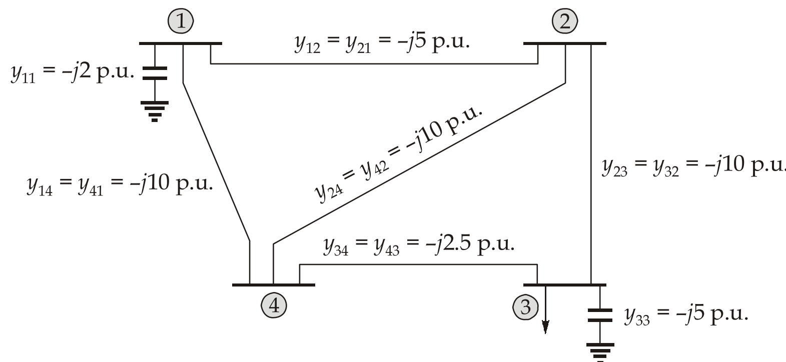
$$= (K^2 + 3K + 1) \times \frac{V_{ph}}{(K^2 + 4K + 3)}$$

$$= \frac{(0.05^2 + 3 \times 0.05 + 1)}{(0.05^2 + 4 \times 0.05 + 3)} \times \frac{20}{\sqrt{3}} = 4.155 \text{ kV}$$

Alternate method:

Due to voltage distribution none of the disc can have voltage more than the operating voltage of 20 kV (L-L) hence with 92.62% efficiency, option (a) is eliminated and correct option is (d).

5. **(c)**



$$Y_{11} = y_{11} + y_{12} + y_{14} = -j2 - j5 - j10 = -j17 \text{ p.u.}$$
$$Y_{22} = y_{21} + y_{24} + y_{23} = -j5 - j10 - j10 = -j25 \text{ p.u.}$$
$$Y_{33} = y_{33} + y_{32} + y_{34} = -j5 - j10 - j2.5 = -j17.5 \text{ p.u.}$$
$$Y_{44} = y_{41} + y_{42} + y_{43} = -j10 - j10 - j2.5 = -j22.5 \text{ p.u.}$$
$$Y_{12} = Y_{21} = -y_{12} = j5 \text{ p.u.}$$
$$Y_{13} = Y_{31} = -y_{13} = 0$$
$$Y_{23} = Y_{32} = -y_{23} = j10 \text{ p.u.}$$
$$Y_{34} = Y_{43} = -y_{34} = j2.5 \text{ p.u.}$$
$$Y_{42} = Y_{24} = -y_{24} = j10 \text{ p.u.}$$

$\therefore$
$$Y_{bus} = \begin{bmatrix} -j17 & j5 & 0 & j10 \\ j5 & -j25 & j10 & j10 \\ 0 & j10 & -j17.5 & j2.5 \\ j10 & j10 & j2.5 & -j22.5 \end{bmatrix}$$

i.e. 14 non-zero elements.

Alternate Solution:

Bus-1 and 3 does not have common line, the elements corresponding to $Y_{13} = Y_{31}$ will be zero in Y-bus.

7. **(d)**

$$\delta_{cr} = \cos^{-1}\left[\frac{P_m(\delta_{2\max} - \delta_0) - P_{\max 2}\cos\delta_0 + P_{\max 3}\cos\delta_{2\max}}{P_{\max 3} - P_{\max 2}}\right]$$
$$= \cos^{-1}\left[\frac{1.0(\delta_{2\max} - \delta_0) - 0.4\cos\delta_0 + 1.25\cos\delta_{2\max}}{1.25 - 0.4}\right]$$
$$= \cos^{-1}\left[\frac{1.0(\delta_{2\max} - \delta_0) - 0.4\cos\delta_0 + 1.25\cos\delta_{2\max}}{0.85}\right]$$

8. (a)

$$(\text{TRV})_{max} = 1.632\, K_1 K_2 K_3 V_L$$

K_1: 1 for grounded fault; K_2: armature reaction component; K_3: sine of the p.f. angle; V_L: line voltage

$$= 1.632 \times 1 \times 0.9 \times \frac{\sqrt{3}}{2} \times 220 \times 10^3$$

$$= 279.844 \text{ kV}$$

9. (b)

Inductance of the Peterson coil is

$$L_n = \frac{1}{3\omega^2 C_g}$$

$$\Rightarrow \quad \omega = \sqrt{\frac{1}{3L_n C_g}} = \sqrt{\frac{1}{3 \times \frac{1}{27} \times 4 \times 10^{-6}}}$$

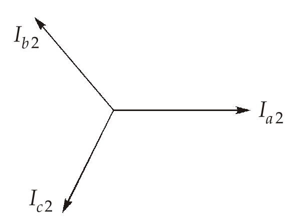
$$= 1.5 \text{ krad/sec}$$

10. (a)

$$I_f = 3I_{a1} = 3I_{a2} = 3I_{a0}$$

$$\Rightarrow \quad I_{a2} = \frac{1}{3} I_f = \frac{1}{3} \times 400\angle 0° = \frac{400}{3}\angle 0° \text{A}$$

Negative phase sequence is



$$I_{c2} = (I_{a2})\alpha^2$$

$$= \left(\frac{400}{3}\angle 0°\right)(1\angle 240°)$$

$$= \frac{400}{3}\angle 240° \text{A} = 133.33\angle 240° \text{ A}$$

11. (c)

Uranium is used as fuel in the reactor of the Nuclear power plant.

12. (d)

For optimum power generation (economic scheduling)

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2}$$

$\Rightarrow$ $$0.05P_1 + 0.4 = 0.04P_2 + 0.6$$

$\Rightarrow$ $$0.05P_1 - 0.04P_2 = 0.2 \quad \text{...(i)}$$

and $$P_1 + P_2 = 200 \quad \text{...(ii)}$$

$\therefore$ $$0.04P_1 + 0.04P_2 = 8 \quad \text{(Multiplying equation (ii) with 0.04)} \quad \text{...(iii)}$$

Solving (i) and (iii),

$$P_1 = \frac{820}{9}\text{MW}$$

and $$P_2 = \frac{980}{9}\text{MW}$$

13. (c)

As the spacing between the same phase conductors increases, the self GMD/GMR increases resulting in reduction in inductance per phase.

$\because$ $$L_{ph} \propto \left(\frac{\text{GMD}}{\text{GMR}}\right)$$

14. (a)

$$V_S = AV_R + BI_R$$
$$I_S = CV_R + DI_R$$

Under no-load condition,

$$I_R = 0$$

and $$I_C = I_S$$

$\therefore$ $$I_C = I_S = CV_R = C\left(\frac{V_{RL}}{\sqrt{3}}\right) \quad \text{...(i)}$$

Also, $$V_S = AV_R = A\left(\frac{V_{RL}}{\sqrt{3}}\right)$$

$\Rightarrow$ $$V_{RL} = \frac{\sqrt{3}}{A}V_S \quad \text{...(ii)}$$

Using equation (i) and (ii),

$$|I_c| = |I_s| = \frac{C}{\sqrt{3}} \times \frac{\sqrt{3}}{A}V_s = \left|\frac{C}{A}\right|V_s$$

$\therefore$ $$= \frac{1.15\times10^{-3}}{0.95} \times \frac{400}{\sqrt{3}} \times 10^3$$

$$|I_c| = \frac{1.15}{0.95} \times 230.94 = 279.56 \text{ A}$$

15. (c)

Increment in V_R, $\Delta V_R = V_S \times B_C \cdot X_L$

$$\Rightarrow \quad \Delta V_R = V_S B_C \cdot \frac{1}{B_L}$$

$$\Rightarrow \quad B_C = \frac{\Delta V_R \cdot B_L}{V_S} = \frac{5 \times 10^3 \times 5}{220 \times 10^3} = 0.11364\,\text{S}$$

$$\Rightarrow \quad \frac{B_C}{l} = 1.1364 \text{ m S/km}$$

16. (a)

$$V_L = 400 \text{ kV}$$
$$S = 300 \text{ MVA}$$
$$R = 18.06\ \Omega/\text{phase}$$

$$\Rightarrow \quad I_{\text{ph}} = \frac{S}{\sqrt{3}V_L} = \frac{300 \times 10^6}{\sqrt{3} \times 400 \times 10^3} = 433.013\,\text{A}$$

$$\therefore \quad \text{Total line losses} = 3I_{\text{ph}}^2 R$$
$$= 3 \times 433.013^2 \times 18.06$$
$$= 10.16 \text{ MW}$$

17. (c)

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{YZ}{2}\right) & Z \\ Y\left(1 + \frac{YZ}{4}\right) & \left(1 + \frac{YZ}{2}\right) \end{bmatrix}$$

$$B = Z$$

and

$$C = Y\left(1 + \frac{YZ}{4}\right) = \left(Y + \frac{Y^2 Z}{4}\right)$$

$$\therefore \quad \frac{B}{C} = \frac{Z}{Y + \frac{Y^2 Z}{4}} = \frac{1}{\left(\frac{Y}{Z} + \frac{Y^2}{4}\right)}$$

18. (b)

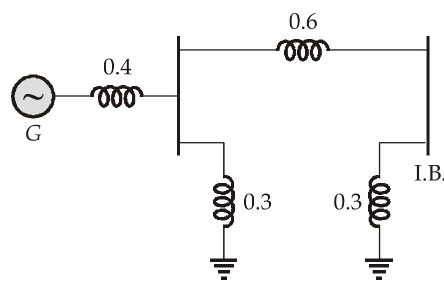
$$\because \quad Z_C = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

and

$$L \propto \ln\left(\frac{\text{GMD}}{\text{GMR}}\right)$$

- $R \uparrow es$ $\quad Z_C \uparrow es$
- $GMR \uparrow es$ $\quad L \downarrow es \quad Z_C \downarrow es$
- $G \uparrow es$ $\quad Z_C \downarrow es$
- $C \uparrow es$ $\quad Z_C \downarrow es$

19. (c)



$$X_T = 0.4 + 0.6 + \frac{0.4 \times 0.6}{0.3} = 1.8 \text{ p.u.}$$

20. (d)

$$V_{SL} = 120 \text{ kV}$$
$$V_{RL} = 110 \text{ kV}$$
$$P_R = 80 \text{ MW at } \cos\phi_R = 0.9 \text{ lag}$$

Per phase :

$$P_R = \left|\frac{V_S V_R}{B}\right| \cos(\beta - \delta) - \left|\frac{A V_R^2}{B}\right| \cos(\beta - \alpha)$$

$$Q_R = \left|\frac{V_S V_R}{B}\right| \sin(\beta - \delta) - \left|\frac{A V_R^2}{B}\right| \sin(\beta - \alpha)$$

$P_{R(\max)}$ will occur when $\delta = \beta = 70°$ and Q_R at $P_{R(\max)}$ will be

$$Q_R\big|_{P_{R\max}} = -\left|\frac{A V_R^2}{B}\right| \sin(\beta - \alpha) = -\frac{0.95 \times (110 \times 10^3)}{100} \sin(70° - 10°)$$

$$= -99.55 \text{ MVAR} \approx -100 \text{ MVAR}$$

21. (d)

$$C_S = 0.5 \ \mu\text{F}, \qquad f = 50 \text{ Hz}$$
$$I_C = 10 \text{ A}, \qquad V_L = 20 \text{ kV}$$

$\Rightarrow$ $$V_{ph} = \frac{20}{\sqrt{3}} \text{kV} = 11.55 \text{ kV}$$

Charging current, $$I_C = \frac{V_{ph}}{X_C} = 2\pi C_{ph} V_{ph}$$

$$10 = 2\pi \times 50 \times C_{ph} (11.55 \times 10^3)$$

$\Rightarrow \quad C_{ph} = 2.76\ \mu F$

But $\quad C_{ph} = 3C_C + C_S = 2.76$

$\Rightarrow \quad 3 \times C_C + 0.5 = 2.76$

$\Rightarrow \quad C_C = 0.75\ \mu F$

23. (b)

For under ground cables, L is less and C is more $Z_{C\ (UG\ \text{cable})} < Z_{C\ (OH\ \text{cable})}$

$\Rightarrow \quad \text{SIL}_{(\text{UG cable})} > \text{SIL}_{(\text{OH cable})}$

Thus, the loading in case of UG cables is decided on the basis of thermal limit and thus, the most economical loading on UG cable is less than SIL.

In practical power cables the loading is less than surge impedance loading.

24. (a)

$$|I_f| = 8.4$$

$$|I_{a0}| = |I_{a1}| = |I_{a2}|$$

$$= \frac{1}{3}|I_f| = \frac{8.4}{3} = 2.8 \text{ p.u.}$$

$$\therefore \quad I_{a1}^2 + \frac{1}{4}I_{a0}^2 = (2.8)^2 + \frac{1}{4} \times (2.8)^2 = 2.8^2\left(1 + \frac{1}{4}\right)$$

$$= 2.8^2 \times \frac{5}{4} = 9.8$$

25. (a)

Total number of buses, $\quad n = 48$

Let total number of PV bus = p

then size of the Jacobian matrix

$$= (2n - p - 2) \times (2n - p - 2)$$

$\Rightarrow \quad 82 \times 82 = (2 \times 48 - p - 2) \times (2 \times 48 - p - 2)$

$\Rightarrow \quad 82 \times 82 = (94 - p) \times (94 - p)$

$\Rightarrow \quad p = 12$

26. (c)

$f_0 = 50$ Hz, $\quad G = 100$ MVA

$H = 8$ MJ/MVA, $\quad T_d = 0.4$ sec

$\Delta P_D = 60$ MW

Steady state new frequency,

$$f_1 = f_0\left[\frac{GH + \Delta P_D Td}{GH}\right]^{1/2}$$

$$= 50\left[\frac{100\times 8+60\times 0.4}{100\times 8}\right]^{1/2} = 50\sqrt{\frac{824}{800}}$$

$$f_1 = 50.74 \text{ Hz}$$

27. (b)

In nominal π-model,

$$\Rightarrow \quad \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \left(1+\frac{ZY}{2}\right) & Z \\ Y\left(1+\frac{ZY}{4}\right) & \left(1+\frac{ZY}{2}\right) \end{bmatrix}$$

So,

$$C = Y\left(1+\frac{ZY}{4}\right)$$

28. (d)

$$\eta = 0.75 = \frac{V_{ph}}{3V_3} = \frac{K^2+4K+3}{3\times(K^2+3K+1)}$$

$$\Rightarrow \quad \frac{K^2+4K+3}{K^2+3K+1} = 2.25$$

$$\Rightarrow \quad 1.25K^2 + 2.75K - 0.75 = 0$$

Solving the above equation,

$$\Rightarrow \quad K = 0.25$$

i.e.

$$\frac{C_m}{C_s} = K = 0.25$$

$$\%\frac{C_m}{C_s} = 25\%$$

29. (b)

$$4B_{12} = 4B_{21} = -0.002 \text{ MW}^{-1}$$

$$\Rightarrow \quad B_{12} = B_{21} = -0.0005 \text{ MW}^{-1}$$

$$L_2 = 1.43 = \frac{1}{1-\frac{\partial P_L}{\partial P_2}}$$

$$\Rightarrow \quad \frac{\partial P_L}{\partial P_2} = 0.3007 \quad \text{...(i)}$$

But,

$$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$\frac{\partial P_L}{\partial P_2} = 2B_{12}P_1 + 2B_{22}P_2 \quad \text{...(ii)}$$

From (i) and (ii),

$2 \times (-0.0005) \times 100 + 2 \times (0.001)P_2 = 0.3007$

$\Rightarrow \quad P_2 = 200.35 \text{ MW}$

$\therefore$ Total load, $\quad P_D = P_1 + P_2 = 100 + 200.35$

$\Rightarrow \quad P_D = 300.35 \text{ MW}$

30. (c)

All the fault currents are equal

$\therefore \quad I_{f\,3\text{-}\phi} = I_{f\,LL} = I_{f\,LG}$

$$\Rightarrow \quad \frac{E}{X_1} = \frac{\sqrt{3}E}{X_1 + X_2} = \frac{3E}{X_1 + X_2 + X_0}$$

$\Rightarrow \quad X_1 + X_2 = \sqrt{3}X_1$

$\Rightarrow \quad X_2 = (\sqrt{3} - 1)X_1$

$\Rightarrow \quad X_2 = 0.732X_1 \quad$ ...(i)

and $\quad \sqrt{3}(X_1 + X_2 + X_0) = 3(X_1 + X_2)$

$\Rightarrow \quad (3 - \sqrt{3})(X_1 + X_2) = \sqrt{3}X_0$

$\Rightarrow \quad \sqrt{3}X_0 = 1.268(X_1 + X_2)$

$X_0 = 0.732X_1 + 0.732X_2 \quad$ ...(ii)

$= 0.732X_1 + 0.732 \times 0.732X_1$

$\Rightarrow \quad X_0 = 1.268X_1 \quad$ ...(iii)

Also, $\quad X_0 = 0.732X_1 + 0.732X_2 \quad$ (from (ii))

$$= 0.732 \times \frac{1}{0.732} X_2 + 0.732X_2 \quad \text{(from (i))}$$

$= 1.732X_2$

$X_0 \approx \sqrt{3}X_2 \quad$ ...(iv)

From equation (iii), we can say that option (c) is not correct.

31. (d)

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\substack{\text{end condenser} \\ \text{network}}} = \begin{bmatrix} (1 + YZ) & Z \\ Y & 1 \end{bmatrix}$$

Phase angle difference between two nodes/buses is responsible to meet the active power demand while voltage magnitude difference is responsible for reactive power demand.

32. (a)

There is no technical limitation to the distance over which power may be transmitted due to absence of charging current and skin effect.

35. (b)

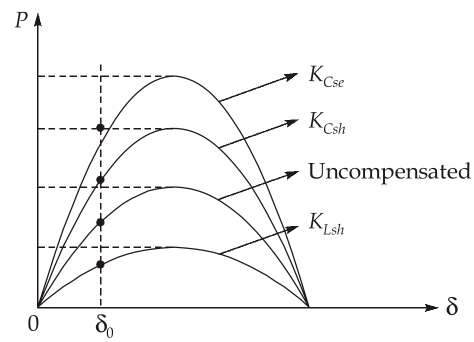
Reactive power requirement of the line inductance is supplied by the line capacitance, hence the line is operating at upf.

36. (a)

As line reactance reduces, the power transfer capability is increased.

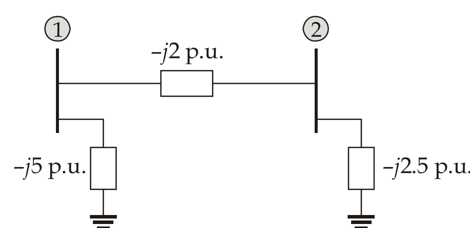
37. (a)

$$(\text{SIL})_C = (SIL)_0\sqrt{\frac{(1+K_{Csh})(1-K_{Lsh})}{(1-K_{Cse})}}$$



38. (d)

Deachivating all the sources and load in the network



Marked values are p.u. admittances

$$Y_{12} = Y_{21} = -y_{12} = j2 \text{ p.u.}$$

$$Y_{11} = y_{11} + y_{12} = -j5 - j2 = -j7 \text{ p.u.}$$

$$Y_{22} = y_{22} + y_{21} = -j2.5 - j2 = -j4.5 \text{ p.u.}$$

$$[Y_{\text{bus}}] = \begin{bmatrix} -j7 & j2 \\ j2 & j4.5 \end{bmatrix} \text{p.u.}$$

39. (a)

Kinetic energy, $\quad \text{K.E.} = \frac{1}{2}J\omega_s^2 = \text{GH}$

Where, $\quad \omega_s = \frac{120f}{P}\times\frac{2\pi}{60} = \frac{120\times 50}{6}\times\frac{2\pi}{60} = \frac{100\pi}{3}\text{rad/sec}$

Now, $$\text{K.E.} = \frac{1}{2}\times 10000\times\left(\frac{100\pi}{3}\right)^2 = 54.83 \text{ MJ}$$

Now, $$H = \frac{K.E.}{G} = \frac{54.83}{500}\text{MJ/MVA} = 0.11 \text{ sec or } 0.11 \text{ MJ/MVA}$$

40. (d)

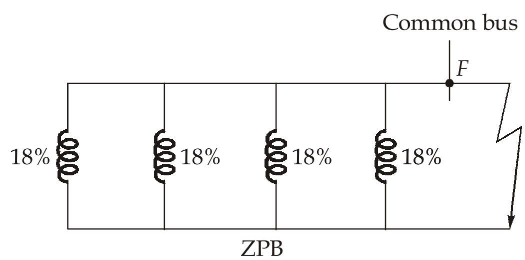
Insulation resistance, $$R_i \propto \frac{1}{l}$$

$$\Rightarrow \quad \frac{R_2}{R_1} = \frac{l_1}{l_2}$$

$$\Rightarrow \quad \frac{R_2}{550} = \frac{100}{270}$$

$$R_2 = \frac{550\times 100}{270} = 203.7 \text{ M}\Omega$$

41. (d)



$$X_{\text{Th}} = \frac{0.18}{4} = 0.045 \text{ p.u.}$$

$$\text{Short circuit MVA} = 200\times\frac{1}{X_{Th}} = 200\times\frac{1}{0.045} = 4444.44 \text{ MVA}$$

42. (a)

$$S_{\text{old}} = 100 \text{ MVA}$$
$$S_{\text{new}} = 200 \text{ MVA}$$
$$V_{\text{old}} = 11 \text{ kV}$$
$$V_{\text{new}} = 22 \text{ kV}$$
$$Z_{\text{old (p.u.)}} = j0.023 \text{ p.u.}$$

$$Z_{\text{new (p.u.)}} = Z_{\text{old(p.u.)}}\left[\frac{S_{\text{new}}}{S_{\text{old}}}\right]\left[\frac{V_{\text{old}}}{V_{\text{new}}}\right]^2$$

$$= j0.023\left[\frac{200}{100}\right]\left[\frac{11}{22}\right]^2 = j0.0115 \text{ p.u.}$$

43. (d)

For an infinite line the reflection coefficients are equal to zero.

45. (d)

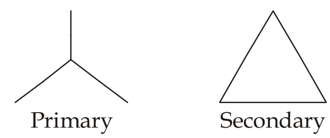
For a lossless transmission line, line resistance and conductance must be zero.

Section B : Electrical Machines-1

46. (c)

If the ratio of transformation of an auto-transformer differs far from unity, the economic advantage of auto-transformer over two-winding transformer decrease.

47. (d)



$$\text{Rated primary phase Voltage} = \frac{2200}{\sqrt{3}}\text{ V}$$

$$\text{Rated secondary phase voltage} = 220\text{ V}$$

$$\text{Transformation ratio, } a = \frac{\frac{2200}{\sqrt{3}}}{220} = \frac{10}{\sqrt{3}}$$

$$\text{primary input line voltage} = V_1 = 100\sqrt{3}V$$

$$\text{primary input phase voltage} = V_{1\text{ph}} = \frac{100\sqrt{3}}{\sqrt{3}} = 100\text{ V}$$

Secondary phase voltage (= line voltage)

$$= \frac{V_{1Ph}}{a} = \frac{100}{\frac{10}{\sqrt{3}}} = 10\sqrt{3}\text{ volts}$$

48. (a)

External resistance in the rotor circuit of a wound-rotor improves its starting power factor.

49. (b)

Output of each transformer at $\frac{3}{4}$th of the full load at 0.8 p.f. lag is

$$P_0 = \frac{3}{4}\times 200\times 10^3 \times 0.8 = 120\text{ kW}$$

$$\text{Iron losses of both the transformer} = P_1 = 6.72\text{ kW}$$

$$\text{Iron losses of each transformer,} \quad P_i = \frac{P_1}{2} = \frac{6.72}{2} = 3.36\text{ kW}$$

Copper loss of both transformer, P_2 = 9.4 kW at full load

Full load copper loss of each transformer,

$$P_{(fL)} = \frac{P_2}{2} = \frac{9.4}{2} = 4.7\text{ kW}$$

At $\frac{3}{4}$th load, copper loss will be,

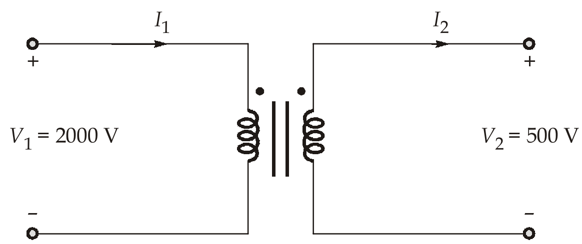
$$x^2 P_{(fL)} = \left(\frac{3}{4}\right)^2 \times 4.7 = 2.64 \text{ kW}$$

Efficiency of each transformer at $\frac{3}{4}$th of full load and at 0.8 p.f. lagging is

$$\eta = \frac{P_0}{P_0 + P_i + x^2 P_{(fL)}} \times 100 = \frac{120}{120 + 3.36 + 2.64} \times 100$$

$$= 95.24\%$$

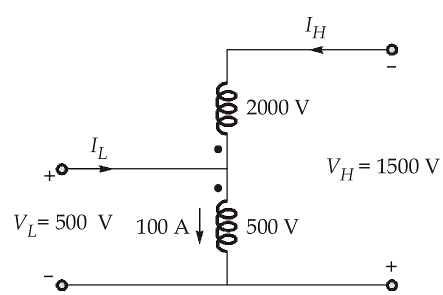
50. (d)



$$S = V_1 I_1$$
$$50 \times 10^3 = 2000 \times I_1$$
$$\Rightarrow \quad I_1 = 25 \text{ A}$$
So, $$V_1 I_1 = V_2 I_2$$
$$2000 \times 25 = 500 \times I_2$$
$$\Rightarrow \quad I_2 = 100 \text{ A}$$

The minimum kVA for additive connection is possible when $a_{auto} >> 1$

So, $$V_L = 500 \text{ V}$$



$$I_L = \frac{V_H I_H}{V_L} = \frac{1500 \times 25}{500} = 75 \text{ A}$$

To maintain winding current rating

$$I_H = I_1 = 25$$

$$\therefore \quad S_{auto} = 1500 \times 25 = 37500 \text{ VA} = 37.5 \text{ kVA}$$

51. (c)

No losses are present in an ideal transformer.

52. (a)

Power transformer is used for the transmission purpose at heavy load, so its efficiency is greater than that of distribution transformer.

53. (d)

$$N_r = 1440 \text{ rpm at full load/rated torque}$$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$\text{Slip at full load, } s_{fl} = \frac{N_s - N_r}{Ns} = \frac{1500 - 1440}{1500} = 0.04$$

$\because$ $$T \propto s$$

$\therefore$ $$\frac{T_1}{T_2} = \frac{s_1}{s_2}$$

$\Rightarrow$ $$\frac{T_{fl}}{(T_{fl}/2)} = \frac{s_{fl}}{s_2}$$

$$2 = \frac{0.04}{s_2}$$

$\Rightarrow$ $$s_2 = 0.02$$

$$\text{Speed, } N_{r2} = (1 - s_2)N_s = (1 - 0.02) \times 1500$$

$$= 1470 \text{ rpm}$$

54. (a)

Given that, $$r_2' = 4.5\ \Omega,$$

$$x_2' = 8.5\ \Omega$$

$$T_{st} = \frac{3}{\omega_s} \cdot \frac{V_{ph}^2 \cdot r_2'}{(r_2')^2 + (x_2')^2}$$

$$\omega_s = \frac{4\pi f}{P} = 50\pi = 157.1 \text{ rad/sec}$$

$$85 = \frac{3}{157.1} \cdot \frac{V_{ph}^2 \times 4.5}{(4.5)^2 + (8.5)^2}$$

$$V_{ph} = 302.48 \text{ V}$$

55. (d)

$$N_s = 600 \text{ rpm}$$
$$P_1 = 10 \text{ (alternator)}$$
$$P_2 = 4 \text{ (induction motor)}$$

Frequency of supply, $f = \frac{N_s P_1}{120} = \frac{600 \times 10}{120} = 50\text{Hz}$

Synchronous speed of I.M.,

$$N_s' = \frac{120f}{P_2} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Full load slip, $s = 3\% = 0.03$

$\therefore$ Full load speed, $N_{fL} = (1 - s)N_s' = 0.97 \times 1500 = 1455$ rpm

56. (d)

$$s = 3\% = 0.03$$
$$P_i = 60 \text{ KW}$$

per phase, stator loss = 250 W

$\Rightarrow$ Total stator loss $= P_{st} = 3 \times 250$

$= 750 \text{ W} = 0.75 \text{ KW}$

Air Gap power, $P_g = P_i - P_{st}$

$= 60 - 0.75 = 59.25$ KW

Total Rotor copper loss, $P_w = sp_g$

$= 0.03 \times 59.25 \text{ KW} = 1.7775 \text{ KW}$

Rotor copper loss per phase $= \frac{P_{cu}}{3} = \frac{1.7775}{3}$

$= 0.5925 \text{ KW} = 592.5 \text{ W}$

57. (a)

$$V_0 = V_{HV} = 1000 \text{ V}$$
$$P_0 = 300 \text{ W}$$
$$I_0 = 2\text{A}$$
$$\cos\phi_0 = \frac{P_0}{V_0 I_0} = \frac{300}{1000 \times 2} = 0.15$$

And, core loss component,

$$I_C = I_0 \cos\phi_0 = 2 \times 0.15$$
$$= 0.3 \text{ A}$$

58. (a)

All the statements are correct.

59. (b)

If α is the step angle then

$$\text{speed (in rps)} = n = \frac{\alpha f}{360°}$$

$$\Rightarrow \quad \frac{750}{60} = \frac{\alpha \times 250}{360°}$$

$$\Rightarrow \quad \alpha = 18°$$

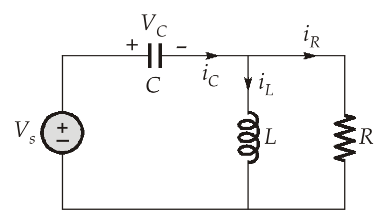
60. (d)

Stator mmf rotates at synchronous speed.

Section C : Control Systems-2 + Engineering Mathematics-2

61. (c)

The state variables are V_C and i_L



Using KCL,

$$i_C = i_L + i_R$$

$$\frac{CdV_c(t)}{dt} = i_L + \frac{V_s - V_c(t)}{R}$$

$$\dot{V_C}(t) = \frac{i_L}{C} - \frac{V_c(t)}{RC} + \frac{V_s}{RC}$$

$$V_L(t) = \frac{Ldi_L(t)}{dt} = V_s - V_c(t)$$

$$L\dot{i_L}(t) = V_s - V_c(t)$$

$$\dot{i_L}(t) = \frac{-V_c(t)}{L} + \frac{V_s}{L}$$

State model:

$$\begin{bmatrix} \dot{i_L}(t) \\ \dot{V_C}(t) \end{bmatrix} = \begin{bmatrix} 0 & -1/L \\ 1/C & -1/RC \end{bmatrix}\begin{bmatrix} i_L(t) \\ V_C(t) \end{bmatrix} + \begin{bmatrix} 1/L \\ 1/RC \end{bmatrix} V_s$$

62. (d)

- Both the given statements are correct.
- Integral controller adds a pole to the system transfer function there by reducing the stability of the system by pulling root locus towards the $j\omega$-axis.

63. (a)

$$\text{Initial slope} = 6 \text{ dB/oct} = 20 \text{ dB/dec}$$

$$\frac{a - 0}{\log_{10} 20 - \log_{10} 2} = 20$$

$$\frac{a}{\log_{10}\left(\frac{20}{2}\right)} = 20$$

$$\frac{a}{\log_{10} 10} = 20$$

$$a = 20 \text{ dB}$$

64. (d)

$$T(s) = C[(sI - A)^{-1} B] \qquad \left(\text{Where } A = \begin{bmatrix} -3 & 0 \\ 0 & -2 \end{bmatrix}, \; B = \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \; C = \begin{bmatrix} 1 & 0 \end{bmatrix} \right)$$

$$sI - A = \begin{bmatrix} s+3 & 0 \\ 0 & s+2 \end{bmatrix}$$

$$(SI - A)^{-1} = \frac{1}{(s+2)(s+3)} \begin{bmatrix} (s+2) & 0 \\ 0 & (s+3) \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{(s+3)} & 0 \\ 0 & \frac{1}{(s+2)} \end{bmatrix}$$

$$(SI - A)^{-1} B = \begin{bmatrix} \frac{1}{(s+3)} & 0 \\ 0 & \frac{1}{(s+2)} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{(s+3)} \\ \frac{1}{(s+2)} \end{bmatrix}$$

$$T(s) = C[(SI - A)^{-1} B] = [1 \quad 0] \begin{bmatrix} \frac{1}{(s+3)} \\ \frac{1}{(s+2)} \end{bmatrix}$$

$$T(s) = \frac{1}{(s+3)}$$

65. (a)

$$Q_c = [B \quad AB]$$

Here, $A = \begin{bmatrix} 0 & 1 \\ 2 & -3 \end{bmatrix}, \; B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \; C = [1 \quad 1]$

$$AB = \begin{bmatrix} 1 \\ -3 \end{bmatrix}$$

$$Q_c = \begin{bmatrix} 0 & 1 \\ 1 & -3 \end{bmatrix}$$

$$|Q_c| \neq 0$$

$\therefore$ System is controllable

$$Q_0 = [C \quad CA]^T$$

$$[CA] = \begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 \\ 2 & -3 \end{bmatrix} = \begin{bmatrix} 2 & -2 \end{bmatrix}$$

$$Q_0 = \begin{bmatrix} 1 & 1 \\ 2 & -2 \end{bmatrix}$$

$$|Q_0| = -2 - 2 = -4 \neq 0$$

$\therefore$ System is observable.

66. (d)

A lead compensator reduces the rise time of the response and hence increases the bandwidth.

67. (a)

Let,
$$f(x) = \frac{a_0}{2} + a_1 \cos x + a_2 \cos 2x + ... + b_1 \sin x + b_2 \sin 2x + ... \quad ...(i)$$

Hence
$$a_0 = \frac{1}{\pi}\int_0^{2\pi} f(x)dx = \frac{1}{\pi}\int_0^{2\pi} x\,dx = \frac{1}{\pi}\left[\frac{x^2}{2}\right]_0^{2\pi} = 2\pi$$

$$a_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\cos nx\,dx = \frac{1}{\pi}\int_0^{2\pi} x\cos nx\,dx$$

$$= \frac{1}{\pi}\left[\frac{x\sin nx}{n} - 1\cdot\left(\frac{-\cos nx}{n^2}\right)\right]_0^{2\pi}$$

$$= \frac{1}{\pi}\left[\frac{\cos 2n\pi}{n^2} - \frac{1}{n^2}\right] = \frac{1}{n^2\pi}[1-1] = 0$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\sin nx\,dx = \frac{1}{\pi}\int_0^{2\pi} x\sin nx\,dx$$

$$= \frac{1}{\pi}\left[x\left(-\frac{\cos nx}{n}\right) - 1\cdot\left(\frac{-\sin nx}{n^2}\right)\right]_0^{2\pi}$$

$$= \frac{1}{\pi}\left[\frac{-2\pi\cos 2n\pi}{n}\right] = \frac{-2}{n}$$

Substituting the values of a_0 , a_n , b_n in (i) we get

$$x = \pi - 2\left[\sin x + \frac{1}{2}\sin 2x + \frac{1}{3}\sin 3x + ...\right]$$

68. (b)

According to given condition,

$$P(\text{Yellow at the first toss}) = \frac{3}{6} = \frac{1}{2}$$

$$P(\text{Red at the second toss}) = \frac{2}{6} = \frac{1}{3}$$

And $P(\text{Blue at the third toss}) = \dfrac{1}{6}$

Therefore, the probability of the required event

$$= \frac{1}{2} \times \frac{1}{3} \times \frac{1}{6} = \frac{1}{36}$$

69. (a)

$$P = 1\% = 0.01$$

$$n = 100$$

$$m = nP = 100 \times 0.01 = 1$$

$$P(r) = \frac{e^{-m} m^r}{r!}$$

P(3 or more faulty condensers)

$$= P(3) + P(4) + ... + P(100)$$

$$= 1 - [P(0) + P(1) + P(2)]$$

$$= 1 - \left[\frac{e^{-1}1^0}{0!} + \frac{e^{-1}1^1}{1!} + \frac{e^{-1}1^2}{2!}\right] = 1 - \left[e^{-1} + e^{-1} + \frac{e^{-1}}{2}\right]$$

$$= 1 - e^{-1}\left[\frac{5}{2}\right]$$

70. (b)

Poles of $f(z)$ are given by

$$(z - 1)^2 (z + 2) = 0$$

i.e, $z = 1, 1, -2$

The pole at z = 1 is of second order and the pole at $z = -2$ is simple.

Residue of $f(z)$ {at $z = 1$}

$$= \lim_{z \to 1} \frac{1}{(2-1)!} \frac{d}{dz} \frac{(z-1)^2 z^2}{(z-1)^2 (z+2)}$$

$$\lim_{z \to 1} \frac{d}{dz} \frac{z^2}{z+2} = \lim_{z \to 1} \frac{(z+2)2z - z^2}{(z+2)^2}$$

$$\lim_{z\to 1}\frac{z^2+4z}{(z+2)^2} = \frac{1+4}{(1+2)^2} = \frac{5}{9}$$

Residue of $f(z)$ {at z = –2}

$$\lim_{z\to -2}\frac{(z+2)z^2}{(z-1)^2(z+2)}$$

$$\lim_{z\to -2}\frac{z^2}{(z-1)^2} = \frac{4}{(-2-1)^2} = \frac{4}{9}$$

$$\int_C \frac{z^2 dz}{(z-1)^2(z+2)} = 2\pi i\left(\frac{5}{9}+\frac{4}{9}\right) = 2\pi i$$

71. (a)

For given PDE,

$$\sin x\, dx = \cos y . dy = \tan z\, dz$$

$$\Rightarrow \quad \sin x\, dx = \cos y\, dy$$

$$\Rightarrow \quad \int \sin x\, dx = \int \cos y\, dy$$

$$\Rightarrow \quad -\cos x = \sin y + a$$

$$\Rightarrow \quad \sin y + \cos x = -a \qquad \text{...(i)}$$

& also,

$$\int \sin x\, dx = \int \tan z dz$$

$$\Rightarrow \quad -\cos x = \log \sec z + b$$

$$\Rightarrow \quad \log \cos z - \cos x = b \qquad \text{...(ii)}$$

from (i) and (ii),

ψ ($\sin y + \cos x$, $\log \cos z - \cos x$) = 0 is required solution

72. (c)

$$f(x) = e^{\sin x}$$

$$\Rightarrow \quad f(0) = 1$$

$$f'(x) = e^{\sin x}\cos x = f(x)\cdot \cos x$$

$$\Rightarrow \quad f'(0) = 1$$

$$f''(x) = f'(x)\cos x - f(x)\sin x$$

$$\Rightarrow \quad f''(0) = 1 - 0 = 1$$

$$f'''(x) = f''(x)\cos x - 2f'(x)\sin x - f(x)\cos x$$

$$= 1 - 1 = 0$$

$$f''''(x) = f'''(x)\cos x - \sin x\, f''(x) - 2f''(x)\,.\,\sin x - 2f'(x)\cos x - f'(x)\cos x + f(x)\sin x$$
$$f''''(x) = 0 \times 1 - 0 \times 1 - 2 \times 1 \times 0 - 2 \times 1 \times 1 - 1 \times 1 + 1 \times 0 = -3$$

Substituting the values of $f(0)$, $f'(0)$ etc in the Maclaurin's series, we obtain

$$e^{\sin x} = 1 + x \cdot 1 + \frac{x^2}{2!} \cdot 1 + \frac{x^3}{3!} \cdot 0 + \frac{x^4}{4!} \cdot (-3) + ...$$

$$= 1 + x + \frac{x^2}{2} - \frac{x^4}{8} + ...$$

Hence coefficient of x^4 is $-\frac{1}{8}$

73. (a)

If $r = 0$, then there is no relationship between the two variables and they are independent.

74. (c)

The frequency at which the maximum phase occurs for phase lead compensator is the geometric mean of the two corner frequencies.

$$\omega_n = \frac{1}{T\sqrt{\alpha}}$$

75. (c)

Phase margin is defined for minimum phase systems only.

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