



GATE | PSUs



Electrical Engineering

POWER SYSTEMS

Text Book: Theory with worked out Examples and Practice Questions

Power Systems

(Solutions for Text Book Practice Questions)

1. Generating Stations

01. Ans: (a, c)

$$\text{Sol: PUF} = \frac{\text{Max. demand}}{\text{Installed capacity}}$$

$$\text{I.C} = \frac{100}{0.7} = 142.86 \text{ MW}$$

$$\begin{aligned}\text{Reserve capacity} &= \text{IC} - \text{MD} \\ &= 142.86 - 100 \\ &= 42.86 \text{ MW}\end{aligned}$$

02. Ans: (a, b, c, d)

Sol: Maximum demand = 100 MW

$$\begin{aligned}\text{Average load} &= \frac{\text{no. of units}}{\text{duration}} \\ &= \frac{1000 \times 100 + \frac{1}{2} \times 7760 \times 90 + 7760 \times 10}{8760} \\ &= 60.13 \text{ MW}\end{aligned}$$

$$\begin{aligned}\text{PLF} &= \frac{\text{avg load}}{\text{MD}} = \\ &= \frac{60.13}{100} = 0.6\end{aligned}$$

$$\text{PUF} = \frac{\text{MD}}{\text{IC}} = \frac{100}{130} = 0.77$$

No. of units generated = area under the curve = 526.8 GW

03. Ans: (a)

$$\text{Sol: PUF} = \frac{\text{MD}}{\text{IC}}$$

$$\Rightarrow \text{MD} = 0.2 \times 100 = 20 \text{ MW}$$

$$\text{L.F} = \frac{\text{Avg. load}}{\text{MD}}$$

$$\text{Average load} = 0.5 \times 20 = 10 \text{ MW}$$

04. Ans: (c)

$$\text{Sol: PCF} = \frac{\text{Avg. load}}{\text{MD}}$$

$$\Rightarrow \text{Avg. load} = 0.5 \times 300 = 150 \text{ MW}$$

$$\text{LF} = \frac{\text{Avg. load}}{\text{MD}}$$

$$\Rightarrow \text{MD} = \frac{150}{0.75} = 200 \text{ MW}$$

05. Ans: (a)

$$\text{Sol: LF} = \frac{\text{Avg. load}}{\text{MD}}$$

$$\begin{aligned}\Rightarrow \text{Avg. load} &= 0.75 \times 1000 \\ &= 750 \text{ MW}\end{aligned}$$

$$\text{PCF} = \frac{\text{Avg. load}}{\text{IC}}$$

$$\Rightarrow \text{IC} = \frac{750}{0.6} = 1250 \text{ MW}$$

$$\begin{aligned}\text{Reserve capacity} &= \text{IC} - \text{MD} \\ &= 250 \text{ MW}\end{aligned}$$

06. Ans: (b)

$$\text{Sol: LF} = \frac{\text{Avg. load}}{\text{MD}}$$

$$= \left[\frac{40 \times 6 + 2 \times 50 + 4 \times 60 + 50 \times 2 + 70 \times 4 + 80 \times 4 + 40 \times 2}{24} \right] \times \frac{1}{80}$$

$$= 0.71$$

07. Ans: (b)

Sol: $LF = \frac{\text{Avg. load}}{MD}$

Avg. load = $0.5 \times 8000 = 4000$ kW

Avg. load = $\frac{\text{no. of units generated}}{\text{duration}}$

$t = \frac{16,000 \times 10^6}{4000 \times 10^3} = 4000$ hrs

08. Ans: (b)

Sol: Load factor = $\frac{\text{Avg. load}}{MD}$

Avg. load = 0.45×25
= 11250 kW

2. Transmission & Distribution

2.1 Basic Concepts

01. Ans: (b)

Sol: Given data:

Complex power delivered by load:

$S = V I^*$

= $(100 \angle 60^\circ) (10 \angle 150^\circ)$

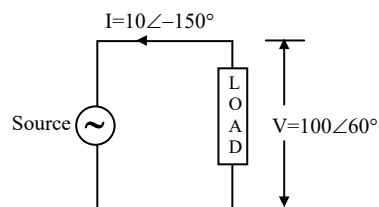
= $1000 \angle 210$

= $-866.6 - j 500$ VA

Complex power absorbed by load

$S_{\text{load}} = 866.6 + j 500$ VA

$\therefore$ Ans: (b) i.e., load absorbs both real and reactive power.



02. Ans: (b)

Sol: Given data:

$V_s = V_r = 1,$

$X = 0.5,$

Real power $P_r = \frac{|V_s||V_r|}{|X|} \sin \delta$

$1 = \frac{1.0 \times 1.0}{0.5} \sin \delta$

$\Rightarrow \delta = \sin^{-1}(0.5) = 30^\circ$

Reactive power

$Q_r = \frac{(V_s)(V_r)}{X} \cos \delta - \frac{(V)^2}{(X)}$

= $\frac{1.0 \times 1.0}{0.5} \cos 30 - \frac{1^2}{0.5}$

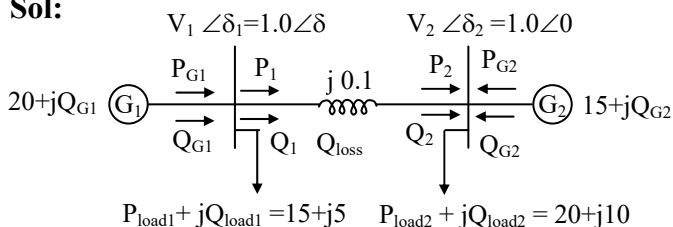
= $\left(\frac{\sqrt{3}}{2} \right) - 2 = 1.732 - 2 = -0.268$

But $Q_r + Q_c = 0$

$Q_c = -Q_r = 0.268$ p.u

03. Ans: (c)

Sol:



P_1 = Active power sent by bus (1)

$$= \frac{V_1 V_2}{X_L} \sin(\delta_1 - \delta_2)$$

P_2 = Active power received by bus (2)

$$= \frac{V_1 V_2}{X_L} \sin(\delta_1 - \delta_2)$$

Q_1 = Reactive power sent by bus (1)

$$= \frac{V_1}{X_L} (V_1 - V_2 \cos(\delta_1 - \delta_2))$$

Q_2 = Reactive power received by bus (2)

$$= \frac{V_2}{X_L} (V_1 \cos(\delta_1 - \delta_2) - V_2)$$

Active power balance at bus (1):

Active power balance at bus 2:

$$P_{G1} = P_1 + P_{load1}$$

$$P_2 + P_{G2} = P_{load2}$$

$$20 = P_1 + 15$$

$$P_2 + 15 = 20$$

$$P_1 = 5, P_2 = 5$$

$$\therefore P_1 = P_2 = \frac{V_1 V_2}{X_L} \sin(\delta_1 - \delta_2) = 5$$

$$\Rightarrow \frac{1 \times 1}{0.1} \sin(\delta - 0) = 5$$

$$\Rightarrow \sin \delta = 0.5$$

$$\Rightarrow \delta = 30^\circ$$

$$Q_1 = \frac{V_1}{X_L} [V_1 - V_2 \cos(\delta_1 - \delta_2)]$$

$$Q_2 = \frac{V_2}{X_L} [V_1 \cos(\delta_1 - \delta_2) - V_2]$$

$$= \frac{1}{0.1} [1 - 1 \cos 30^\circ]$$

$$= \frac{1}{0.1} [1 \cos 30^\circ - 1]$$

$$= 1.34 \text{ pu}$$

$$= -1.34 \text{ pu}$$

$$Q_{line} = Q_{loss} = Q_1 - Q_2$$

$$= 1.34 - (-1.34)$$

$$= 2.68 \text{ pu}$$

$$Q_{loss} = 2.68 \text{ pu}$$

Reactive power balance at bus (1):

Reactive power balance at bus (2):

$$Q_{G1} = Q_1 + Q_{load1}$$

$$Q_2 + Q_{G2} = Q_{load2}$$

$$Q_{G1} = 1.34 + 5$$

$$Q_{G2} = 10 - (-1.34)$$

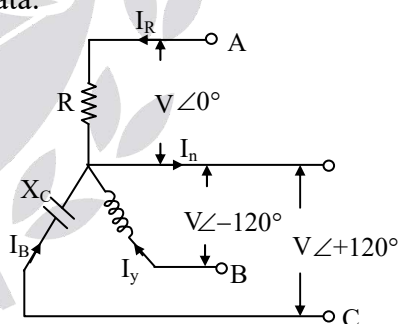
$$Q_{G1} = 6.34 \text{ pu}$$

$$Q_{G2} = 11.34 \text{ pu}$$

$$\therefore Q_{G1} = 6.34 \text{ pu}, Q_{G2} = 11.34 \text{ pu}, Q_{loss} = 2.68 \text{ pu}$$

04. Ans: (b)

Sol: Given data:



$$I_R + I_Y + I_B = I_n = 0$$

$$\frac{V^2}{R} = 4000, R = \frac{230^2}{4000} = 13.225$$

$$\Rightarrow I_n = 0 = \frac{V \angle 0^\circ}{R} + \frac{V \angle -120^\circ}{\omega L \angle +90^\circ} + V \omega C \angle +120^\circ \angle +90^\circ$$

$$\Rightarrow \frac{V}{R} + \frac{V}{\omega L} \angle -210^\circ + V \omega C \angle +210^\circ = 0$$

$$\Rightarrow \frac{V}{R} + \frac{V}{\omega L} \cos 210^\circ + V \omega C \cos 210^\circ = 0$$

$$\Rightarrow -\frac{V}{\omega L} \sin 210^\circ + V\omega C \sin 210^\circ = 0$$

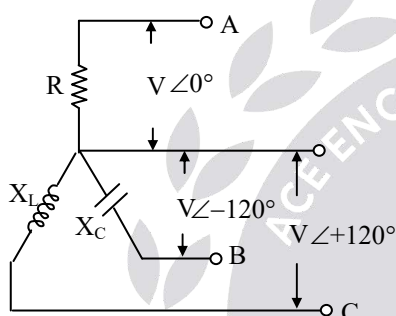
$$\omega = \frac{1}{\sqrt{LC}} \dots\dots\dots (i)$$

$$\frac{1}{R} = \left(\frac{\omega^2 LC + 1}{\omega L} \right) \times \frac{\sqrt{3}}{2}$$

$$L = 72.9 \text{ mH}$$

$$C = 139.02 \text{ } \mu\text{F}$$

If suppose ' X_C ' on phase B, X_L on phase C



$$\frac{V}{R} + \frac{V}{X_C} + \frac{V}{X_L} = 0$$

$$\frac{1}{R} + \omega C \angle -30^\circ + \frac{1}{\omega L} \angle +30^\circ = 0$$

$$\frac{1}{R} + \omega C \cos 30^\circ + \frac{1}{\omega L} \cos 30^\circ \neq 0$$

$$\omega C \sin 30^\circ = \frac{1}{\omega L} \sin 30^\circ$$

1st condition never be zero, because all the positive parts never becomes zero

2.2 Transmission Line Constants:

01. Ans: n^2

Sol: Given data:

For same length, same material, same power loss and same power transfer

If the voltage is increased by ' n ' times, what will happen to area of cross section of conductor.

$$P_{\text{Loss } 1} = P_{\text{Loss } 2}$$

$$P_{\text{Loss } 1} = 3I_1^2 R_1$$

$$P = \sqrt{3} V_1 I_1 \cos \phi$$

$$P_{\text{Loss } 1} = 3 \left(\frac{P_1}{\sqrt{3} V_1 \cos \phi} \right)^2 \times R_1$$

$$P_{\text{Loss } 1} = \frac{P_1^2 R_1}{V_1^2 \cos^2 \phi}$$

$$P_{\text{Loss } 1} \propto \frac{R}{V_1^2} \propto \frac{1}{a V_2^2}$$

$$\Rightarrow a V^2 \propto \frac{1}{P_{\text{Loss}}}$$

$$\Rightarrow a V^2 = \text{constant}$$

$$\therefore P_{\text{Loss}} = \text{Constant}$$

$$\frac{a_1 V_1^2}{a_2 V_2^2} = 1$$

$$\frac{V_2}{V_1} = n \rightarrow \text{given}$$

$$\Rightarrow a_2 = \frac{1}{n^2} a_1$$

In this efficiency is constant since same power loss.

02. Ans: (b)

Sol: Given data:

We know that $P = VI \cos \phi$

$$I = \frac{P}{(V \cos \phi)} \dots\dots\dots (1)$$

$$\text{Power loss } P = I^2 R$$

$$= I^2 \frac{\rho \ell}{a} \left(\because R = \frac{\rho \ell}{a} \right)$$

$$a = I^2 \frac{\rho \ell}{P} \dots\dots\dots (2)$$

Substitute eq. (1) in eq. (2)

$$I = \left(\frac{P}{V \cos \phi} \right)^2 \frac{\rho \ell}{a}$$

$$a = \frac{K}{(V \cos \phi)^2}$$

$$a \propto \frac{1}{(V \cos \phi)^2}$$

$$\text{Volume} \propto \frac{1}{(V \cos \phi)^2} \quad (\because \text{volume} \propto \text{area})$$

03. Ans: (b)

Sol: Given data:

Self-inductance of a long cylindrical conductor due to its internal flux linkages is 1 kH/m.

$$L_a = \underbrace{\frac{\mu_0 \mu_r}{8\pi}}_{\psi_{\text{int}}} + \underbrace{\frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{1}{r}\right) - \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{1}{d}\right)}_{\psi_{\text{ext}}}$$

$$L_{\text{self}} = L_{\text{self}} \text{ due to } \psi_{\text{int}} + L_{\text{self}} \text{ due to } \psi_{\text{ext}}$$

$$= \frac{\mu_0 \mu_r}{8\pi} + \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{1}{r}\right)$$

$$L_{\text{mutual}} = L_{\text{mutual due to ext}} = \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{1}{d}\right)$$

Ans: 1 K H/m ($\because$ 1st term is independent of diameter)

04. Ans: 31.6% (Range: 30 to 32)

Sol: Given data:

$$L_n = 1.10 \text{ mH/km increased } 5\%$$

$$L_n = 0.2 \ln\left(\frac{d_1}{r_1}\right) \text{ mH/km}$$

$$1.10 \text{ mH/km} = 0.2 \ln\left(\frac{d_1}{r_1}\right) \text{ mH/km}$$

$$1.10 = 0.2 \ln\left(\frac{d_1}{r_1}\right)$$

$$\frac{1.10}{0.2} = \ln\left(\frac{d_1}{r_1}\right)$$

$$5.5 = \ln\left(\frac{d_1}{r_1}\right)$$

$$e^{5.5} = \frac{d_1}{r_1}$$

$$244.69 r_1 = d_1$$

$$(1.10) \times 1.05 = 0.2 \ln\left(\frac{d_2}{r_2}\right)$$

$$1.155 = 0.2 \ln\left(\frac{d_2}{r_2}\right)$$

$$e^{\frac{1.155}{0.2}} = \frac{d_2}{r_2}$$

$$322.14 r_2 = d_2$$

$$\frac{d_2 - d_1}{d_1} \times 100 = \frac{322.14 r_2 - 244.69 r_1}{244.69 r_1} \times 100$$

$$= 0.3165 \times 100$$

$$= 31.6\%$$

05. Ans: (b)

Sol: Given data:

$$d = 4;$$

$$(i) L_1 C_{n1}$$

After Transposition

$$\text{GMD}_1 = \sqrt[3]{4 \times 4 \times 4} = 4$$

$$(ii) L_2 C_{n2}$$

After Transposition

$$\text{GMD}_2 = \sqrt[3]{4 \times 4 \times 8} = 5.02 \text{ m}$$

$$\text{GMD}_1 < \text{GMD}_2$$

$$L_1 < L_2$$

$$C_{n1} > C_{n2}$$

Resistances $R_1 = R_2$

$$\uparrow Z_c = \sqrt{\frac{L \uparrow}{C \downarrow}}$$

$$\left[Z_{c1} = \left(\frac{L_1}{C_{n1}} \right)^{1/2} \right] < \left[Z_{c2} = \left(\frac{L_2}{C_{n2}} \right)^{1/2} \right]$$

$$\left[\text{SIL}_1 = \left(\frac{V^2}{Z_{c1}} \right) \right] > \left[\text{SIL}_2 = \left(\frac{V^2}{Z_{c2}} \right) \right]$$

06. Ans: (b)

Sol: Given data:

The impedance of a Transmission line

$$Z = 0.05 + j0.35 \Omega/\text{phase/km}$$

Spacing is doubled $d_2 = 2d_1$; $R = 0.05$

radius is doubled $r_2 = 2r_1$

$$X_L = 0.35 \Omega/\text{phase/km}$$

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

l remain constant

$$2\pi fL = 0.35$$

$$L = \frac{0.35}{2\pi f}$$

$$\text{B let } R \propto \frac{\ell}{A} ; R \propto \frac{\ell}{\pi r^2}$$

$$\frac{R_2}{R_1} = \left(\frac{r_1}{r_2} \right)^2 \quad R_L = R \left(\frac{1}{2} \right)^2$$

$$= \frac{R_1}{4} = \frac{0.05}{4} = 0.0125$$

$$\therefore (Z_2)_{\text{new}} = 0.0125 + j 0.35 \Omega/\text{km}.$$

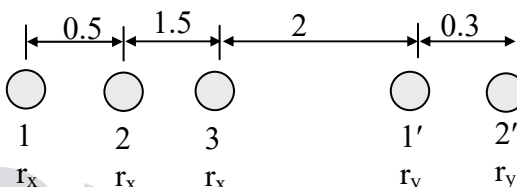
07. Ans: (c)

Sol: Given data:

$$r_x = 0.03 \text{ m}$$

$$r_y = 0.04 \text{ m}$$

$$\text{GMD}_{\text{system}} = \text{GMD}_a \cdot \text{GMD}_b$$



$$\begin{aligned} \text{GMD}_a &= (d_{11'} \times d_{12'} \times d_{21'} \times d_{22'} \times d_{31'} \times d_{32'})^{1/6} \\ &= (4 \times 4.3 \times 3.5 \times 3.8 \times 2 \times 2.3)^{1/6} \\ &= 3.189 \text{ m} \end{aligned}$$

$$\text{GMD}_b = \text{GMD}_a = 3.189$$

$$\begin{aligned} \therefore \text{GMD}_{\text{system}} &= \sqrt{\text{GMD}_a \times \text{GMD}_b} \\ &= 3.189 \text{ m.} \end{aligned}$$

(Self GMD)_{system}

$$= \sqrt{(\text{self GMD of system a}) \times \text{self GMD}_b}$$

$$\text{self GMD}_a =$$

$$\begin{aligned} &= (r'_x \times 0.5 \times 2 \times r'_x \times 0.5 \times 1.5 \times r'_x \times 0.5 \times 2)^{1/9} \\ &= (0.7788^3 \times (0.03)^3 \times (0.5)^3 \times 2^2)^{1/9} = 0.276 \text{ m} \end{aligned}$$

$$\text{Self GMD}_b = (r'_y \times 0.3 \times r'_y \times 0.3)^{1/4}$$

$$= \sqrt{0.7788 \times 0.04 \times 0.3}$$

$$= 0.096 \text{ m}$$

$$\therefore \text{Self GMD} \sqrt{0.096 \times 0.276} = 0.162 \text{ m}$$

$$L = 2 \times 0.2 \ln \left(\frac{\text{GMD}}{\text{GMR}} \right) \text{ mH / km}$$

$$= 0.4 \ln \left(\frac{3.189}{0.162} \right) \times 10^{-6} \text{ H / m}$$

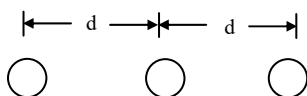
$$L = 11.93 \times 10^{-7} \text{ H/m}$$

08. Ans: d = 2.49 m (Range: 2.2 to 2.6)

Sol: Given data:

$$r = 1 \text{ cm}$$

$$L = 1.2 \text{ mH/km}$$



$$\text{GMD} = \sqrt[3]{2} \times d$$

$$0.2 \ln \left(\frac{1.2599 d}{0.7788 \times 0.01} \right) = 1.2$$

$$d = 2.49 \text{ m}$$

09. Ans: 3.251 nF/km

Sol: Given data:

$$f = 50 \text{ Hz}, d = 0.04 \text{ m}, r = 0.02 \text{ m}$$

$$V = 132 \text{ kV}$$

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\ln \left(\frac{\text{GMD}}{\text{GMR}} \right)}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12} \times 1}{\ln \left(\frac{6}{0.02} \right)}$$

$$= 9.75 \text{ nF/km}$$

$$\text{Interline capacitance} = \frac{C}{3} = \frac{9.75}{3}$$

$$\Rightarrow 3.25 \text{ nF/km}$$

10. Ans: 1.914 (Range: 1.85 to 1.95)

Sol: Given data:

$$\text{Self GMD} = kR$$

$$\text{Self GMD} = \sqrt[3]{R^1 \times 3R \times 3R}$$

$$= \sqrt[3]{0.7788R \times 3R \times 3R}$$

$$= R\sqrt[3]{0.7788 \times 3 \times 3}$$

$$kR = 1.914 R$$

$$k = 1.914$$

11. Ans: (a & c)

Sol: Corona loss can be reduced by using the bundled conductor and by the increasing the critical disruptive voltage

12. Ans: (a, d)

Sol: The advantages of the interconnected operation of power systems are:

I. Less reserve capacity requirement:

True

- Each station does not need to keep full standby, the reserve can be shared across the system.
- This reduces the overall reserve capacity requirement.

II. More reliability: True

- If one generating unit falls, others in the interconnected system can supply power.
- Improves the reliability of supply

III. High power factor: False

- Not a direct advantage of interconnection. The power factor depends more on the load characteristics and reactive power compensation.

IV. Reduction in short-circuit level: False

- Actually, the short-circuit level increases because more source are available to feed fault current
- So this is not an advantage.

The correct answer is option (c)

2.3 Steady state performance analysis Of Transmission lines

01. Ans: (c)

Sol: Given data:

$$A = D = 0.936 + j0.016 = 0.936 \angle 0.98^\circ,$$

$$B = 33.5 + j138 = 142.0 \angle 76.4^\circ,$$

$$C = (-5.18 + j914) \times 10^{-6},$$

$$V_r = 50 \text{ MW, p.f} = 0.9 \text{ lag,}$$

$$V_s \text{ (L-L)} = ?$$

$$V_{s \text{ ph}} = A V_{r \text{ ph}} + B I_{r \text{ ph}}$$

$$V_{r \text{ ph}} = \frac{220 \text{ kV}}{\sqrt{3}}$$

$$I_{rL} = \frac{P_r}{\sqrt{3} V_L \cos \phi_r}$$

$$= \frac{50 \text{ M}}{\sqrt{3} \times 220 \text{ k} \times 0.9} = 145.7 \text{ A}$$

$$I_{r \text{ ph}} = 145.7 \angle -\cos^{-1}(0.9) = 145.7 \angle -25.84$$

$$V_{s \text{ ph}} = (0.936 \angle 0.98) \left(\frac{220 \text{ k}}{\sqrt{3}} \right) + (142 \angle 76.4)(145.7 \angle -25.84)$$

$$= 133.24 \angle 7.7^\circ \text{ kV}$$

$$V_s \text{ (L-L)} = \sqrt{3} \times 133.24 = 230.6 \text{ kV}$$

$$V_R = \frac{V_s}{A}$$

$$\frac{230.6}{0.936} = 246.36 \text{ kV}$$

02. Ans: (c)

Sol: Given data:

Load delivered at nominal rating

$$V_{rl} = 220 \text{ kV}$$

$$\% \text{ V.R} = \frac{\left| \frac{V_s}{A} \right| - |V_r|}{|V_r|} \times 100\%$$

$$= \frac{\frac{240}{0.94} - 220}{220} \times 100\% = 16\%$$

03. Ans: (c)

Sol: Given data:

$$A = D = 0.95 \angle 1.27^\circ ; B = 92.4 \angle 76.87$$

$$C = 0.006 \angle 90^\circ ; V_s = V_r = 138 \text{ kV}$$

R, Y are neglected

$$\therefore P_{\max} = \frac{|V_s| |V_r|}{X}$$

In nominal- $\pi \Rightarrow B = Z$

$$Z = 92.4 \angle 76.87^\circ = 21 + j90 \Omega$$

$$X = 90 \Omega$$

$$\therefore P_{\max} = \frac{138 \times 138}{90} = 211.6 \text{ MW}$$

04. Ans: 81.04 kW (Range: 79 to 82)

Sol: Given data:

$$A = 0.977 \angle 0.66$$

$$B = 90.18 \angle 64.12^\circ$$

$$V = 132 \text{ kV}$$

$$AD - BC = 1$$

$$C = \frac{AD - 1}{B}$$

$$V_c = \frac{132 \times 10^3}{\sqrt{3} \times 0.97} \angle -0.66$$

$$C = \frac{0.977 \angle 0.66 \times 0.977 \angle 0.66 - 1}{90.18 \angle 64.12^\circ}$$

$$= \frac{0.9545 \angle 1.32 - 1}{90.18 \angle 64.12^\circ}$$

$$= 5.62 \times 10^{-4} \angle 90.2$$

$$I_S = CV_r + BI_r$$

$$5.62 \times 10^{-4} \angle 90^\circ \times \frac{132 \times 10^3}{\sqrt{3}}$$

$$P = 3V_L I_L \cos \phi$$

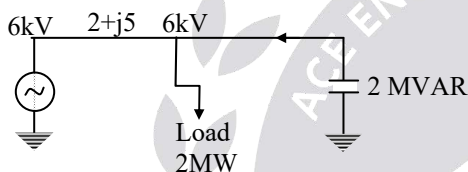
$$P = 3 \times \frac{132 \times 74.184 \cos(90^\circ - 0.66)}{3 \times 0.97}$$

$$P = 81.04 \text{ kW}$$

05. Ans: 0.936 lag

Sol: Given data:

Short transmission line having impedance =
 $2 + j5 \Omega$



$$\beta = \cos^{-1}\left(\frac{2}{\sqrt{29}}\right) = 68.2$$

$$P = \frac{V_s V_r}{B} \cos(\beta - \delta) - \frac{AV_r^2}{B} \cos(\beta - \alpha)$$

$$2 \times 10^6 = \frac{36 \times 10^6}{\sqrt{29}} [\cos(68.2 - \delta) - \cos(68.2)]$$

$$\cos(68.28 - \delta) = 0.6705$$

$$\delta = 20.309^\circ$$

$$Q = \frac{V_s V_r}{B} \sin(\beta - \delta) - \frac{AV_r^2}{B} \sin(\beta - \alpha)$$

$$= \frac{36 \times 10^6}{\sqrt{29}} [\sin(68.2 - 20.309) - \sin 68.2]$$

$$= -1.24 \text{ MW}$$

$$\therefore -1.24 + 2 = Q_c$$

$$Q_c = 0.7524 \text{ MW}$$

$$\therefore \cos \phi = \frac{P}{\sqrt{P^2 + Q^2}} = \frac{2}{\sqrt{4 + (0.7524)^2}}$$

$$= 0.9359 \text{ lag}$$

$$\approx 0.936 \text{ lag}$$

06. Ans: (a)

Sol: Given data:

$$f = 50 \text{ Hz}$$

$$\text{Surge impedance } Z_0 = \sqrt{\frac{L}{C}} = 1$$

$$L = C$$

Velocity of wave

$$V = \frac{1}{\sqrt{LC}} = 3 \times 10^5$$

$$\frac{1}{\sqrt{LC}} = 3 \times 10^5$$

$$\frac{1}{C} = 3 \times 10^5$$

$$C = \frac{10^{-5}}{3}$$

$$X = \frac{2\pi f L}{2} \times \ell$$

$$= \pi 50 \times \frac{10^{-5}}{3} \times 400$$

$$= 0.209$$

$$y = [2\pi f c] \ell$$

$$= 2 \times \pi \times 50 \times \frac{10^{-5}}{3} \times 400$$

$$= 0.418$$

07. Ans: (a, b)

$$\text{Sol: } \bar{V}_S = A\bar{V}_R + B\bar{I}_R$$

$$\therefore V_S = V_R$$

$$V_R = AV_R + BI_R$$

$$V_R(1 - A) = BI_R$$

$$\frac{V_R}{I_R} = \frac{|B|}{|1-A|} = \frac{250}{1-0.9} = 2500 \Omega$$

$$X_L = 2500 = 2\pi fL$$

$$L = \frac{2500}{2\pi \times 50} = 7.96 \text{ H}$$

08. Ans: (c)

Sol: Given data:

Let characteristic impedance

$$(Z_c) = \sqrt{\frac{Z_{sc}}{Y_{oc}}} = \sqrt{\frac{1.0}{1.0}} = 1 \text{ p.u.}$$

$$= \sqrt{\frac{\text{impedance / km}}{\text{admittance / km}}}$$

Given that for a given line 30% series capacitive compensation is provided. Hence the series impedance of line is 0.7 or (70%) of original value.

$$\therefore Z_{\text{new}} = \sqrt{\frac{0.7}{1.0}} = 0.836 \text{ p.u.}$$

$$\text{Surge impedance loading (SIL)} = \frac{V^2}{Z_c}$$

$$\Rightarrow \text{SIL} \propto \frac{1}{Z_c}$$

$$\frac{(\text{SIL})_2}{(\text{SIL})_1} = \frac{Z_{c1}}{Z_{c2}}$$

$$(\text{SIL}^2) = \frac{1.0}{0.836} \times 2280 \times 10^6$$

$$= 2725 \times 10^6$$

$$= 2725 \text{ MW.}$$

2.4. Transient Analysis & 2.5. Wave Traveling Analysis

01. Ans: (c)

Sol: Given data:

Let “l” be the total length of line

$$\text{Total reactance of line} = 0.045 \text{ p.u.} = 2\pi fL$$

$$\text{Total inductance of line} = \frac{0.045}{2\pi \times 50}$$

$$\text{Total susceptance of line} = 1.2 \text{ p.u.} = 2\pi fC$$

$$\text{Total capacitance of line} = \frac{1}{2\pi \times 50}$$

$$\text{Inductance/km} = \frac{0.045}{2\pi \times 50 \times 1}$$

$$\text{Capacitance/km} = \frac{1.2}{2\pi \times 50 \times 1}$$

Velocity wave propagation

$$(V) = \frac{\ell}{\sqrt{\left(\frac{L}{\text{km}}\right)\left(\frac{C}{\text{km}}\right)}}$$

$$V = \frac{\ell}{\sqrt{\frac{0.045}{2\pi \times 50 \times 1} \times \frac{1.2}{2\pi \times 50 \times 1}}}$$

$$30 \times 10^5 = \frac{\ell}{7.4 \times 10^{-4}}$$

$$\therefore \text{Length of the line (l)} = 222 \text{ km}$$

02. Ans: (c)

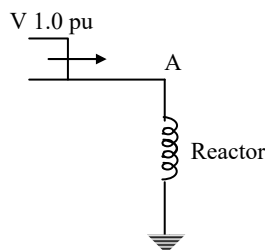
Sol: Since load impedance is equal to surge impedance, the voltage & current wave forms are not going to experience any reflection.

Hence reflection coefficient is zero.

$$V_{\text{reflection}} = i_{\text{reflection}} = 0.$$

03. Ans: (c)

Sol:



$$Z_s = \sqrt{\frac{L}{C}} = \sqrt{\frac{L}{0}} = \infty$$

The Reactor is initially open circuit

$$V_2 = V + V_1 = 1.0 + 1.0 = 2.0 \text{ p.u.}$$

V_1 = reflected voltage

V_2 = Switched voltage

04. Ans: (b)

Sol: Given data:

$$V = 50 \text{ kV,}$$

$$Z_L = 100 \Omega,$$

$$Z_C = 400 \Omega,$$

The transmitted (or) refracted voltage

$$V_2 = 2V \left(\frac{Z_L}{Z_L + Z_C} \right)$$

Here '2' indicates that the voltage V_2 is calculating in transient condition

$$\therefore V_2 = 2 \times 50 \times 10^3 \times \left(\frac{100}{100 + 400} \right)$$

$$V_2 = 20 \text{ kV}$$

05. Ans: (b)

Sol: Given data:

$$L_{\text{cable}} = 0.185 \text{ mH/km}$$

$$C_{\text{cable}} = 0.285 \mu\text{F/km}$$

$$L_{\text{Line}} = 1.24 \text{ mH}$$

$$C_{\text{Line}} = 0.087 \mu\text{F/km}$$

$$\begin{aligned} Z_{C(\text{Cable})} &= \sqrt{\frac{L}{C}} \\ &= \sqrt{\frac{0.185 \times 10^{-3}}{0.285 \times 10^{-6}}} \\ &= 25.4778 \Omega \end{aligned}$$

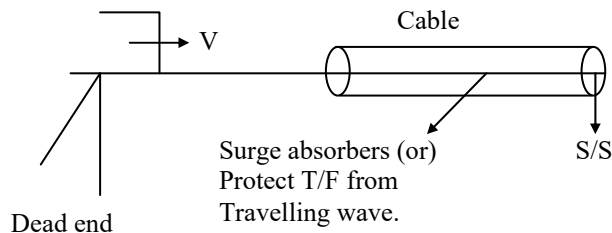
$$\begin{aligned} Z_{C(\text{Line})} &= \sqrt{\frac{L}{C}} \\ &= \sqrt{\frac{1.24 \times 10^{-3}}{0.087 \times 10^{-6}}} \\ &= 119.385 \Omega \end{aligned}$$

$$\begin{aligned} V_2 &= 2V \left[\frac{Z_L}{Z_L + Z_C} \right] \\ &= 2 \times 110 \text{ kV} \left[\frac{119.385}{119.385 + 25.4778} \right] \\ &= 181.307 \text{ kV} \end{aligned}$$

06. Ans: (d)

Sol: A short length of cable is connected between dead-end tower and sub-station at the end of a transmission line. This of the following will decrease, when voltage wave is entering from overhead to cable is

- (i) Velocity of propagation of voltage wave.
- (ii) Steepness of voltage wave.
- (iii) Magnitude of voltage wave.



Velocity of propagation

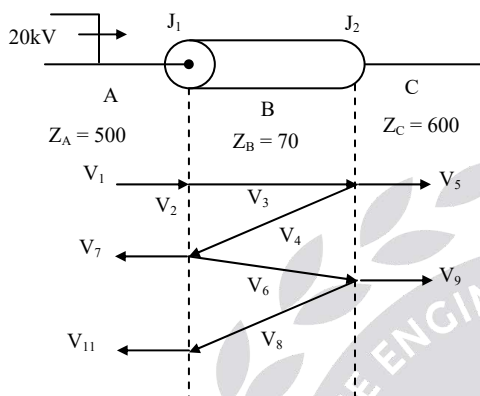
$$V_{(\text{Line})} = 3 \times 10^8$$

$$V_{(\text{Cable})} = \frac{3 \times 10^8}{\sqrt{\epsilon_r}} \text{ m/s}$$

$$V_{\text{Cable}} > V_{(\text{OH line})}$$

07. Ans: 2.93 kV (Range: 2.8 to 3.0)

Sol:



DC (or) step voltage
($\because$ line is of infinite length)

$$V_3 = 2V_1 \frac{Z_B}{Z_B + Z_A}$$

$$= 2 \times 20 \text{ k} \times \frac{70}{70 + 500}$$

$$V_3 = 4.91 \text{ kV}$$

$$V_4 \text{ (Reflection of } V_3) = V_3 \left[\frac{Z_C - Z_B}{Z_C + Z_B} \right]$$

$$= 4.91 \left[\frac{600 - 70}{600 + 70} \right] = 3.88 \text{ kV}$$

$$V_6 = V_4 \left[\frac{Z_A - Z_B}{Z_A + Z_B} \right]$$

$$= 3.88 \text{ K} \left[\frac{500 - 70}{500 + 70} \right] = 2.93 \text{ kV}$$

08. Ans: (d)

Sol: Given data

$$V_6 = 2.93$$

$$V_7 = 2V_4 \times \frac{500}{570}$$

$$= 6.8 \text{ kV}$$

$$V_9 = 2V_6 \times \frac{600}{670}$$

$$= 2 \times 2.93 \times \frac{600}{670} = 5.25 \text{ V}$$

09. Ans: (a, c, d)

Sol: for long transmission line

$$\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} = \begin{bmatrix} \cosh \gamma \ell & z_c \sinh \gamma \ell \\ \frac{1}{z_c} \sinh \gamma \ell & \cosh \gamma \ell \end{bmatrix}$$

$$A = B \text{ and } C = \frac{1}{z_c \sinh \gamma \ell}$$

$$AD - BC = 1 \rightarrow \text{reciprocal network}$$

2.6. Voltage Control

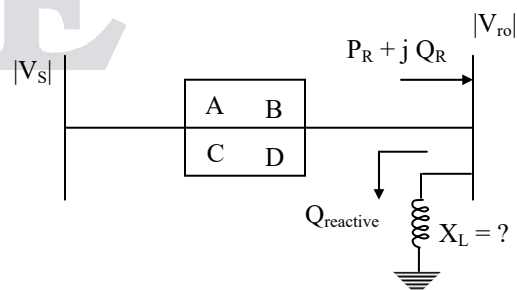
01. Ans: (a)

Sol: Given data:

$$A = D = 0.9 \angle 0^\circ$$

$$B = 200 \angle 90^\circ \Omega$$

$$C = 0.95 \times 10^{-3} \angle 90^\circ$$



Without shunt reactor

$$|V_{ro}| = \frac{|V_s|}{A}$$

By adding shunt reactor

$$|V_{r_0}| = |V_S|$$

$P_R = 0$ (no load)

$$Q_R = Q_{\text{reactor}}$$

$$= \frac{|V_S| |V_{r_0}|}{|B|} \sin(\beta - \delta) - \frac{|A|}{|B|} |V_{r_0}|^2 \sin(\beta - \alpha)$$

$$Q_r = \frac{|V_r|^2}{X_L}$$

$$\text{At } |V_{r_0}| = |V_S|$$

$$\frac{1}{|B|} \sin(\beta - \delta) - \frac{|A|}{|B|} \sin(\beta - \alpha) = \frac{1}{X_L}$$

To get δ at $(|V_{r_0}| = |V_S|)$

$$P_r = \frac{|V_S|^2}{|B|} \cos(\beta - \delta) - \frac{|A|}{|B|} |V_S|^2 \cos(\beta - \alpha) = 0$$

$$= \cos(\beta - \delta) - |A| \cos(\beta - \alpha)$$

$$= \cos(90 - \delta) - 0.9 \cos(90 - 0)$$

$$\cos(90 - \delta) = 0$$

$$\sin \delta = 0, \delta = 0$$

$$\frac{1}{X_L} = \frac{1}{200} \sin(90 - 0) - \frac{0.9}{200} \sin(90 - 0)$$

$$X_L = 2000 \Omega \text{ or } 2 \text{ k}\Omega$$

02. Ans: (d)

Sol: Given data:

$$P = 2000$$

$$Q = 2000 \tan(36.86)$$

$$= 2000(0.749) = 1499.46 \text{ kW}$$

$$R(S)_{\text{s-motor}} = 1000 - j1000$$

$$S_{\text{Total}} = S_{I_m} + S_{s_m}$$

$$= (2000 + j1499.46) + (1000 - j1000)$$

$$= 3000 + j499.46$$

$$\cos \phi = \frac{3000}{3041.29} \times 100\% = 0.9861 \text{ lag}$$

03. Ans: (a)

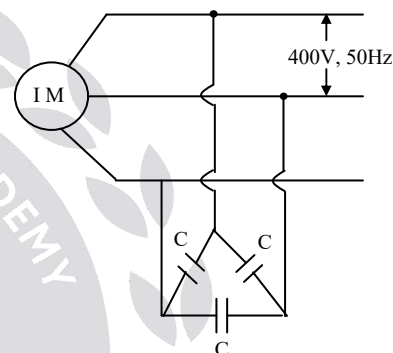
Sol: Given data:

IM = 400 V, 50 Hz, pf = 0.6 lag,

input = 4.5 kVA

p.f = 0.6 load

total supply = ?



$$S = \sqrt{3} V_L I_L ; 4.5 \text{ kVA}$$

$$Q_{\text{Sh (3-}\phi)} = P_1 (\tan \phi_1 - \tan \phi_2)$$

P_1 = Real power drawn by IM

$$= P_{\text{IM}}$$

$$= S_{\text{IM}} \cos \phi_{\text{IM}}$$

$$= 4.5 \times 0.6 \text{ kW}$$

$$P_1 = 2.7 \text{ kW}$$

$$Q_{\text{Sh (3-}\phi)} = 2.7 [\tan(\cos^{-1} 0.6) - \tan(\cos^{-1} 0.8)]$$

$$= 1.575 \text{ kVAr}$$

$$Q_{\text{S/ph}} = \frac{1.575}{3} \text{ kVAr}$$

$$= 0.525 \text{ kVAr}$$

$$\text{Reactive power supplied} = \frac{V_s^2}{X_C} = 525$$

$$(400)^2 (2\pi \times 50) C = 525$$

$$C = 10.1 \mu\text{F}$$

04. Ans: (c)

Sol: Given data $A = 0.85 \angle 5^\circ$

$$\alpha = 5^\circ$$

$$B = 200 \angle 75^\circ \quad \beta = 75^\circ$$

Power demand by the load = 150 MW at upf

$$P_D = P_R = 150 \text{ MW} \quad Q_D = 0$$

Power at receiving end

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

$$\Rightarrow 150 = \frac{275 \times 275}{200} \cos(75^\circ - \delta) - \frac{0.85}{200} (275)^2 \cos 70^\circ$$

$$\delta = 28.46^\circ$$

$$\text{So } Q_R = \frac{|V_s| |V_R|}{B} \sin(\beta - \delta) - \frac{|A|^2}{B} |V_R|^2 \sin(\beta - \alpha)$$

$$= \frac{275 \times 275}{200} \sin(75^\circ - 28.46^\circ) - \frac{0.85}{200} (275)^2 \sin 70^\circ$$

$$= -27.56 \text{ MVAR}$$

In order to maintain 275 kV at receiving end

$$Q_R = -27.56 \text{ MVAR must be drawn along}$$

with the real power.

$$\text{So } -27.56 + Q_C = 0$$

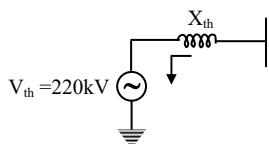
$$Q_C = 27.56 \text{ MVAR}$$

So compensation equipment must be feed in to 27.56 MVAR to the line.

05. Ans: (c)

Sol: Given data:

$$X_{th} = 0.25 \text{ pu} ; 250 \text{ MVA}, 220 \text{ kV}$$



To boost the voltage 4 kV shunt capacitor is used.

$$\Delta V_C = \frac{X}{|V_S|} Q_{sh \text{ Cap}}$$

$$Q_{sh \text{ Cap}} = \frac{\Delta V_C |V_S|}{X}$$

$$X_{\Omega} = X_{pu} \times \frac{(\text{kV}_{base})^2}{\text{MVA}_{base}}$$

$$= 0.25 \times \frac{(220^2)}{250} = 48.4$$

$$Q_{sh \text{ Cap}} = \frac{4 \times 220 \text{ k}}{48.4} = 18.18 \text{ kVAr}$$

To reduce voltage by 2 kV, shunt reactor is used.

$$\Delta V_L = \frac{X}{|V_S|} Q_{sh \text{ Ind}}$$

$$Q_{sh \text{ Ind}} = \frac{2 \text{ k} \times 220 \text{ k}}{48.4} = 9.09 \text{ MVAR}$$

06. Ans: (d)

Sol: Given data:

$$V_2 = 1.1 V_1$$

$$F_2 = 0.9 f_1$$

$$\text{Reactive power absorbed by reactor} = \frac{V^2}{X_L}$$

$$Q_1 = \frac{V_1^2}{2\pi f_1 L} = 100 \text{ MVAR}$$

Then reactive power absorbed

$$Q \propto \frac{V^2}{X} \propto \frac{V^2}{f}$$

$$\frac{Q_2}{Q_1} = \left(\frac{V_2}{V_1} \right)^2 \left(\frac{f_1}{f_2} \right)$$

$$= \left(\frac{1.1 V_1}{V_1} \right)^2 \left(\frac{f_1}{0.9 f_1} \right)$$

$$= \frac{(1.1)^2}{0.9} \times Q_1 = \frac{1.21}{0.9} \times 100$$

$$= 134.4 \text{ MVAR}$$

07. Ans: (b)

Sol: 3-phase, 11kV, 50Hz, 200kW load, at power factor = 0.8

kVAR demand of Load

$$(Q_1) = \frac{200 \times 10^3}{0.8} \times \sin(\cos^{-1} 0.8)$$

$$\therefore Q_1 = 150 \text{ kVAR}$$

kVAR demand of load at upf = 0

So as to operate the load at upf, we have to supply the 150 kVAR by using capacitor bank.

$\therefore$ kVAR rating of Δ - connected

$$\text{capacitor bank} = \frac{3V_{ph}^2}{X_{C_{ph}}} = 150 \text{ kVAR}$$

$$\frac{3 \times (11000)^2}{X_{C_{ph}}} = 150 \times 10^3$$

$$X_{C_{ph}} = 2420 \Omega$$

$$\frac{1}{2\pi f C} = 2420 \Omega$$

$$C = \frac{1}{2\pi \times 50 \times 2420}$$

$$= 1.3153 \mu\text{F}$$

$$\approx 1.316 \mu\text{F}$$

08. Ans: (c)

Sol: Given Data:

Let the initial power factor angle = ϕ_1

After connecting a capacitor, the power factor angle = ϕ_2

$$\text{Given } \phi_2 = \cos^{-1} 0.97$$

$$= 14.07^\circ$$

$P(\tan \phi_1 - \tan \phi_2) = \text{kVAR supplied by capacitor}$

$$4 \times 10^6 (\tan \phi_1 - \tan 14.07) = 2 \times 10^6$$

$$\phi_1 = 36.89^\circ$$

$$\cos \phi_1 = 0.8 \text{ lag}$$

Hence if the capacitor goes out of service the load power factor becomes 0.8 lag

09. Ans: (d)

Sol: The appearance will inject leading VARs into the system is induction generator, under excited synchronous generator, under excited synchronous motor and induction motor.

10. Ans: (a, c)

Sol: Shunt capacitor is employed to improve power factor

$$P = \frac{EV}{X} \sin \delta$$

By adding the reactor series, reactance of the line increasing which limits the fault current.

11. Ans: (a, d)

Sol: Reactive power (Q) = $P \tan \phi$

$$= 300 \times \tan[\cos^{-1}(0.6)]$$

$$= 400 \text{ kVr}$$

$$\text{pf} = \frac{P}{\sqrt{P^2 + Q^2}}$$

$$= \frac{100}{\sqrt{(100)^2 + (400)^2}} = 0.24 \text{ lead}$$

2.7. Under ground cables

01.

Sol: Given data:

$$L = 5 \text{ km}$$

$$C = 0.2 \text{ } \mu\text{F/km}$$

$$E_r = 3.5 \text{ core } d = 1.5 \text{ cm,}$$

$$r = 0.75 \text{ cm}$$

$$V = 66 \text{ kV, } 50\text{Hz} = f$$

$$D = ?$$

$$E_{r(\text{rms})} = ? \quad I_{c(\text{rms})} = ?$$

- (a) Concentric cable: core a placed exactly of the center of the cable

$$C_{\text{Ph}} = \frac{2\pi\epsilon_0\epsilon_r}{\ln(D/d)} \text{ F/M}$$

$$C = 0.2 \times 10^{-6} \times 10^3$$

$$C = 0.2 \times 10^{-3}$$

$$0.2 \times 10^{-3} = \frac{2\pi \times 8.854 \times 10^{-12} \times 3.5}{\ln\left(\frac{D}{d}\right)}$$

$$\ln\left(\frac{D}{d}\right) = \frac{2\pi \times 8.854 \times 10^{-12} \times 3.5}{(0.2 \times 10^{-3})}$$

$$= 9.731 \times 10^{13}$$

$$\ln\left(\frac{D}{d}\right) = 0.9731$$

$$\frac{D}{d} = e^{0.9731}$$

$$D = d \times e^{0.9731} = 1.5 \times e^{0.9731}$$

$$D = 3.9707 \text{ cm}$$

(b) $E_{r(\text{rms})} = \frac{V}{r \ln\left(\frac{R}{r}\right)} \quad \frac{R}{r} = \frac{D}{d}$

$$= \frac{66}{0.75 \ln\left(\frac{3.97}{1.5}\right)}$$

$$E_{\text{rms}} = 90.413 \text{ kV/cm}$$

(c) At charging current $= I_C \times l$

$$= 4.146 \times 5$$

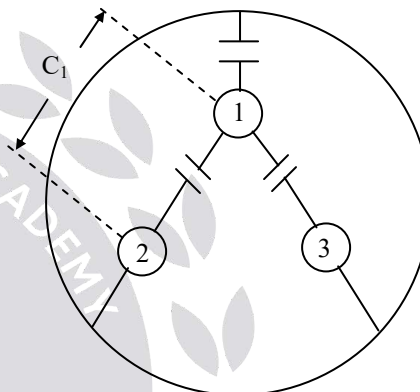
$$= 20.73 \text{ A}$$

02. **Ans: (b)**

Sol: Given data:

$$V = 11 \text{ kV; } C_1 = 0.6 \text{ } \mu\text{F; } C_2 = 0.96 \text{ } \mu\text{F}$$

(i)



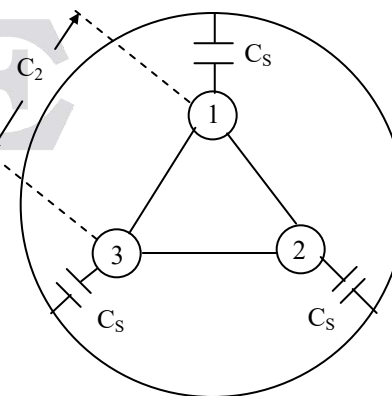
$$C_1 = 0.6 \text{ } \mu\text{F (given)}$$

From network

$$C_1 = C_S + 2 C_C$$

$$\Rightarrow C_S + 2 C_C = 0.6 \text{ } \mu\text{F} \dots\dots\dots (1)$$

(ii)



$$C_2 = 0.96 \text{ } \mu\text{F (given)}$$

From network

$$C_2 = 3 C_S \Rightarrow 0.96 \text{ } \mu\text{F}$$

$$C_S = 0.32 \mu\text{F}$$

From (1)

$$0.32 + 2 C_C = 0.6$$

$$C_C = 0.14 \mu\text{F}$$

Effective capacitance from core to neutral

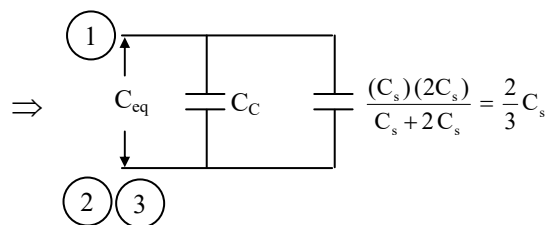
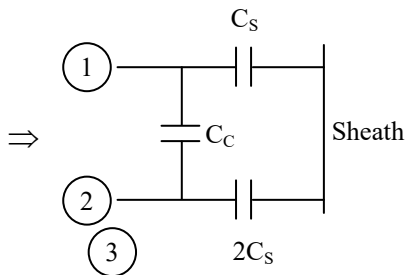
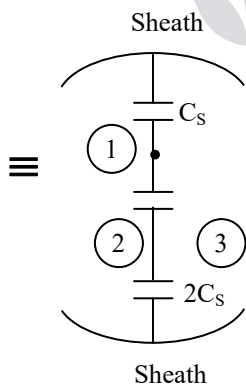
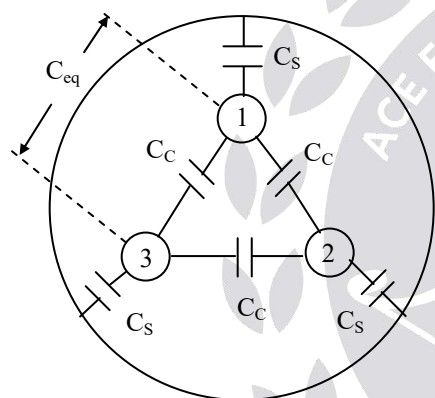
$$C/\text{ph} = C_S + 3 C_C$$

$$= 0.32 + 3 \times 0.14 = 0.74 \mu\text{F}$$

03. Ans: (b)

Sol: Given data:

$$C_C = 0.5 \mu\text{F}; \quad C_S = 0.3 \mu\text{F}$$



$$\begin{aligned} \therefore C_{eq} &= \frac{2}{3} C_S + C_C \\ &= 2 \times 0.5 + \frac{2}{3} \times 0.3 \\ &= 1.2 \mu\text{F} \end{aligned}$$

04. Ans: 38.32kW (Range: 37.5 to 39.5)

Sol: Given data

$$L = 40 \text{ km}$$

$$3\text{-core ground cable} = 12.77 \text{ kVAr/km}$$

$$f = 50 \text{ Hz}$$

$$\text{Dielectric material is } 0.025$$

$$\cos \phi = 0.025$$

$$\phi = \cos^{-1}(0.025)$$

$$\phi = 88.56$$

$$\tan \phi = \frac{Q}{P}$$

$$\begin{aligned} P &= \frac{3 \times 12.77 \times 40}{\tan(88.56)} \\ &= 38.32 \text{ kW} \end{aligned}$$

05. Ans: (a)

Sol: Given data:

$$C_1 = 0.2 \times 10^{-6} \text{ F}, C_2 = 0.4 \times 10^{-6} \text{ F}$$

$$f = 50 \text{ Hz}, V = 11 \text{ kV}$$

$$C/\text{ph} = C_2 + 3C_1$$

$$= 0.4 \times 10^{-6} + 3 \times 0.2 \times 10^{-6}$$

$$= 1 \times 10^{-6} = 1 \mu\text{F}.$$

$$\therefore \text{Per phase charging current} = V_{ph} \omega C_{ph}$$

$$= \frac{11}{\sqrt{3}} \times 10^3 \times 2\pi \times 50 \times 1 \times 10^{-6} = 2 \text{ A.}$$

2.8. Overhead line Insulators

01. Ans: (d)

Sol: Given data:

$$n = 20; \quad 3-\phi;$$

$$V = 400 \text{ kV}; \quad \eta = 80\%$$

$$\eta_{\text{string}} = \frac{V_{ph}}{n \times V_{20}}$$

$$0.8 = \frac{400 \text{ k} / \sqrt{3}}{20 \times V_{20}}$$

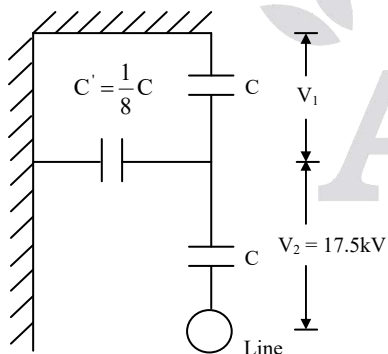
$$\therefore V_{20} = \frac{25}{\sqrt{3}} \text{ kV}$$

02. Ans: (b)

Sol: Given data:

$$V_2 = 17.5 \text{ kV}$$

$$C' = 1/8 C$$



$$V_1 + V_2 = V$$

$$V_2 = (1 + K) V$$

$$V_1 = \frac{V_2}{1+K} = \frac{17.5}{1+\frac{1}{8}} \text{ kV}$$

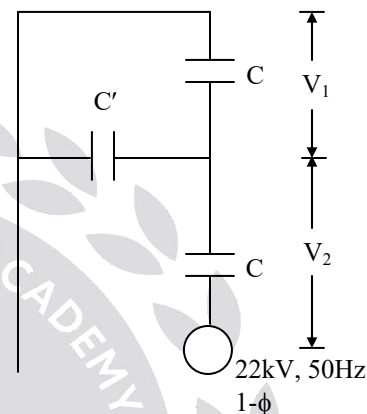
$$V_1 = 15.55 \text{ kV}$$

$$V = V_1 + V_2 = 33.05 \text{ kV}$$

03. Ans: (b)

Sol: Given data:

$$V = 22 \text{ kV}, \quad f = 50 \text{ Hz}$$



$$\eta_{\text{string}} = \frac{V_1 + V_2}{2 V_2} = \frac{V_1 + (1+K) V_1}{2 \times V_1 (1+K)}$$

$$= \frac{2+K}{2} = \frac{2+1}{2(1+1)} = \frac{3}{4} = 75\%$$

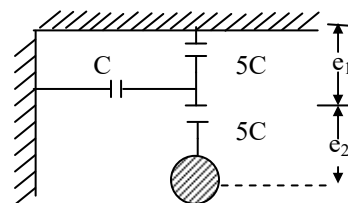
04. Ans: (b)

Sol: Given data:

$$f = 50 \text{ Hz}$$

$$V = 11 \text{ kV}$$

Capacitance of insulators is 5 times the shunt capacitance between the link and the ground.



$$e_2 = e_1 (1 + K)$$

$$e_1 + e_2 = \frac{11}{\sqrt{3}}$$

$$K = \frac{C}{5C} = \frac{1}{5} = 0.2$$

$$\therefore e_1 (1 + K) + e_1 = \frac{11}{\sqrt{3}} \times 10^3$$

$$e_1 (2 + K) = \frac{11}{\sqrt{3}} \times 10^3$$

$$e_1 = 2.8867 \approx 2.89 \text{ kV}$$

$$e_2 = e_1 (1 + K)$$

$$= 2.8867 \times 1.2$$

$$= 3.46 \text{ kV.}$$

05. Ans: (a, b & c)

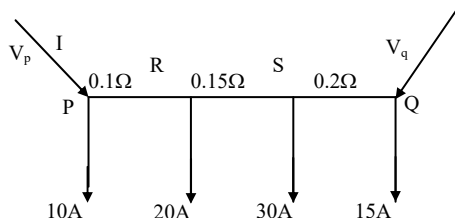
Sol: Insulator used in power system should be

- have high mechanical strength
- have zero (or) low leakage current
- have ability to withstand high temperature

2.10. Distribution Systems

01. Ans: (a)

Sol: Given data:



Let “ V_D ” be the drop of voltage in line

Applying KVL,

$$V_P - V_D - V_Q = 0$$

$$V_P - V_Q = V_D$$

$$V_D = V_P - V_Q = 3V$$

$$\text{But } V_D = (I - 10)0.1 + (I - 30)0.15 + (I - 60)0.2$$

$$3 = 0.45I - 17.5$$

$$I = \frac{20.5}{0.45} = 45.55A$$

$$\therefore V_D = 35.55 \times 0.1 + 15.55 \times 0.15 + 14.45 \times 0.2$$

Here we have to take magnitude only

$$\therefore V_D = 8.77$$

$$\therefore V_P = 220 + 8.77 = 228.7V$$

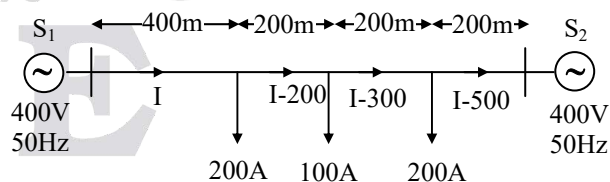
$$V_Q = V_P - 3 = 225.7V.$$

02. Ans: (d)

Sol: Given data:

All the loads are at unity factor. Let us take current in 400 m section as I such that currents in remaining sections are shown.

Assume that loop resistance feeder $r\Omega /m$ (reactance is neglected).



KVL From S_1 and S_2 is given as

$$V_{S1} - V_{S2} = I (400r) + (I - 200) (200r)$$

$$+ (I - 300)(200r) + (I - 500) (200r)$$

$$0 = 400 I + 200I - 200 \times 200 + 200 I$$

$$- 300 \times 200 + 200 I - 500 \times 200$$

$$1000 I = 200000$$

$$I = \frac{200000}{1000} \Rightarrow I = 200 \text{ A as } I = 200 \text{ A,}$$

Contribution to load at point P from source
S₁ is 0A from source S₂ is 100 A.

03 Ans: V_s = 271.04∠2.78°, pf = 0.74 (lag)

Sol: Given Data:

$$V_r = 220$$

$$I_s = 80\angle-36.86 + 50\angle-45 \\ = 129.9\angle-39.98$$

$$V_s = V_r + \Delta V$$

$$\Delta V = (80\angle-36.86)(0.15+j0.2) + \\ (129.9\angle-39.98)(0.15+j0.2) \\ = 52.45\angle-14.33$$

$$V_s = 220\angle^\circ + 52.45\angle14.33 \\ = 271.12\angle2.74$$

$$\text{P.F.} = \cos(\text{angle between } V_s \text{ and } I_{sc}) \\ = \cos(42.72) \\ = 0.734 \text{ lag}$$

3. PU System, Symmetrical Components & Fault Analysis

01. Ans: (b)

$$\text{Sol: } X_{G_1} = j0.09 \times \left(\frac{200}{100}\right) \times \left(\frac{25}{25}\right)^2 \\ = j0.18 \text{ p.u.}$$

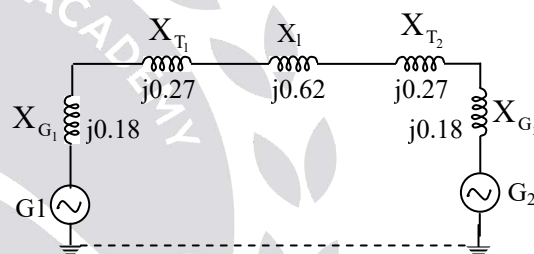
$$X_{T_1} = j0.12 \times \left(\frac{200}{90}\right) \times \left(\frac{25}{25}\right)^2 \\ = j0.27 \text{ p.u.}$$

$$X_1 = X_\Omega \times \frac{MVA_{base}}{(kV_b)^2}$$

$$X_1 = j150 \times \frac{200}{(220)^2} \\ = j0.62 \text{ p.u.}$$

$$X_{T_2} = X_{T_1} \\ = j0.27 \text{ P.u}$$

$$X_{G_2} = j0.09 \times \left(\frac{200}{100}\right) \times \left(\frac{25}{25}\right)^2 \\ = j0.18 \text{ p.u.}$$



02. Ans: (a)

Sol: The value of the load. When referred to generator circuit in per unit is

$$Z_{P,unew} = Z_{P,uold} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{kV_{b\ old}}{kV_{b\ new}}\right)^2 \\ = 0.72 \times \frac{20}{10} \times \left(\frac{69}{13.8}\right)^2 = 36 \text{ p.u}$$

03.

Sol: Given data:

Select the base MVA as 100MVA, Base voltage as 33KV on the Generator side

Base voltage on the line side = 110 kV

$$Z_{pu\ new} = Z_{pu\ old} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{kV_{old}}{kV_{new}}\right)^2$$

Generator:

$$X_{pu \text{ new}} = 0.15 \times \frac{100}{100} \times \left(\frac{33}{33}\right)^2 = 0.15 \text{ pu}$$

Transformer:

$$X_{pu \text{ new}} = 0.09 \times \frac{100}{100} \times \left(\frac{33}{33}\right)^2 = 0.09 \text{ pu.}$$

Transmission line:

$$X_{pu} = 50 \times \frac{100}{(110)^2} = 0.4132 \text{ pu.}$$

Motor 1:

$$X_{pu \text{ new}} = 0.18 \times \frac{100}{30} \times \left(\frac{30}{33}\right)^2 = 0.4958 \text{ pu.}$$

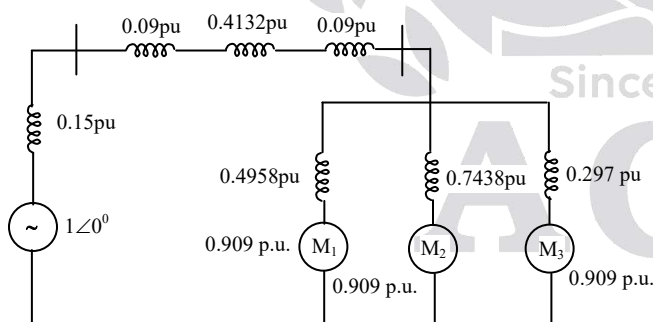
Motor 2:

$$X_{pu \text{ new}} = 0.18 \times \frac{100}{20} \times \left(\frac{30}{33}\right)^2 = 0.7438 \text{ pu.}$$

Motor 3:

$$X_{pu \text{ new}} = 0.18 \times \frac{100}{50} \times \left(\frac{30}{33}\right)^2 = 0.2975 \text{ pu.}$$

The per unit reactance diagram of the system can given in below.



04. Ans: (d)

Sol: Given data:

$$E_a = 10 \angle 0^\circ \text{ V}, E_b = 10 \angle -90^\circ \text{ V}$$

$$E_c = 10 \angle 120^\circ \text{ V},$$

As both sides of the circuit are grounded we can take each branch is considered as one circuit

$$I_a = \frac{E_a}{X_a} = \frac{10 \angle 0^\circ}{j2} = 5 \angle -90^\circ$$

$$I_b = \frac{E_b}{X_b} = \frac{10 \angle -90^\circ}{j3} = 3.33 \angle -180^\circ$$

$$I_c = \frac{E_c}{X_c} = \frac{10 \angle 120^\circ}{j4} = 2.5 \angle 30^\circ$$

Positive sequence current,

$$I_1 = \frac{1}{3} (I_a + aI_b + a^2I_c)$$

$$\text{Where } a = 1 \angle 120^\circ$$

$$\begin{aligned} I_1 &= \frac{1}{3} (5 \angle -90^\circ + 1 \angle 120^\circ \times 3.33 \angle -180^\circ \\ &\quad + 1 \angle 240^\circ \times 2.5 \angle 30^\circ) \\ &= 3.510 \angle -81^\circ \end{aligned}$$

05. Ans: (c)

Sol: $V_{an} = 277 \angle 0^\circ$

$$V_{bn} = 277 \angle -120^\circ$$

$$V_{cn} = 277 \angle +120^\circ$$

$$V_0 = \frac{1}{3} (V_{an} + V_{bn} + V_{cn}) = 0$$

$$V_1 = \frac{1}{3} (V_{an} + \alpha V_{bn} + \alpha^2 V_{cn})$$

$$\begin{aligned} &= \frac{1}{3} [277 \angle 0^\circ + (1 \angle 120^\circ)(277 \angle -120^\circ) \\ &\quad + (1 \angle -120^\circ)(277 \angle 120^\circ)] \end{aligned}$$

$$= \frac{1}{3} [3 \times 277 \angle 0^\circ] = 277 \angle 0^\circ \text{ V}$$

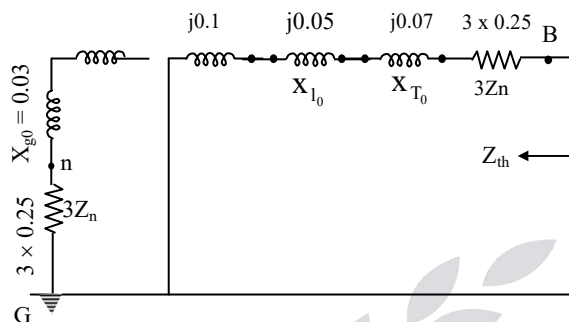
$$V_2 = \frac{1}{3} (V_{an} + \alpha^2 V_{bn} + \alpha V_{cn})$$

$$\begin{aligned} &= \frac{1}{3} [277 \angle 0^\circ + (1 \angle 240^\circ)(277 \angle -120^\circ) \\ &\quad + (1 \angle -120^\circ)(277 \angle 120^\circ)] \end{aligned}$$

$$= 0$$

06. Ans: (b)

Sol: Per unit zero sequence reactance diagram of the given single line diagram is shown below.



Thevenin equivalent impedance, Z_{th} at 'B' is $Z_{th} = j0.1 + j0.05 + j0.07 + 0.75 = 0.75 + j0.22$

07. Ans: (b)

Sol: Given data:

$$X_1 = 0.3,$$

$$X_2 = 0.4,$$

$$X_0 = 0.05$$

Fault current = Rated current

$$I_{d.p.u} = 1.0 \text{ p.u.}$$

$$1.0 = \frac{3 E_{R1}}{X_1 + X_2 + X_0 + 3 X_n}$$

$$1.0 (X_1 + X_2 + X_0 + 3 X_n) = 3$$

$$0.3 + 0.4 + 0.05 + 3 X_n = 3$$

$$X_n = 0.75 \text{ p.u.}$$

$$X_{n(\Omega)} = 0.75 \left(\frac{k V_b^2}{MVA_b} \right)$$

$$= 0.75 \left[\frac{13.8^2}{10 \text{ MVA}} \right] = 14.28 \Omega$$

08. Ans: (i) $V_n = 1429$ volts

(ii) $V_n = 1905$ volts

Sol: Given data:

$$(i) X_{1eq} = \frac{j0.1}{2} = j0.05$$

$$X_{2eq} = \frac{j0.1}{2} = j0.05$$

$$X_{0eq} = \frac{X_0 + 3X_n}{2} = j0.1$$

$$I_{R0} = I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{1.0}{j0.2} = 5.0 \text{ p.u.}$$

$$V_n = 3 I_{R0} X_n = 3 \times 5 \times 0.05 = 0.75 \text{ p.u.}$$

$$V_n = 0.75 \times \frac{6.6 \times 10^3}{\sqrt{3}} = 2858 \text{ volts}$$

$$V_n = \frac{2858}{2} = 1429 \text{ volts}$$

$$(ii) X_{1eq} = \frac{j0.1}{2} = j0.05$$

$$X_{2eq} = \frac{j0.1}{2} = j0.05$$

$$X_{0eq} = X_0 + 3X_n = j0.2$$

$$I_{R0} = I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}} = \frac{1.0}{0.3} = 3.33$$

$$V_n = 3 I_{R0} X_n = 3 \times 3.33 \times 0.05 = 0.5 \text{ p.u.}$$

$$V_n = 0.5 \times \frac{6.6 \times 10^3}{\sqrt{3}} = 1905 \text{ Volts}$$

09. Ans: $|I_f| = 8.39 \angle -47.83^\circ \text{ pu.}$

Sol: Given data:

Two identical generators are operate in parallel and positive sequence reactance diagram is given by figure (a).

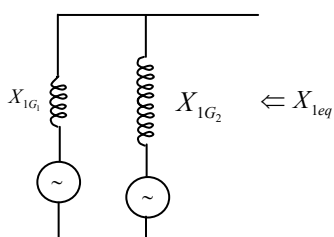


Fig.(a)

$$X_{1eq} = \frac{j0.18}{2} = 0.09 \text{ j p.u.}$$

where X_{1G1} = positive sequence reactance in p.u. of generator (1)

X_{1G2} = positive sequence reactance in p.u. of generator (2)

Negative sequence reactance diagram is given by figure (b).

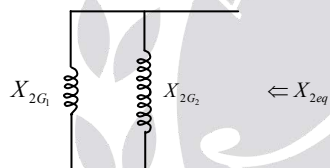


Fig (b)

$$X_{2eq} = \frac{j0.15}{2} = 0.075 \text{ j p.u.}$$

Since the star point of the second generator is isolated. Its zero sequence reactance does not come into picture. The zero sequence reactance diagram is given by figure (c).

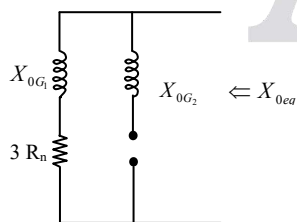


Fig.

Now all values are in p.u. ,then

$$R_{pu} = 0.5 \times \frac{20}{11^2} = 0.08 \text{ pu}$$

$$\therefore X_{0eq} = j0.1 + (3 \times 0.08) = 0.24 + 0.1j$$

For LG Fault, Fault current

$$(I_f) = 3I_{R1} = \frac{3E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$I_f = \frac{3 \times 1}{j0.09 + j0.075 + j0.1 + 0.24}$$

(Assume $E_{R1} = 1.0 \text{ p.u.}$)

$$= \frac{3}{0.24 + j0.265}$$

$$|I_f| = 8.39 \text{ pu}$$

10. Ans: (d)

Sol: Given data:

$$Z_0 = j0.1 + j0.1 = j0.2;$$

$$Z_1 = j0.1 + j0.1 = j0.2$$

$$Z_n = 0.05$$

$$Z_1 = Z_{l1} + Z_{g1}$$

$$Z_2 = Z_{l2} + Z_{g2}$$

$$I_{a1} = \frac{E_a}{Z_0 + Z_1 + Z_2 + 3Z_n}$$

$$= \frac{1}{j0.2 + j0.2 + 0.34j + j0.15}$$

For L-G fault

$$= -j1.12 \text{ (pu)}$$

$$I_B \text{ (Base Current)} = \frac{20 \times 10^6}{\sqrt{3 \times 6.6 \times 10^3}}$$

$$= 1750 \text{ Amp}$$

$$I_f \text{ (fault current)} = (3I_{ac}) I_B$$

$$= -j 5897.6 \text{ A}$$

$$\text{Neutral voltage } V_N = I_f \cdot Z_n$$

$$\text{Where } Z_n = Z_B \times 0.05 = \frac{(6.6)^2}{20} \times 0.05$$

$$= 0.1089 \Omega$$

$$V_N = 5897.6 \times 0.1089 = 642.2 \text{ volts}$$

11. Ans: 7 kA

Sol: Given data: $X_1 = X_2 = j0.1$, $X_f = j0.05$

$$I_{a1} = \frac{E}{X_1 + X_2 + X_f}$$

$$= \frac{1}{j0.1 + j0.1 + j0.05} = \frac{1}{j0.25} = 4 \text{ pu}$$

$$I_{\text{fault}} = \frac{20 \times 10^3}{\sqrt{3} \times 6.6} \times = 7 \text{ kA}$$

12. Ans: $V_{AB} = 13.33 \text{ kV}$

Sol: Given data:

$X_{1eq} = 0.2 \text{ p.u.}$, $X_{2eq} = 0.3 \text{ p.u.}$ and
Alternator neutral is solidly grounded ($X_n = 0$)

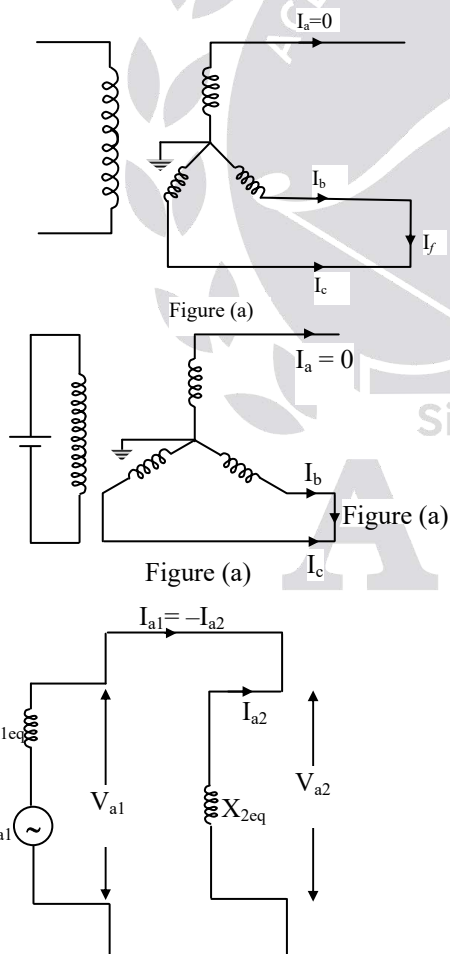


Figure (b) Sequence Network with respective Fig.(a)

From figure (a), $I_b = -I_c$

From figure (b), $I_{a1} = -I_{a2}$

Positive sequence current

$$I_{a1} = \frac{E_{a1}}{X_{1eq} + X_{2eq}}$$

(assume pre-fault voltage $E_{a1} = 1 \text{ pu.}$)

Positive sequence current

$$I_{a1} = \frac{1 + j0}{j0.2 + j0.3} = -2j \text{ pu.}$$

Negative sequence current ($I_{a2} = -I_{a1}$)

$$= 2j \text{ pu.}$$

A zero sequence current doesn't exist in L-L fault because this fault is not associated with the ground

$$\therefore I_{a0} = 0.$$

In this LL fault, fault current ($I_f = |I_b| = |I_c|$)

$$I_b = I_{b0} + I_{b1} + I_{b2}$$

$$= 0 + K^2 I_{a1} + K I_{a2} \quad (\because I_{a1} = -I_{a2})$$

$$= (K^2 - K) I_{a1}$$

$$= [(-0.5 - j0.8667) - (-0.5 + j0.8667)] I_{a1}$$

$$= -j1.732 I_{a1}$$

$$|I_b| = \sqrt{3} I_{a1} = \sqrt{3} \times \frac{E_{a1}}{X_{1eq} + X_{2eq}}$$

$$= \sqrt{3} \times \Rightarrow 3.464 \text{ p.u.}$$

$$\therefore \text{Fault current } (I_f) = |I_b| = |I_c|$$

$$= 3.464 \text{ pu.}$$

$$\text{Base current} = \frac{\text{Base MVA}}{\sqrt{3} \times \text{Base voltage}}$$

$$= \frac{25 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3} = 1093.4 \text{ A}$$

$\therefore$ Fault current in amps,

$$I_{f \text{ actual}} = I_{f \text{ pu}} \times I_{\text{base}}$$

$$= 3.464 \times 1093.4$$

$$= 3787.5 \text{ A.}$$

$$\begin{aligned} V_{a1} &= E_a - I_{a1} X_{1eq} \\ &= 1 + j0 - (-2j)(j0.2) \\ &= 1 - 0.4 = 0.6 \text{ p.u.} \end{aligned}$$

$$V_{a2} = -I_{a2} \times X_{2eq} = -(2j) \times (0.3j) = 0.6 \text{ pu}$$

$$\therefore |V_{a1}| = |V_{a2}| = 0.6 \text{ pu}$$

For Phase 'a',

$$\begin{aligned} V_a &= V_{a1} + V_{a2} + V_{a0} \quad (\because V_{a0} = 0) \\ &= 2V_{a1} = 2 \times 0.6 = 1.2 \text{ pu.} \end{aligned}$$

For Phase 'b',

$$\begin{aligned} V_b &= V_{a0} + \lambda^2 V_{a1} + \lambda V_{a2} \\ &= (k^2 + k)V_{a1} \quad (\because V_{a1} = V_{a2}) \\ &= (-0.5 - 0.8667j) + (-0.5 + 0.8667j)V_{a1} \\ &= -0.6 \text{ pu.} \end{aligned}$$

But we know that $V_b = V_c$

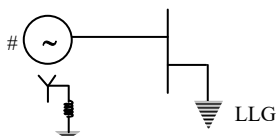
$$\therefore V_b = V_c = -0.6$$

$$\begin{aligned} \text{Line voltages, } V_{ab} &= V_a - V_b \\ &= 1.2 - (-0.6) = 1.8 \text{ p.u.} \\ V_{bc} &= V_b - V_c = 0 \text{ p.u.} \\ V_{ca} &= V_c - V_a \\ &= -0.6 - (1.2) = 1.8 \text{ p.u.} \end{aligned}$$

$$V_{ab} = 1.8 \times \frac{13.2}{\sqrt{3}} = 13.33 \text{ kV,}$$

13. Ans: $I_f = 4.8 \text{ p.u.}$

Sol: Given data:



$$\text{Prefault voltage} = \frac{13.9}{13.2} = 1.05$$

Current through ground = Fault current

$$I_f = 3 I_{a0}$$

$$I_{a0} = -I_{a1} \frac{X_{2eq}}{X_{2eq} + X_{0eq}} \dots\dots\dots (1)$$

$$\begin{aligned} I_{a1} &= \frac{E_{a1}}{X_1 + \frac{X_2 X_0}{X_2 + X_0}} \\ &= \frac{1.05}{0.2 + \left[\frac{0.2 \times (3 \times 0.05 + 0.08)}{0.2 + (3 \times 0.05 + 0.08)} \right]} \\ &= 3.42 \end{aligned}$$

Substitute I_{a1} value in equation (1)

$$\therefore I_{a0} = 3.42 \left[\frac{0.2}{0.2 + (0.15 + 0.08)} \right] = 1.59$$

$$I_f = 3 I_{a0} = 3 \times 1.59 = 4.77 \approx 4.8 \text{ p.u.}$$

$$\begin{aligned} I_{f \text{ amp}} &= 4.77 \left[\frac{15}{\sqrt{3} \times 13.2} \right] \text{ kA} \\ &\approx 3.13 \text{ kA} \end{aligned}$$

14. Ans: $I_{R1} = 6.22 \text{ kA}$

Sol: Given data:

The rating each generator 20 MVA,
6.6 kV, $X_1 = X_2 = 0.12 \text{ pu}$,

$$X_0 = 0.05 \text{ pu}$$

$$X_n = 0.05$$

The sequence reactance $X_1 = X_2 = 0.1 \text{ pu}$

$$X_0 = 0.3 \text{ pu}$$

$$X_{1eq} = \frac{j0.12}{2} + j0.1 = j0.16$$

$$X_{2eq} = X_{1eq} = j0.16$$

$$\begin{aligned} X_{0eq} &= X_0 + 3X_n + X_0 \\ &= j0.05 + 3(j0.05) + j0.3 = j0.5 \end{aligned}$$

$$\begin{aligned} I_{R1} &= \frac{E_{R1}}{X_{1eq} + \frac{X_{2eq} X_{0eq}}{X_{2eq} + X_{0eq}}} \\ &= \frac{1.0}{0.16 + \frac{0.16 \times 0.5}{0.66}} = \frac{1.0}{0.2812} \end{aligned}$$

$$I_{R1} = 3.55 \text{ p.u} = 3.55 \times \frac{20}{\sqrt{3} \times 6.6} = 6.22 \text{ kA}$$

15. Ans: (c)

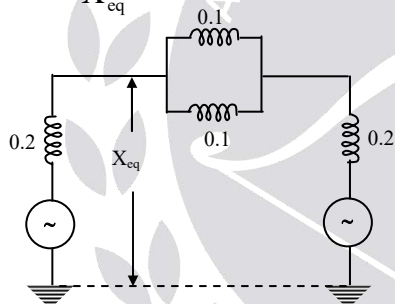
Sol: Equivalent reactance seen from the fault point

$$X_{PU} = \frac{(j0.3 + j0.08) \times (j0.1 + j0.08)}{j0.1 + j0.2 + j0.08 + j0.08 + j0.1} = j0.12214$$

$$\text{Fault level current} = 1/X_{(PU)} = 1/j0.12214 = -j8.1871$$

16. Ans: (c)

Sol: SC MVA = $\frac{\text{Base MVA}}{X_{eq}}$



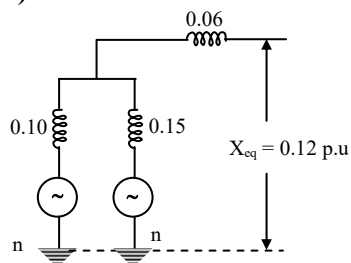
$$X_{G2} \text{ New} = 0.16 \left[\frac{1000}{800} \right] = 0.2$$

$$X_{eq} = \frac{0.2 \times 0.25}{0.45} = \frac{1}{9}$$

$$\therefore \text{SC MVA} = \frac{1000}{(1/9)} = 9000 \text{ MVA}$$

17. Ans: (b)

Sol:



X_{G2} New on 15 MVA Base

$$= 0.10 \left[\frac{15}{10} \right] [1]^2 = 0.15 \text{ p.u}$$

$$I_f = \frac{E_{R1}}{X_{eq}} = \frac{1}{0.12} = 8.33 \text{ p.u}$$

$$I_{fG2} = 8.33 \left[\frac{0.1}{0.25} \right] = 3.33$$

$$\Rightarrow 3.33 \left[\frac{15}{\sqrt{3} \times 11} \right] = 2.62 \text{ kA}$$

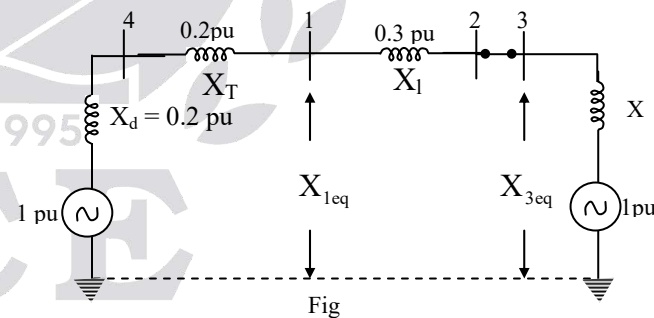
$$I_{fG1} = 8.33 - 3.33 = 5$$

$$I_{fG1(\text{actual})} = 5 \left[\frac{15}{\sqrt{3} \times 11} \right] = 3.93 \text{ kA}$$

18. Ans: $I_f = 11.43 \text{ pu}$

Sol: Given data:

Per unit positive sequence reactance diagram of the given system when the breaker closed is shown in fig.



The equivalent reactance with respect to point "1" is [short circuit 1P.u sources]

$$X_{1eq} = (X_T + X_d) // (X_l + X) = \frac{0.4 \times (0.3 + X)}{0.4 + 0.3 + X} = \frac{0.12 + 0.4X}{0.7 + X}$$

Given prefault voltage (V_{th}) = 1 pu.

$$\therefore \text{Fault current } (I_f) = \frac{V_{th}}{X_{1eq}}$$

$$= \frac{1}{\left(\frac{0.12 + 0.4X}{0.7 + X} \right)} = 5 \text{ pu}$$

$$0.7 + X = 5(0.12 + 0.4X)$$

$$\therefore X = 0.1 \text{ pu}$$

To find fault level at bus '3':

The equivalent reactance w.r.t. point '3' in reactance diagram is

$$X_{3eq} = (X_d + X_T + X_I) // X$$

$$= (0.2 + 0.2 + 0.3) // 0.1$$

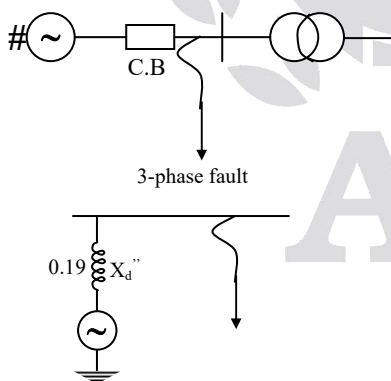
$$= \frac{0.7 \times 0.1}{0.8} = 0.0875 \text{ pu}$$

$$\therefore \text{Fault current } (I_{f3}) = \frac{V_{th}}{X_{3eq}}$$

$$= \frac{1.0}{0.0875} = 11.43 \text{ pu}$$

19. Ans: (c)

Sol:



For a 3-phase fault

$$\text{Fault current } I_f = \frac{E_{R1}}{X_{1eq}}$$

$$\text{where, } E_{R1} = V_{th} = 1.0 \text{ p.u., } X_{1eq} = X_d''$$

$$\therefore I_f = \frac{1.0}{0.19} = 5.263 \text{ p.u.}$$

$$I_{base} = \frac{110 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 5773.5 \text{ A}$$

$$\therefore I_{f \text{ actual}} = I_{base} \times I_f \text{ p.u.}$$

$$= 5773.5 \times 5.263 = 30.39 \text{ kA}$$

20. Ans: (d)

Sol: In phasor diagram $|V_1| > |V_2|$, so fault may not be at location P. If fault occurs at any point, the voltage will be almost 90° lead with the current at that point.

In phasor diagram currents $\bar{I}_1, \bar{I}_2$ are almost 90° lag with respect to V_{S1} .

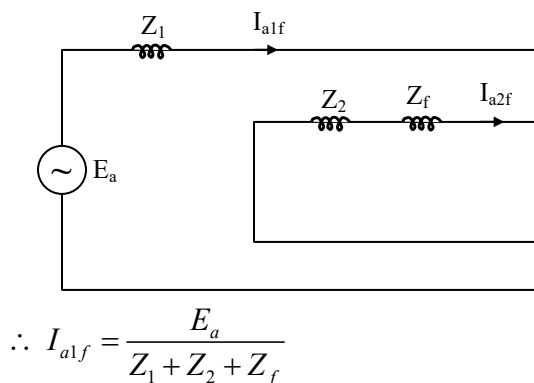
In phasor diagram current $\bar{I}_3, \bar{I}_4$ are almost 90° lead with respect to V_{S2} .

But in given diagram $\bar{I}_3$ and $\bar{I}_4$ are in reverse (or) out of phase.

All the conditions are satisfied if the fault occurs at a point 'S'.

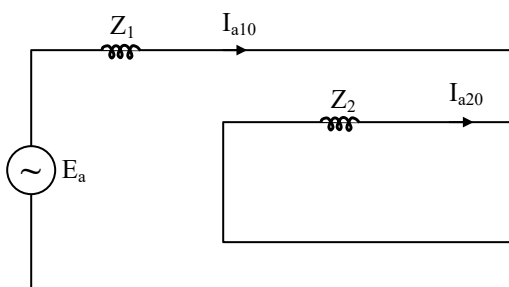
21. Ans: (a)

Sol: For a line to line fault on a generator through a fault impedance of Z_f , the sequence network is as follows.



$$\therefore I_{a1f} = \frac{E_a}{Z_1 + Z_2 + Z_f}$$

Sequence network with zero fault impedance is as follows



$$\therefore I_{a10} = \frac{E_a}{Z_1 + Z_2}$$

$$I_{f1} = kI_f$$

$$-j\sqrt{3}I_{a1f} = k(-j\sqrt{3}I_{a10})$$

$$\frac{E_a}{Z_1 + Z_2 + Z_f} = \frac{kE_a}{Z_1 + Z_2}$$

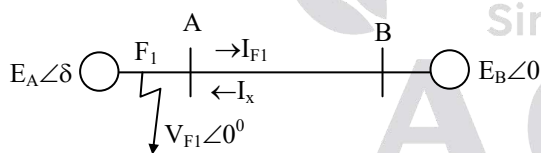
$$Z_1 + Z_2 = kZ_1 + kZ_2 + kZ_f$$

$$Z_1(1 - k) + Z_2(1 - k) = kZ_f$$

$$Z_f = \frac{(Z_1 + Z_2)(1 - k)}{k}$$

22. Ans: (c)

Sol: (i) Fault at F_1



For a fault F_1 :

Both Generator 1 and generator 2 are supplying the fault current the voltage at bus A is due to generator 2. The angle of generator is zero so that the voltage angle at A is negative. Hence V_{F1} lags I_{F1}

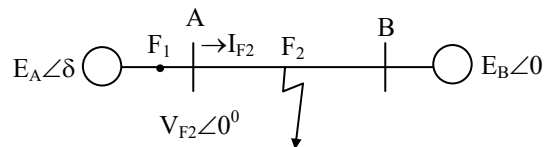
I_x fault current will be $I_x \angle -90^0$

$$I_{F1} = -I_x = (1 \angle 180^0) I_x \angle -90^0$$

$$I_{F1} = I_x \angle 90^0$$

$$\rightarrow V_{F1} \text{ Lags } I_{F1}$$

(ii) Fault at F_2



For a fault F_2 :

Both Generator 1 and generator 2 are supplying the fault current the voltage at bus A due to generator 1 the angle of generator is δ and it is positive so that the voltage angle at bus A is also positive. Hence V_{F2} Leads I_{F2}

Now $\bar{I}_{F2}$ is also $\angle -90^0$

$$\Rightarrow V_{F2} \text{ leads } I_{F2}$$

23. Ans: (a, c)

Sol: For 3- ϕ symmetrical fault,

$$I_f = \frac{1}{X_1} \Rightarrow X_1 = \frac{1}{I_f} = \frac{1}{20} = 0.05 \text{ pu}$$

For LL, fault

$$I_f = -j\sqrt{3}I_{a1}$$

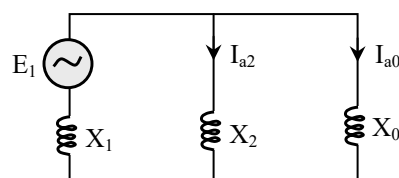
$$I_{a1} = 10 \text{ pu} = \frac{1}{X_1 + X_2}$$

$$X_1 + X_2 = 0.1$$

$$X_2 = 0.1 - 0.05 = 0.05$$

For LG fault

$$I_f = \frac{3}{X_1 + X_2 + X_0}$$



$$I_{a0} = -I_{a1} \times \frac{X_2}{X_2 + X_0}$$

$$I_{a0} = \frac{1}{(X_0 \parallel X_2) + X_1} \times \frac{X_2}{X_2 + X_0}$$

$$10 = \frac{1}{(X_0 \parallel 0.05)} \times \frac{0.05}{0.05 + X_0}$$

$$X_0 = 0.025 \text{ pu}$$

24. Ans: (b, c)

Sol: $L_S = 3 \text{ mH}$; $L_m = 0.1 \text{ mH}$

$$L_0 = L_S + 2L_m$$

$$= 3 + 2(0.1)$$

$$= 3.2 \text{ mH}$$

$$L_{01} = L_{02} = L_S - L_m = 3 - 0.1 = 2.9 \text{ mH}$$

25. Ans: (a)

Sol:
$$\begin{bmatrix} Z_{a0} \\ Z_{a1} \\ Z_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Z_a \\ Z_b \\ Z_c \end{bmatrix}$$

$$Z_{a1} = \frac{1}{3}(Z_a + aZ_b + a^2Z_c)$$

4. Power Systems Stability

01. Ans: (i) 180 MJ (ii) 23.54 k N-m

(iii) 184.9 Elec.deg/sec²

Sol: Given data:

$$H = 9 \text{ kW} - \text{sec/kVA}$$

K.E = stored?

(i) Inertia constant $H = \frac{\text{K.E stored}}{\text{rating of the machine}}$

$$\text{K.E stored} = H \times S$$

$$= 9 \times 20 \text{ MVA}$$

$$= 180 \text{ MW} - \text{sec} \Rightarrow 180 \text{ MJ}$$

(ii) Accelerating torque $T_a = ?$

$$P_a = T_a \omega \quad T_a = \frac{P_a}{\omega}$$

$$P_a = P_s - P_e$$

$$P_s = 26800 \times 0.735 = 1998 \text{ kW}$$

$$P_a = 19698 - 16000 = 3698 \text{ kW}$$

$$T_a = \frac{3698}{\frac{2\pi \times 1500}{60}} = 23.54 \text{ kN} - \text{m.}$$

(iii) $M \frac{d^2\delta}{dt^2} = P_a$

$$M = \frac{SH}{\pi f} = \frac{180}{180 \times 50} = 0.02$$

$$0.02 \times \frac{d^2\delta}{dt^2} = 3698$$

$$\frac{d^2\delta}{dt^2} = \frac{3698}{0.02} = 184.9 \text{ elec. deg/sec}^2$$

02. Ans: (c)

Sol: Given data:

$$N_s = 3000,$$

$$f = 60 \text{ Hz,}$$

$$S = \frac{P}{\cos \phi} = \frac{60 \text{ MW}}{0.85} = 70.58 \text{ MVA}$$

$$H = \frac{\frac{1}{2} I \omega_s^2}{S} \text{ due to moment of Inertia, there}$$

is no sudden change in angular velocity

$$= \frac{\frac{1}{2} I \left(\frac{2\pi N_s}{60} \right)^2 \times 10^{-6}}{70.58}$$

$$= \frac{\frac{1}{2} (8800) \left(\frac{2\pi \times 3000}{60} \right)^2 \times 10^{-6}}{70.58}$$

$$= 6.152 \text{ MJ/MVA}$$

$$M = \frac{SH}{180f} = \frac{70.58 \times 6.15}{180 \times 50} = 0.04825$$

03. Ans: (d)

Sol: Inertia constant, $H \propto \frac{1}{\text{MVA rating}(S)}$

$$H_{A \text{ new}} = H_{A \text{ old}} \times \frac{S_{\text{old}}}{S_{\text{new}}}$$

$$= 1.6 \times \frac{250}{100} = 4.0 \text{ pu}$$

$$H_{B \text{ new}} = H_{B \text{ old}} \times \frac{S_{\text{old}}}{S_{\text{new}}}$$

$$= 1.0 \times \frac{500}{100} = 5.0 \text{ pu}$$

$$\therefore H_{\text{eq}} = H_{A \text{ new}} + H_{B \text{ new}}$$

$$= 4.0 + 5.0 = 9.0 \text{ pu}$$

04. Ans: $f_n = 1.53 \text{ Hz}$

Sol: Given data:

Since the system is operating initially under steady state condition, a small perturbation in power will make the rotor oscillate. The natural frequency of oscillation is given by

$$f_n = \left(\frac{\left(\frac{dp_e}{d\delta} \right)_{\delta_0}}{M} \right)^{\frac{1}{2}}$$

As load increases, load angle (δ) increases, there by $\sin \delta_0$ increases.

$\therefore \sin \delta_0 = \text{loading}$

At 60% of loading $\sin \delta_0 = 0.6$
 $\delta_0 = 36.86$

We know that $P_e = \frac{EV}{X} \sin \delta_0$,

where E = no-load voltage,

V = load voltage

$$\frac{dP_e}{d\delta} = \frac{EV}{X} \cos \delta_0$$

$$\Rightarrow \frac{1.1 \times 1}{(0.3 + 0.2)} \cos 36.86 = 1.76$$

$$\text{Moment of inertia } M = \frac{SH}{\pi f},$$

where S = Rating of the machine,

f = frequency,

Inertia constant, $H = 3 \text{ MW-sec/MVA}$

($\therefore$ Assume rating of machine 1 pu.)

$$= \frac{1 \times 3}{\pi \times 50} \Rightarrow \frac{3}{50\pi}$$

The natural frequency of oscillation at 60% loading,

$$f_n = \left\{ \left(\frac{dP_e}{d\delta} \right)_{\delta_0} / M \right\}^{1/2}$$

$$= \left(1.76 \times \frac{50\pi}{3} \right)^{\frac{1}{2}} \Rightarrow 9.6 \text{ rad/sec}$$

$$= \frac{9.6}{2\pi} \text{ Hz} = 1.53 \text{ Hz}$$

05. Ans: 12.7

Sol: $H = \frac{1000}{250} = 4 \text{ MJ}; \delta = 10^\circ$

$$P_s = P_e = 60 \text{ MW}$$

$$\delta = \delta + \Delta \delta$$

$$\Delta \delta = \delta \frac{(\Delta t)^2}{2} = \frac{P_s - P_e}{M}$$

$$= \frac{(\Delta t)^2}{2} = \frac{60 - 0}{5H} \times \frac{(0.1)^2}{2}$$

$$= \frac{(0.1)^2}{2} = \frac{0.01}{2} = 0.005$$

$$\Delta\delta = \frac{60 \times 186 \times 50}{250 \times 4} \times \frac{(0.1)^2}{2}$$

$$6 \times 180 \times 5 \times \frac{(0.1)^2}{2} = 2.7^\circ$$

$$\delta = 10 + 2.7 = 12.7^\circ$$

06. Ans: 27 deg

Sol: Given data:

$$E = 1.1 \text{ pu} \quad V = 1.0 \text{ pu}$$

Assuming inertia constant (H) = 1 pu

$$P = \frac{EV}{X} \sin \delta$$

$$X = j0.015 + j0.015 = j0.030 \text{ pu}$$

$$\sin \delta = \frac{PX}{EV}$$

$$= \frac{j0.3 \times 1}{1.1 \times 1.0} = 0.2727$$

$$\delta = 15.82^\circ$$

$$M = \frac{GH}{\pi f} = 1.11 \times 10^{-4} \text{ pu}$$

$$P_{a(+)} = \frac{1.0 - 0.0}{2} = 0.5$$

$$\alpha(0_+) = \frac{0.5}{1.11 \times 10^{-4}} = 4504 \text{ deg/sec}^2$$

$$\Delta\delta_1 = (\Delta t)^2 \alpha(0.05)^2 \times 4504 = 11.26 \text{ deg}$$

$$\begin{aligned} \text{Rotor angle } \delta_1 &= \delta_0 + \Delta\delta_1 \\ &= 15.82 + 11.26 \\ &= 27 \text{ deg} \end{aligned}$$

07. Ans: $\delta_{cr} = 70.336^\circ$

Sol: Given data:

$$\delta = 30^\circ, P_{m2} = 0.5, P_{m3} = 1.5, P_s = 1.0$$

$$\delta_{0(\text{rad})} = 0.52$$

$$\delta_{\max} = 180 - \sin^{-1} \left(\frac{P_s}{P_{m3}} \right)$$

$$= 180 - \sin^{-1} \left(\frac{1.0}{1.5} \right)$$

$$\delta_{\max} = 180 - 41.80 = 138.18$$

$$\delta_{\max} = 138.18 \times \frac{\pi}{180} = 2.41$$

$$\delta_c = \cos^{-1} \left[\frac{1.0(2.41 - 0.523) + 1.5 \cos 138.18 - 0.5 \cos 30^\circ}{1.5 - 0.5} \right]$$

$$= \cos^{-1} \left[\frac{1.00 \times 1.887 + 1.5 \times -0.7452 - 0.5 \times \frac{\sqrt{3}}{2}}{1} \right]$$

$$= \cos^{-1} [1.887 + (-1.1175) - 0.433]$$

$$= \cos^{-1} [1.887 - 1.5505]$$

$$= \cos^{-1} [0.3365] = 70.336^\circ.$$

08. Ans: $\delta_{cr} = 55^\circ$

Sol: Given data:

$$P_s = 1.0 \text{ p.u}$$

$$P_{m1} = 1.8 \text{ p.u}$$

$$X_{1eq} = 0.72 \text{ p.u}$$

$$X_{2eq} = 3.0 \text{ p.u}$$

$$X_{3eq} = 1.0 \text{ p.u}$$

$$P_{m2} = \frac{EV}{X_2}$$

$$= \frac{EV}{X_1} \times \frac{X_1}{X_2}$$

$$P_{m2} = P_{m1} \times r_1 \text{ where } r_1 = \frac{X_1}{X_2}$$

$$P_{m3} = \frac{EV}{X_3} = \frac{EV}{X_1} \times \frac{X_1}{X_3}$$

$$P_{m3} = P_{m1} \times r_2 \text{ where } r_2 = \frac{X_1}{X_3}$$

Substitute these values to get P_{m2} & P_{m3}

$$\therefore P_{m2} = 1.8 \times \frac{0.72}{3.0} = 0.416$$

$$P_{m3} = 1.245$$

$$\delta_0 = \sin^{-1} \left(\frac{P_s}{P_{m1}} \right)$$

$$\delta_0 = 35.17^\circ = 0.614 \text{ rad}$$

$$\delta_{\max} = 180 - \sin^{-1} \left(\frac{P_s}{P_{m3}} \right)$$

$$= 126.56^\circ = 2.208 \text{ rad}$$

$$\delta_{cr} = \cos^{-1} \left[\frac{P_s (\delta_{\max} - \delta_0) + P_{m3} \cos \delta_{\max} - P_{m2} \cos \delta_0}{P_{m3} - P_{m2}} \right]$$

$$\delta_{cr} = \cos^{-1} \left[\frac{1.0(2.208 - 0.614) + 1.245 \cos 126.56 - 0.416 \cos 35.17}{1.245 - 0.416} \right]$$

$$\delta_{cr} = 51.82^\circ \approx 55^\circ$$

09. Ans: $\delta_c = 65^\circ$

Sol: Given data:

$$P_s = P_{e1} = 1.0$$

$$P_{e1} = 2.2 \sin \delta$$

$$P_{m1} = 2.2$$

$$P_{e2} = 0, P_{m2} = 0$$

$$P_{m3} = 0.75 \times 2.2 = 1.65$$

$$\delta_0 = \sin^{-1} \left(\frac{P_s}{P_{m1}} \right) = \sin^{-1} \left(\frac{1}{2.2} \right)$$

$$= 27^\circ \times \frac{\pi}{180} = 0.471$$

$$\delta_m = 180 - \sin^{-1} \left(\frac{P_s}{P_{m3}} \right)$$

$$= 180 - \sin^{-1} \left(\frac{1.0}{1.65} \right) = 142.7^\circ$$

$$\delta_m = 142.7 \times \frac{\pi}{180} = 2.48 \text{ rad}$$

$$\delta_c = \cos^{-1} \left[\frac{P_s (\delta_m - \delta_0) + P_{m3} \cos \delta_m}{P_{m3}} \right]$$

$$\cos^{-1} \left[\frac{1.0(2.48 - 0.471) + 1.65 \cos(142.7)}{1.65} \right]$$

$$\delta_c = \cos^{-1} \left[\frac{(2.48 - 0.471) - 1.31}{1.65} \right]$$

$$= \cos^{-1} [0.423] = 65^\circ$$

10. Ans: $\delta_c = 84^\circ$

Sol: Given data:

$$P_s = P_{e1} = 1.0$$

$$P_{e1} = 2.2 \sin \delta$$

$$P_{m1} = 2.2$$

$$P_{e2} = 0, P_{m2} = 0$$

$$P_{m3} = P_{m1} = 2.2$$

$$\delta_0 = 27^\circ$$

$$\delta_0(\text{rad}) = 0.471$$

$$\delta_m = 180 - \delta_0 = 153^\circ = 153 \times \frac{\pi}{180} = 2.66$$

$$\delta_c = \cos^{-1} \left[\frac{1.0(2.66 - 0.471) + 2.2 \cos(153)}{2.2} \right]$$

$$\delta_c = \cos^{-1} \left[\frac{2.66 - 0.471 - 1.96}{2.2} \right]$$

$$\delta_c = 84^\circ$$

11. Ans: 0.20682 sec

Sol: Given data:

$$S = 1.0, H = 5, \delta = 68.5^\circ, \delta_0 = 30, P_s = 1.0$$

$$t_c = \sqrt{\frac{2M(\delta_c - \delta_0)}{P_s}}$$

$$t_c = \sqrt{\frac{2 \times SH (\delta_L - \delta_0)}{\pi f (P_s)}}$$

$$t_c = \sqrt{\frac{2 \times 1.0 \times 5(68.5 - 30) \times \frac{\pi}{180}}{\pi \times 50 \times 1.0}}$$

$$= 0.20682 \text{ sec}$$

12. Ans: Permissible increase = 60.34°

Sol: Given data:

$$P_s = 2.5 \text{ p.u.}$$

$$P_{\max 1} = 5.0 \text{ p.u.}$$

$$\therefore \text{Before fault } \frac{d\delta}{dt} = 0, \delta = \delta_0, P_a = 0$$

$$P_s = P_{e1}$$

$$P_s = P_{\max 1} \sin \delta_0 \Rightarrow \delta_0 = \sin^{-1} \left[\frac{P_s}{P_{\max 1}} \right]$$

$$\delta_0 = \sin^{-1} \left[\frac{2.5}{5} \right]$$

$$\delta_0 = 30^\circ \Rightarrow 0.523 \text{ rad}$$

$$P_{\max 2} = 2 \text{ p.u.}$$

$$P_{\max 3} = 4 \text{ p.u.}$$

$$\delta_{\max} = 180^\circ - \sin^{-1} \left[\frac{P_s}{P_{\max 3}} \right]$$

$$= 180 - \sin^{-1} \left[\frac{2.5}{4} \right]$$

$$= 180 - 36.68$$

$$\delta_{\max} = 141.32^\circ \Rightarrow 2.4664 \text{ rad}$$

$$\cos \delta = \frac{P_s [\delta_{\max} - \delta_0] \times \frac{\pi}{180} + P_{\max 3} \cos(\delta_{\max}) - P_{\max 2} \cos(\delta_0)}{P_{\max 3} - P_{\max 2}}$$

$$= \frac{2.5[141.32 - 30] \times \frac{\pi}{180} + 4 \cos(141.32) - 2 \cos(30^\circ)}{4 - 2}$$

$$= \frac{4.84 + (-3.122) - 1.73}{2}$$

$$\cos \delta_c = -6 \times 10^{-3}$$

$$\delta_c = \cos^{-1}(-6 \times 10^{-3}) \Rightarrow 90.34^\circ$$

$$\text{Permissible increases} = \delta_c - \delta_0$$

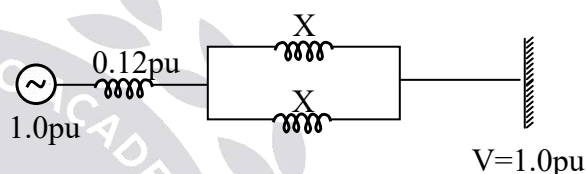
$$= 90.34^\circ - 30^\circ$$

$$= 60.34^\circ$$

13. Ans: (d)

Sol: Given data:

$$V = 1.0 \text{ pu}; \chi_T = 0.12 \text{ pu}; |E| = 1.0 \text{ pu}$$



when one of the double circuit tripped, then

$$P_{m2} = \frac{1 \times 1}{0.12 + x} = \frac{1}{0.2} = 5 \text{ pu}$$

14. Ans: (c)

Sol: Before fault

Mechanical input to alternator

$(P_s) = \text{electrical output } (P_e) = 1.0 \text{ P.u.}$

Given $\delta = 30^\circ$, $V = 1.0 \text{ P.u.}$

During fault

$$X_{eq} = \frac{1}{0.8} \text{ pu}$$

$$E = 1.1 \text{ p.u.}, V = 1.0 \text{ P.u.}$$

' δ ' value cannot change instantaneously.

$\therefore$ Initial accelerating power

$$(P_a) = P_s - P_e$$

$$P_a = 1.0 - \frac{1.1 \times 1.0}{\left(\frac{1}{0.8}\right)} \sin 30^\circ$$

$$P_a = 0.56 \text{ P.u.}$$

15. Ans: (a, d)

$$\text{Sol: } KE = \frac{1}{2} J \omega_s^2 = \frac{1}{2} \times 10^4 \times \left(\frac{4\pi \times 50}{2} \right)^2$$

$$= 493.5 \text{ MJ}$$

$$H = \frac{KE}{MVA} = \frac{493.5}{100} = 4.93 \text{ sec}$$

$$H = \frac{\frac{1}{2} M \omega_s}{G}$$

$$M = \frac{2GH}{\omega_s} = \frac{2GM}{2\pi f} = \frac{GH}{\pi f}$$

$$M = \frac{4.93 \times 100}{\pi \times 50} = 3.14 \text{ MJ/elec.rad}$$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{2} = 3000 \text{ rpm}$$

$$\omega_s = \frac{2\pi \times 3000}{60} = 314.16 \text{ rad/sec}$$

16. Ans: a, b, c & d)

Sol: Power system transient stability can be improved by

1. Kinetic energy (KE) is 493.5 MJ
2. Inertia constant M is 0.0493 MJ sec per elec.rad
3. Inertia constant H = 5.24 sec
4. Angular speed is 314.16 rad/s

17. Ans: (c, d)

Sol: During transient stability analysis using equal area criteria, we assume

- rotor speed of the machine constant
- Accelerating area is higher than the decelerating area for unstable system

For stable system $(A)_{\text{decal}} > (A)_{\text{acel}}$.

5. Load Flow Studies

01. Ans: (a)

Sol: Given data:

$$Y_{23} = j10; y_{23} = -Y_{23} = -j10$$

$$z_{23} = \frac{1}{y_{23}} = j0.1$$

02. Ans: (c)

Sol: $Y_{11} = y_{13} + y_{12}$

$$= (j0.2)^{-1} + (j0.5)^{-1} = -j7$$

$$Y_{22} = y_{21} + y_{23}$$

$$= (j0.5)^{-1} + (j0.25)^{-1} = -j6$$

$$Y_{33} = y_{31} + y_{32}$$

$$= (j0.2)^{-1} + (j0.25)^{-1} = -j9$$

03. Ans: (a)

Sol: $Y_{11} = (-j30) + (j10) = -j20$

$$Z_{11} = j0.05$$

$$Y_{12} = -j10$$

$$Z_{12} = j0.1$$

04. Ans: (b)

Sol: Given data:

We know that

$$Y_{22} = y_{21} + y_{22} + y_{23}$$

$$Y_{21} = -y_{21} \quad Y_{23} = -y_{23}$$

$$\text{From the data, } Y_{22} = -18, Y_{21} = 10,$$

$$Y_{23} = 10$$

$$Y_{22} = ?$$

$$-18 = (-10) + y_{22} + (-10)$$

$$\Rightarrow y_{22} = 20 - 18$$

$$\text{Shunt Susceptance, } y_{22} = 2.$$

05. Ans: $Y''_{13} = j0.8$

Sol: $Y_{Bus} = j \begin{bmatrix} -14.4 & 10 & 5 \\ 10 & -11.5 & 2.5 \\ 5 & 2.5 & -6.3 \end{bmatrix}$

$$Y_{11} = \frac{Y'_{12}}{2} + \frac{Y'_{13}}{2} + Y_{12} + Y_{31} = -14.4$$

$$Y_{12} = -Y_{12} = j10$$

$$Y_{23} = -Y_{23} = j2.5$$

$$Y_{31} = -Y_{31} = j5$$

$$Y'_{12} + Y'_{31} = 2[-j14.4 + j10 + j5]$$

$$= j1.2 \dots\dots\dots(1)$$

Similarly

$$Y'_{12} + Y'_{23} = 2[-j11.5 + j10 + j2.5]$$

$$= j2 \dots\dots\dots(2)$$

$$Y'_{23} + Y'_{31} = 2[j(5 + 2.5 - 6.3)]$$

$$= j2.4 \dots\dots\dots(3)$$

$$Y'_{12} + Y'_{31} = j1.2 \dots\dots\dots(1)$$

Subtracting (2) and (3)

$$Y'_{12} + Y'_{23} - Y'_{23} - Y'_{31} = j2 - j2.4$$

$$\Rightarrow Y'_{12} - Y'_{31} = -j0.4 \dots\dots\dots(4)$$

Solving equation (1) & (4) we get

$$Y''_{13} = j0.8$$

06. Ans: $Y_{bus} = j \begin{bmatrix} -14.76 & 10 & 5 \\ 10 & -13.72 & 4 \\ 5 & 4 & -8.64 \end{bmatrix}$

Sol: $z_{12} = j0.001 \times 100 = j0.1$

$$y_{12} = -j10$$

$$z_{13} = j0.001 \times 200 = j0.2$$

$$y_{13} = -j5$$

$$y_{23} = j0.001 \times 250 = j0.25$$

$$y_{23} = -j4$$

$$y'_{12} = j0.0016 \times 100 = j0.16$$

$$y'_{13} = j0.0016 \times 200 = j0.32$$

$$y'_{23} = j0.0016 \times 250 = j0.4$$

$$Y_{11} = y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2}$$

$$= -j10 - j5 + j0.08 + j0.16$$

$$= -j14.76$$

$$Y_{22} = y_{12} + y_{23} + \frac{y'_{12}}{2} + \frac{y'_{23}}{2}$$

$$= -j10 - j4 + j0.08 + j0.2$$

$$= -j13.72$$

$$Y_{33} = y_{13} + y_{23} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2}$$

$$= -j15 - j4 + j0.16 + j0.2$$

$$= -j18.64$$

$$Y_{12} = -y_{12} = j10 + Y_{13} = -y_{13} = j5, Y_{23} = -y_{23} = j4$$

$$y_{BUS} = j \begin{bmatrix} -14.76 & 10 & 5 \\ 10 & -13.72 & 4 \\ 5 & 4 & -8.64 \end{bmatrix}$$

07. Ans: $Y_{bus} = j \begin{bmatrix} -29.76 & 20 & 10 \\ 20 & -27.72 & 8 \\ 10 & 8 & -17.64 \end{bmatrix}$

Sol: $z_{12} = j0.0005 \times j0.05$

$$y_{12} = -20j$$

$$y_{13} = j0.0005 \times 200 = j0.1$$

$$y_{13} = -j10$$

$$z_{23} = j0.0005 \times 250 = j0.125$$

$$y_{23} = -j8$$

$$y'_{12} = j0.0016 \times 100 = j0.16$$

$$y'_{13} = j0.0016 \times 200 = j0.32$$

$$y'_{23} = j0.0016 \times 250 = j0.4$$

$$\begin{aligned} Y_{11} &= y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2} \\ &= -j20 - j10 + j0.08 + j0.16 \\ &= -j29.76 \end{aligned}$$

$$\begin{aligned} Y_{22} &= y_{12} + y_{23} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2} \\ &= -j10 - j8 + j0.16 + j0.2 \\ &= -j17.64 \end{aligned}$$

$$Y_{12} = -y_{12} = j20; Y_{13} = -y_{13} = j10;$$

$$Y_{23} = -y_{23} = j8$$

$$Y_{BUS} = j \begin{bmatrix} -29.76 & 20 & 10 \\ 20 & -27.72 & 8 \\ 10 & 8 & -17.64 \end{bmatrix}$$

08. Ans: $Y_{bus} = j \begin{bmatrix} -14.88 & 10 & 5 \\ 10 & -13.86 & 4 \\ 5 & 4 & -8.82 \end{bmatrix}$

Sol: $z_{12} = 0.001 \times 100 = j0.1$

$$y_{12} = -j10$$

$$z_{13} = j0.001 \times 200 = j0.2$$

$$y_{13} = -j5$$

$$z_{23} = j0.001 \times 250 = j0.25$$

$$y_{23} = -j4$$

$$y'_{12} = j0.0008 \times 100 = j0.08$$

$$y'_{13} = j0.0008 \times 200 = j0.16$$

$$y'_{23} = j0.0008 \times 250 = j0.2$$

$$\begin{aligned} Y_{11} &= y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2} \\ &= -j10 - j5 + j0.04 + j0.08 \\ &= -j14.88 \end{aligned}$$

$$Y_{22} = y_{12} + y_{23} + \frac{y'_{12}}{2} + \frac{y'_{23}}{2}$$

$$\begin{aligned} &= -j10 - j4 + j0.04 + j0.1 \\ &= -j13.86 \end{aligned}$$

$$\begin{aligned} Y_{33} &= y_{13} + y_{23} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2} \\ &= -j5 - j4 + j0.04 + j0.1 \\ &= -j8.82 \end{aligned}$$

$$Y_{12} = -y_{12} = j10;$$

$$Y_{13} = -y_{13} = j5;$$

$$Y_{23} = -y_{23} = j4$$

$$Y_{BUS} = j \begin{bmatrix} -14.88 & 10 & 5 \\ 10 & -13.86 & 4 \\ 5 & 4 & -8.82 \end{bmatrix}$$

09. Ans: 3500 (3500 to 3500)

Sol: Given data:

Number of Buses (N) = 1000

Number of non-zero elements = 8000

$= N + 2N_L$ (N_L = Number of transmission lines)

$$1000 + 2 \times N_L = 8000$$

$$N_L = 3500$$

$\therefore$ Minimum number of transmission lines and transformers = 3500

10. Ans: 14 to 14

Sol: G_1 - Slack bus

G_2 - having reactive power

$$Q_2 \min \leq Q_2 \leq Q_2 \max$$

When it is operating at $Q_2 \max$ means there is a reactive power divergent. Hence it is working as load bus.

$G_2 \rightarrow 2$ equations

$G_3 \rightarrow 1$ equation

$G_4 \rightarrow 1$ equation

$L_1 \rightarrow 2$ equations

$L_2 \rightarrow 2$ equations

$L_5 \rightarrow 2$ equations

$L_6 \rightarrow 2$ equations

$L_3 \rightarrow 1$ equation

$L_4 \rightarrow 1$ equation

Total No. of equations are 14

11. Ans: (b)

Sol: Total No. of buses = 100

Generator bus = $10 - 1 = 9$

Load buses = 90

Slack bus = 1

If 2 buses are converted to PQ from PV it will add 2 unknown voltages to iteration but unknown angles remains constant.

12. Ans: 332 to 332

Sol: 183 Bus power system network, $n = 183$

Number of PQ npq = 150

Number of PV Buses npv = 32

Remaining of PV Buses in slack bus

Number of $|V|$'s to be calculated = npq

Number of δ 's to be calculated = npq + npv

Total simultaneous equations to be solved

$$= (\text{npq}) + (\text{npq} + \text{npv})$$

$$= 150 + 150 + 32 = 332$$

13. Ans: (c)

Sol: Given,

$$P = 1.4 \sin \delta + 0.15 \sin 2\delta \quad \dots\dots\dots(1)$$

$$\text{Initial guess } \delta_0 = 30^\circ = \frac{\pi}{6}$$

$$P = 0.8 \text{ pu}$$

From (1),

$$f(\delta) = P - 1.4 \sin \delta - 0.15 \sin 2\delta$$

$$f'(\delta) = -1.4 \cos \delta - 0.3 \cos 2\delta$$

$$\begin{aligned} f(\delta_0) &= 0.8 - 1.4 \sin 30^\circ - 0.15 \sin(2 \times 30^\circ) \\ &= -0.0299 \end{aligned}$$

$$\begin{aligned} f'(\delta_0) &= -1.4 \cos 30^\circ - 0.3 \cos(2 \times 30^\circ) \\ &= -1.2124 - 0.15 = -1.3624 \end{aligned}$$

According to Newton Raphson method,

$$\delta_{n+1} = \delta_n - \frac{f(\delta_n)}{f'(\delta_n)}$$

$$\delta_1 = \delta_0 - \frac{f(\delta_0)}{f'(\delta_0)}$$

$$\delta_1 = \frac{\pi}{6} - \frac{(-0.0299)}{(-1.3624)}$$

$$\delta_1 = 0.5016 \text{ rad}$$

$$\delta_1 = 28.74^\circ$$

14. Ans: (a, c)

- Sol:**
- PV buses has generator connected to it.
 - Largest generator capacity is considered as slack bus.

6. Load Frequency Control

01. Ans: (c)

Sol: Given data:

Nominal frequency is 60 Hz,

Regulation is 0.1.

When load of 1500 MW,

$$\begin{aligned} \text{The regulation} &= \frac{0.1 \times 60}{1500} \\ &= \frac{6}{1500} \text{ Hz / MW} \end{aligned}$$

02. Ans: (a)

Sol: Given data:

$$D = 2, R = 0.025,$$

We know that Change in load

$$\Delta P_D = -\left(D + \frac{1}{R}\right)\Delta f,$$

where Δf = change in frequency

$$= D + \frac{1}{R} \Rightarrow 2 + \frac{1}{0.025} = 42 \text{ MW / Hz}$$

$$\therefore \text{AFRC} = 42 \text{ MW / Hz}$$

03. Ans: (b)

Sol: Given data:

$$f = 50 \text{ Hz, generator rating} = 120 \text{ MVA}$$

Generator frequency decreases 0.01

$$\frac{\Delta f}{f} = \frac{0.06X}{120}$$

$$\Rightarrow X = \frac{0.01}{50} \times \frac{120}{0.06} = 0.4 \text{ MW}$$

04. Ans: (c)

Sol: Given data:

$$\begin{aligned} \text{The energy stored at no load} &= 5 \times 100 \\ &= 500 \text{ MJ} \end{aligned}$$

Before the steam valves open the energy lost

$$\text{by the rotor} = 25 \times 0.6 = 15 \text{ MJ}$$

As a result of this there is reduction in speed of the rotor and,

$\therefore$ reduction in frequency

$$\begin{aligned} f_{\text{new}} &= \sqrt{\frac{500-15}{500}} \times 50 \\ &= 49.24 \text{ Hz} \end{aligned}$$

05. Ans: (c)

$$\begin{aligned} \text{Sol: \% regulation} &= \frac{\frac{\Delta f}{f}}{\frac{\Delta p}{p}} = \frac{\frac{50-48}{50}}{\frac{100}{100}} \times 100 \\ &= \frac{2}{50} \times 100 = 4\% \end{aligned}$$

7. Circuit Breakers

01. Ans: (a)

Sol: Given data:

$$L = 15 \times 10^{-3} \text{ H}$$

$$C = 0.002 \times 10^{-6} \text{ F}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{15 \times 10^{-3} \times 0.002 \times 10^{-6}}} = 29 \text{ kHz}$$

02. Ans: (b)

Sol: Given data:

$$I = 10 \text{ A, } C = 0.01 \times 10^{-6} \text{ F,}$$

$$L = 1 \text{ H}$$

$$\frac{1}{2} Li^2 = \frac{1}{2} CV^2 \Rightarrow Li^2 = CV^2$$

$$V = i\sqrt{\frac{L}{C}}$$

$$= 10 \left[\sqrt{\frac{1}{0.01 \times 10^{-6}}} \right] = 100 \text{ kV}$$

03. Ans: (a)

Sol: Given data:

Maximum voltage across circuit breakers contacts at current zero point = Maximum value of Restriking voltage (V_{max})

$$V_{\text{rmax}} = 2 \text{ ARV}$$

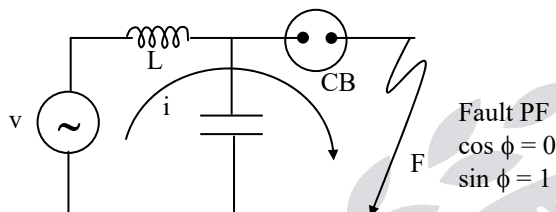
$$\text{ARV} = K_1 K_2 K_3 V_{\text{max}} \sin \phi$$

$$K_1 = 1 \rightarrow \text{No Armature reaction}$$

$$K_2 = 1 \rightarrow \text{Assuming fault as grounded fault}$$

$$K_3 = 1 \rightarrow \text{ARV/phase}$$

$$V_{\text{max}} = \frac{17.32}{\sqrt{3}} \times \sqrt{2}$$



$$V_{\text{rmax}} = 2 \left[1 \times 1 \times 1 \times \frac{17.32}{\sqrt{3}} \times \sqrt{2} \times 1 \right]$$

$$= 28.28 \text{ kV}$$

04. Ans: (d)

$$\text{Sol: Making current} = 2.55 \times I_B$$

$$= 2.55 \left[\frac{2000}{\sqrt{2} \times 25} \right] = 144.25 \text{ kA}$$

05. Ans: (a)

$$\text{Sol: For 1-}\phi, \text{ breaking current} = \left[\frac{2000 \text{ MVA}}{25 \text{ kV}} \right]$$

$$= 80 \text{ kA}$$

$$\text{Making current} = 2.55 [80 \text{ kA}]$$

$$= 204 \text{ kA}$$

06. Ans: (c)

$$\text{Sol: } R = 0.5 \sqrt{\frac{L}{C}}$$

$$= 0.5 \sqrt{\frac{25 \text{ mH}}{0.025 \mu\text{H}}} = 500 \Omega$$

07. Ans: (c)

$$\text{Sol: A.R.V} = K_1 K_2 V_m \sin \phi$$

K_1 – first pole clearing factor

$$K_1 = 1.5 \text{ (LLL fault)}$$

K_2 – Due to armature reaction

$$K_2 = 1 \text{ (Armature reaction not given)}$$

ϕ - p.f angle of the fault

$$\cos \phi = 0.8 \Rightarrow \phi = 36.86^\circ$$

V_m = maximum value of phase voltage of the system

$$V_m = \frac{132 \text{ kV}}{\sqrt{3}} \times \sqrt{2}$$

$$\text{A.R.V} = 1.5 \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times \sin 36.86$$

$$= 96.7 \text{ kV}$$

08. Ans: (a, b & d)

- Sol:**
1. Circuit breaker-Over current protection
 2. Lighening arrester – Over voltage protection
 3. Exciter- Voltage control

8. Protective Relays

01. Ans: (d)

$$\text{Sol: Relay current setting} = 50\% \times 5$$

$$\Rightarrow 0.5 \times 5 \Rightarrow 2.5$$

$$\text{PSM} = \frac{\text{primary current (fault current)}}{\text{relay current setting} \times \text{CT ratio}}$$

$$= \frac{2000}{\frac{400}{5} \times 0.5 \times 5} = 10$$

02. Ans: (c)

Sol: The minimum value of current required for relay operation is the plug setting value of current.

∴ Minimum value of negative sequence

Current required for relay operation

$$= 0.2 \times \frac{5}{1} = 1A$$

But for a line to line fault, $I_{R_2} = -I_{R_1}$

$$\begin{aligned} \text{And fault current } (I_f) &= \sqrt{3} I_{R_2} \\ &= \sqrt{3} \times 1 = 1.732A \end{aligned}$$

∴ Minimum fault current required
= 1.732 A.

03. Ans: (a)

Sol: From figure, it is clear that zone 2 of relay 1 and relay 2 are overlapped. If there is a fault in overlapped section (line 2), the fault should be clear by relay 2. Hence zone 2 operating time of relay 2 must be less than zone 1 operating time. ($TZ2_{R1} > TZ2_{R2}$)

04. Ans: (b)

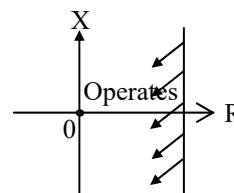
$$\text{Sol: } \frac{I_2}{i_2}; I_2 = 400 \times \frac{11}{66} = \frac{400}{6} = 66.66$$

$$i_2 = \frac{5}{\sqrt{3}} = 2.88$$

$$\frac{I_2}{i_2} = 23:1$$

05. Ans: (b)

Sol: The active power restrained over current relay will have characteristics in R-X plane.



06. Ans: (b)

Sol: CT ratio = $400/5 = 80$

$$\begin{aligned} \text{Relay current setting} &= 50\% \text{ of } 5A \\ &= 0.5 \times 5A \\ &= 2.5A \end{aligned}$$

$$\begin{aligned} \text{PSM} &= \frac{\text{Primary current (fault current)}}{\text{Relay current setting} \times \text{CT ratio}} \\ &= \frac{1000}{2.5 \times 80} = 5 \end{aligned}$$

The operating time from given table at PSM 5 is 1.4 the operating time for TMS of 0.5 will be
 $0.5 \times 1.4 = 0.7 \text{ sec}$

07. Ans: (b)

Sol: $T_{\max} \propto \cos(\theta - \tau)$

When, $\cos(\theta - \tau) = 1$, $T_{\max} = 10$, $\tau = 90^\circ$

Impedance of relay $0.1 + j0.1 = 0.1414 \angle 45^\circ$

$\theta = 45^\circ$

$$\begin{aligned} \text{Operating torque } \frac{T_1}{T_{\max}} &= \frac{\cos(45 - 90)}{1} \\ \frac{T_1}{10} &= \frac{\cos(-45)}{1} \\ T_1 &= 7.07 \text{ N-m.} \end{aligned}$$

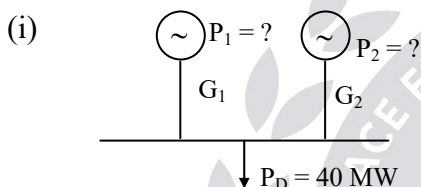
08. Ans: (a, d)

- Sol:**
1. Non-directional relay at the source end
 2. Directional relay at the load end

9. Fundamentals of Power Economics

- 01. Ans: .(i) $P_1 = 20$ MW, $P_2 = 20$ MW,**
 $\lambda = 18.4$ Rs/MWhr
(ii) $P_1 = 125$ MW, $P_2 = 125$ MW,
 $\lambda = 32.5$ Rs/MWhr
(iii) $P_1 = 63.636$ MW, $P_2 = 86.364$ MW,
 $\lambda = 26.36$ Rs/MWhr
(iv) 40 MW; (v) 70 MW; (vi) 250 MW
(vii) 235 MW

Sol:



As per equality constraints $P_1 + P_2 = 40 \dots (1)$

From the coordination equation $I_{C1} = I_{C2}$

$$0.1P_1 + 20 = 0.12P_2 + 16$$

$$0.1P_1 - 0.12P_2 = -4 \dots (2)$$

Solving (1) & (2)

$$P_1 = 3.6363 \text{ MW}$$

$$P_2 = 36.3636 \text{ MW}$$

G_1 violated its min power limit

$$P_1 = P_{1 \min} = 20 \text{ MW}$$

$$P_2 = 40 - 20 = 20 \text{ MW}$$

$$I_{C1} = 0.1 \times 20 + 20 = 22 \text{ Rs/MWhr}$$

$$I_{C2} = 0.12 \times 20 + 16 = 18.4 \text{ Rs/MWhr}$$

λ always decided by the unit (or) group of units which are participated in the economic dispatch.

$$\therefore \lambda = 18.4 \text{ Rs/MWhr}$$

$$(ii) P_D = 250 \text{ MW}$$

$$\therefore P_1 + P_2 = 250 \text{ MW} \dots (3)$$

$$0.1P_1 + 20 = 0.12P_2 + 16$$

$$\Rightarrow 0.1P_1 - 0.12P_2 = -4 \dots (4)$$

Solving (3) and (4)

$$P_1 = 118.1 \text{ MW}, P_2 = 131.81 \text{ MW}$$

G_2 is violating its maximum power limit.

$$\therefore P_2 = 125 \text{ MW}$$

$$\Rightarrow P_1 = 250 - 125 = 125 \text{ MW}$$

$$I_{C1} = 0.1 \times 125 + 20 = 32.5 \text{ Rs/MWhr}$$

$$I_{C2} = 0.12 \times 125 + 16 = 31 \text{ Rs/MWhr}$$

' λ ' is always decided by the unit or group of units which are participated in the economic dispatch.

$$\therefore \lambda = 32.5 \text{ Rs/MWhr}$$

$$(iii) P_D = 150 \text{ MW}$$

$$P_1 + P_2 = 150 \dots (5)$$

$$0.1P_1 + 20 = 0.12P_2 + 16$$

$$\Rightarrow 0.1P_1 - 0.12P_2 = -4 \dots (6)$$

Solving (5) and (6)

$$\Rightarrow P_1 = 63.63 \text{ MW}$$

$$P_2 = 86.36 \text{ MW}$$

$$I_{C1} = 0.1P_1 + 20 = 26.363 \text{ Rs/MWhr}$$

$$I_{C2} = 0.12P_2 + 16 = 26.363 \text{ Rs/MWhr}$$

$$\therefore \lambda = 26.363 \text{ Rs/MWhr}$$

$$(iv) P_{D \min} = P_{1 \min} + P_{2 \min} \dots P_{N \min}$$

$$P_{D \min} = 40 \text{ MW}$$

$$(v) P_{D \min} \text{ economic dispatch}$$

$$P_{D \min} \text{ ED:}$$

It is the minimum demand on two generators, such that both generators operate at the economic dispatch.

To solve for $P_{D \min}$ ED

Solve for $P_D = P_{D \min}$

Calculate P_1 , P_2 and I_{C1} , I_{C2}

$$I_{C \max} = \max \{I_{C1}, I_{C2}\}$$

$$I_{C1} = I_{C \max} \Rightarrow P_1 = ?$$

$$I_{C2} = I_{C \max} \Rightarrow P_2 = ?$$

$P_{D \min} \text{ ED:}$

$$P_D = 40, P_1 = 20; P_2 = 20$$

$$I_{C1} = 22, I_{C2} = 18.4$$

$$I_{C \max} = 22 \text{ Rs/MWhr}$$

$$I_{C1} = I_{C \max}$$

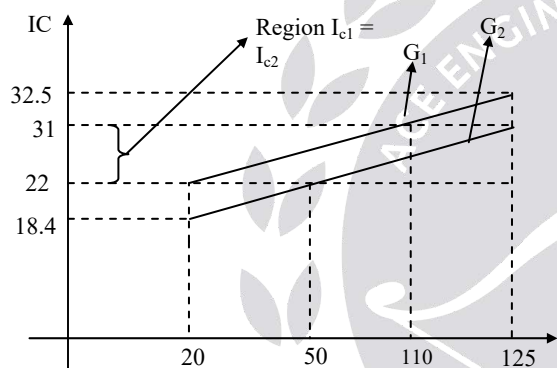
$$0.1P_1 + 20 = 22$$

$$P_1 = 20 \text{ MW}$$

$$0.12 P_2 + 16 = 22$$

$$P_2 = 50 \text{ MW}$$

$$P_{D \min} \text{ ED} = 20 + 50 = 70 \text{ MW}$$



$$\begin{aligned} \text{vi) } P_{D \max} &= P_{1 \max} + P_{2 \max} \\ &= 125 + 125 = 250 \text{ MW} \end{aligned}$$

vii) To solve for $P_{D \max} \text{ ED}$

Solve for $P_D = P_{D \max}$

Calculate P_1, P_2 and I_{C1}, I_{C2}

$$I_{C \min} = \min \{I_{C1}, I_{C2}\}$$

$$I_{C1} = I_{C \min} \Rightarrow P_1 = ?$$

$$I_{C2} = I_{C \min} \Rightarrow P_2 = ?$$

$$P_{D \max} \text{ ED} = P_1 + P_2$$

$$P_{D \max} \text{ ED}$$

$$P_D = P_{D \max} = 250 \text{ MW}$$

$$P_1 = 125 \text{ MW}; P_2 = 125 \text{ MW}$$

$$I_{C1} = 32.5 \text{ \& } I_{C2} = 31$$

$$I_{C \min} = 31$$

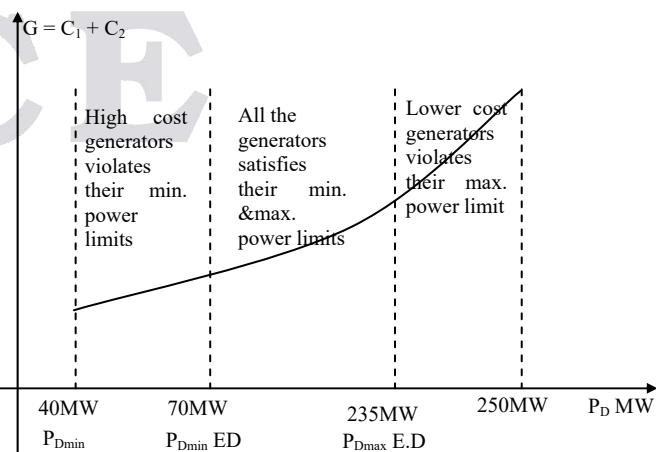
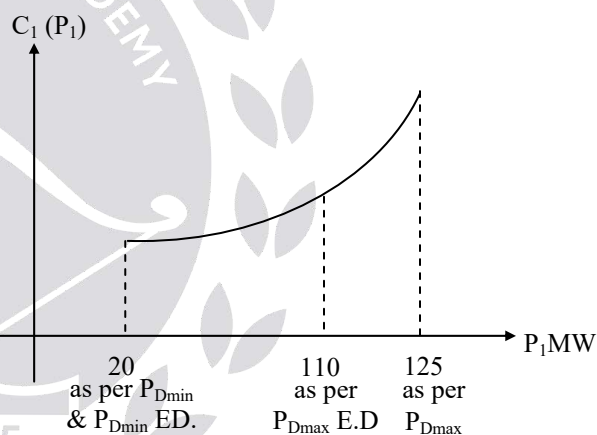
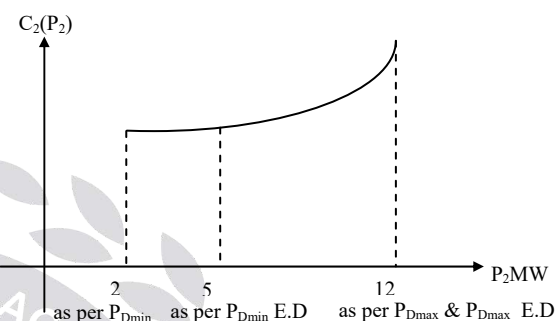
$$I_{C1} = 31 \Rightarrow 0.1P_1 + 20 = 31$$

$$P_1 = 110 \text{ MW}$$

$$I_{C2} = 31 \Rightarrow 0.12P_2 + 16.31$$

$$P_2 = 125 \text{ MW}$$

$$P_{D \max} \text{ ED} = 110 + 125 = 235 \text{ MW}$$



02. Ans: $P_{G1} = 212.44$ MW

$$P_{G2} = 56.51 \text{ MW}$$

$$P_{G3} = 230.98 \text{ MW}$$

Sol: $\frac{dF_1}{dP_1} = -2.5I_{C1}^2 + 60I_{C1} - 120$

$$\frac{dF_2}{dP_2} = -2I_{C2}^2 + 40I_{C2} - 140$$

$$\frac{dF_3}{dP_3} = -1.5I_{C3}^2 + 50I_{C3} - 90$$

$$P_1 + P_2 + P_3 = 500 \text{ MW}$$

Optimal generation schedule

$$I_{C1} = I_{C2} = I_{C3} = \lambda$$

$$-2.5\lambda^2 + 60\lambda - 120 - 2\lambda^2 + 40\lambda - 140$$

$$-1.5\lambda^2 + 50\lambda - 90 = 500$$

$$-6\lambda^2 + 150\lambda - 350 = 500$$

$$6\lambda^2 - 150\lambda + 850 = 0$$

$$\lambda = 16.31; \lambda = 8.68$$

$$P_{G1} = -2.5(8.68)^2 + 60(8.68) - 120$$

$$= 212.44 \text{ MW}$$

$$P_{G2} = -2(8.68)^2 + 40(8.68) - 140$$

$$= 56.51 \text{ MW}$$

$$P_{G3} = -1.5(8.68)^2 + 50(8.68) - 90$$

$$= 230.98 \text{ MW}$$

03. Ans: $P_1 = 326.6$ MW

$$P_2 = 273.33 \text{ MW}$$

Sol: $C_1(PG_1) = 0.006PG_1^2 + 8PG_1 + 350 \rightarrow$

$$100\text{MW} \leq PG_1 \leq 650 \text{ MW}$$

$$C_2(PG_2) = 0.009PG_2^2 + 7PG_2 + 400 \rightarrow$$

$$50\text{MW} \leq PG_2 \leq 500 \text{ MW}$$

$$P_D = 600 \text{ MW}$$

$$\frac{dC_1}{dP_1} = 0.012PG_1 + 8$$

$$\frac{dC_2}{dP_2} = 0.018PG_2 + 7$$

$$\lambda \left[\frac{1}{0.012} + \frac{1}{0.018} \right] = 600 + \left[\frac{8}{0.012} + \frac{7}{0.018} \right]$$

$$\lambda[138.88] = 1655.55$$

$$\lambda = 11.92$$

$$P_1 = \frac{\lambda - \alpha_1}{\beta_1} = \frac{11.92 - 8}{0.012} = 326.6 \text{ MW}$$

$$P_2 = \frac{\lambda - \alpha_2}{\beta_2} = \frac{11.92 - 7}{0.018} = 273.33 \text{ MW}$$

04. Ans: (c)

Sol: Gen A will share more load as its incremental cost is less

05. Ans: $P_1 = 80$ MW, $P_2 = 50$ MW

Sol: $F_1 = 0.2P_1^2 + 30P_1 + 100 \text{ Rs/hr} \rightarrow 20 \leq P_1 \leq 80$

$$F_2 = 0.25P_2^2 + 40P_2 + 150 \text{ Rs/hr} \rightarrow 40 \leq P_2 \leq 100$$

$$\frac{dF_1}{dP_1} = 0.4P_1 + 30 \text{ Rs/MW hr}$$

$$\frac{dF_2}{dP_2} = 0.5P_2 + 40 \text{ Rs/MW hr}$$

$$\lambda \left[\frac{1}{0.4} + \frac{1}{0.5} \right] = 130 + \left[\frac{30}{0.4} + \frac{40}{0.5} \right]$$

$$4.5\lambda = 285 \Rightarrow \lambda = 63.33$$

$$P_1 = \frac{\lambda - \alpha_1}{\beta_1} = \frac{63.33 - 30}{0.4} = 83.32 \text{ MW}$$

$$P_2 = \frac{\lambda - \alpha_2}{\beta_2} = \frac{63.33 - 40}{0.5} = 46.66 \text{ MW}$$

Note: Here Generator 1 is violating upper limit which cannot be allowed instead it is fix to generate 80 MW and remaining rest of the load is shared by unit 2

$$\therefore P_D = P_1 + P_2$$

$$130 = 80 + P_2$$

$$P_2 = 50 \text{ MW}$$

$$\therefore P_1 = 80 \text{ MW}, P_2 = 50 \text{ MW}$$

06. Ans: 79716 Rs/annum

Sol: Given:

Alternators capacity = 200 MW

Load = 300 MW

$$\frac{dF_1}{dP_1} = 0.1P_1 + 20 \text{ RS/MWhr}$$

$$\frac{dF_2}{dP_2} = 0.12P_2 + 15 \text{ RS/MWhr}$$

When the load is economically divided between two generators

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$$

$$\Rightarrow 0.1P_1 - 0.12P_2 = -5 \dots\dots\dots (1)$$

$$P_1 + P_2 = 300 \dots\dots\dots (2)$$

Solving (1) and (2)

$$\Rightarrow P_1 = 140.91 \text{ MW and } P_2 = 159.09 \text{ MW}$$

$$F_1 = 0.1 \frac{P_1^2}{2} + 20P_1 + x$$

$$= 0.05P_1^2 + 20P_1 + x \text{ Rs/hr}$$

$$F_2 = 0.12 \frac{P_2^2}{2} + 15P_2 + y$$

$$= 0.06P_2^2 + 15P_2 + y \text{ Rs/hr}$$

Substitute P_1 and P_2 values in the above equation

$$F_1 = 0.05(140.91)^2 + 20 \times 140.91 + x \text{ Rs/hr}$$

$$F_2 = 0.06(159.09)^2 + 15 \times 159.09 + y \text{ Rs/hr}$$

$$\therefore (F_1 + F_2)_{\text{Economic}} = (3810.98 + x + 3904.92 + y)$$

$$= (7715.9 + x + y) \text{ Rs/hr}$$

When the load is equally shared

$$\Rightarrow P_1 = 150 \text{ MW}, P_2 = 150 \text{ MW}$$

Substitute P_1 and P_2 values F_1 and F_2

$$\therefore F_1 = 0.05(150)^2 + 20 \times 150 + x \text{ Rs/hr}$$

$$F_2 = 0.06(150)^2 + 15 \times 150 + y \text{ Rs/hr}$$

$$\therefore (F_1 + F_2)_{\text{equal}} = (7725 + x + y) \text{ Rs/hr}$$

$$\therefore \text{saving} = (F_1 + F_2)_{\text{equal}} - (F_1 + F_2)_{\text{economic}}$$

$$= 9.1 \text{ Rs/hr}$$

$$\therefore \text{savings in fuel cost per annum}$$

$$= 9.1 \times 365 \times 24 \text{ Rs/annum}$$

$$= 79716 \text{ Rs/annum.}$$

07. Ans: (c)

Sol: Incremental fuel cost of generator 'A' for maximum power generation

$$= 600 \text{ Rs/MWhr}$$

Incremental fuel cost of generator 'B' for minimum power generation

$$= 650 \text{ Rs / MWhr}$$

As the incremental fuel cost for maximum generation of generator 'A' is less than the incremental fuel cost for minimum generation of generator 'B' is Hence we can operate the generator 'A' at its maximum output of 450 MW and the remaining will be generated by generator 'B'.

08. Ans: (c)

Sol: $\frac{dF_1}{dP_1} = b + 2CP_1 \text{ Rs/MWhr}$

$$\frac{dF_2}{dP_2} = b + 4CP_2 \text{ RS/MWhr}$$

For most economic generation

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$$

$$b + 2CP_1 = b + 4CP_2$$

$$P_1 = 2P_2$$

$$\text{Given } P_1 + P_2 = 300$$

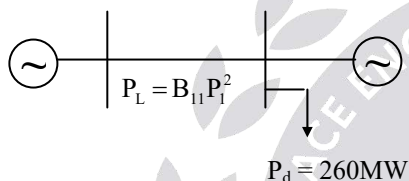
$$\therefore 2P_2 + P_2 = 300$$

$$P_1 = 200\text{MW}, P_2 = 100\text{MW}.$$

09. Ans: $P_1 = 300\text{ MW}$, $P_2 = 50\text{ MW}$

$$P_L = 90\text{ MW}$$

Sol:



$$B_{11} = \frac{10}{100^2} = 0.001$$

$$P_1 + P_2 - P_L = P_d = 260$$

$$P_1 + P_2 - B_{11} P_1^2 = 260$$

$$P_1 + P_2 - 0.001 P_1^2 = 260 \dots\dots\dots (1)$$

Assuming lossless problem

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} = 0.02P_1 + 16 = 0.04P_2 + 20$$

$$-4 + 0.02P_1 = 0.04P_2$$

$$P_2 = \frac{0.02P_1 - 4}{0.04}$$

$$P_2 = 0.5P_1 - 100 \dots\dots\dots (2)$$

Substitute (2) in (1)

$$P_1 + 0.5P_1 - 100 - 0.001 P_1^2 = 260$$

$$1.5P_1 - 0.001 P_1^2 - 360 = 0$$

$$0.001 P_1^2 - 1.5P_1 + 360 = 0$$

$$\Rightarrow P_1 = 300\text{ MW}$$

$$P_2 = 0.5 \times 300 - 100 = 50\text{ MW}$$

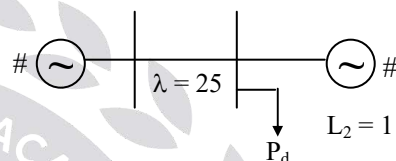
$$P_L = 0.001 \times 300^2 = 90\text{ MW}$$

10. Ans: $P_1 = 133.33\text{ MW}$

$$P_2 = 100\text{ MW}$$

$$P_d = 215.53\text{ MW}$$

Sol:



$$\frac{dF_1}{dP_1} L_1 = \frac{dF_2}{dP_2} L_2 = \lambda$$

$$0.06P_2 + 19 = 25$$

$$P_2 = \frac{25 - 19}{0.06} = 100\text{ MW}$$

$$\frac{dF_1}{dP_1} L_1 = \lambda$$

$$(0.01P_1 + 17) = \lambda \left[1 - \frac{dP_L}{dP_1} \right]$$

$$(0.01P_1 + 17) = 25(1 - 2B_{11}P_1)$$

$$P_L = B_{11} P_1^2$$

$$10 = B_{11} (100)^2$$

$$B_{11} = 10^{-3}$$

$$(0.01P_1 + 17) = 25(1 - 2 \times 0.001P_1)$$

$$0.01P_1 + (0.025P_1)2 = 25 - 17$$

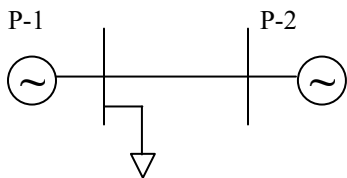
$$0.06P_1 = 25 - 17$$

$$P_1 = 133.33\text{ MW}$$

$$\begin{aligned} \text{Power received} &= P_d = P_1 + P_2 - P_L \\ &= 133.33 + 100 - (0.001)(133.3)^2 \\ &= 215.53\text{ MW} \end{aligned}$$

11. Ans: (b)

Sol:



$$B_{11} = B_{12} = B_{21} = 0, B_{22} \neq 0$$

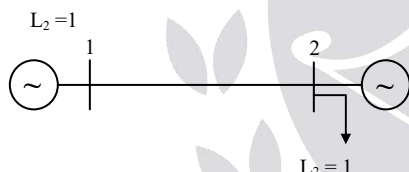
$$L_1 = \frac{1}{1 - \frac{\partial P_L}{\partial P_1}} = \frac{1}{1 - 0} = 1$$

$$L_2 = \frac{1}{1 - \frac{\partial P_L}{\partial P_2}} = \frac{1}{1 - 2B_{22}P_2}$$

$$= \frac{1}{1 - (2 \times 10^{-3} \times 100)} = 1.25$$

12. Ans: (c)

Sol:



$$\Delta P_D = 5 \text{ MW}$$

$$\Delta P_1 = 8 \text{ MW}$$

$$\Delta P_L = 8 - 5 = 3 \text{ MW}$$

$$\frac{P_L}{P_1} = \frac{\Delta P_L}{\Delta P_1} = 3/8 = 0.375$$

$$\text{Penalty factor } L_1 = \frac{1}{1 - \frac{\Delta P_L}{\Delta P_1}} = 1.6$$

13. Ans: $L_1 = 1.5625$, $L_2 = 1.25$

Sol: $\frac{dc_1}{dp_1} = 0.15P_1 + 150 \text{ Rs/MWhr}$

$$\frac{dc_2}{dp_2} = 0.25P_2 + 175 \text{ Rs/MWhr}$$

$$P_1 = P_2 = 200 \text{ MW}$$

$$\frac{dP_L}{dP_2} = 0.2$$

$$L_2 = \frac{1}{1 - \frac{\partial P_L}{\partial P_2}} = \frac{1}{1 - 0.2} = 1.25$$

$$L_1 I_{c1} = L_2 I_{c2}$$

$$L_1 = 1.25 \left(\frac{0.25 \times 200 + 175}{0.15 \times 200 + 150} \right) = 1.5625$$

14. Ans: (b)

Sol: A load curve is a graph shown in the variation in power demand over a specific time period.

Statement (I) is correct because the area under the load curve represents the total energy (units) generated during that period.

Statement (II) is correct because the lowest point on the load curve indicates the minimum demand that occurs regularly, which is the base load.

15. Ans: (a)

Sol: Statement (II) is correct: When a generator is located farther from the main grid, the transmission lines required to connect it are longer. Longer transmission lines inherently have higher resistance and impedance, which leads to increased power losses (primarily I^2R losses) during the transmission of electricity.

Statement (I) is correct: In the context of power systems economics and operation, generators that contribute more to system

losses are typically “penalized” through economic mechanisms (e.g., in the calculation of Locational Marginal Pricing or LMP). This penalty reflects the increased cost of delivering power from that distant location to the load centres.

Relationship: Statement (II) provides the technical reason (higher losses due to distance) that justifies the economic penalty described in statement (I).

16. Ans: (a)

Sol: Unit commitment is optimally out of the available generating sources to meet the expected load and provide a specified margin of operating reserve over a specified period of time.

17. Ans: (d)

Sol: Statement (I) claims that if losses are included but not coordinated in solving economic dispatch, then the overall power loss decreases. This is incorrect. Economic dispatch aims to minimize the total generation cost to meet the load demand, subject to constraints including generator limits and potentially transmission losses.

Statement (II) claims that if losses are included but not coordinated, then the simulation time decreases. This is true.

