GATE | PSUs

ELECTRICAL ENGINEERING

Power Systems

Text Book : Theory with worked out Examples and Practice Questions

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Power Systems

(Solutions for Volume-1 Class Room Practice Questions)

1. Transmission & Distribution

2.1 Basic Concepts & 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.

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

$$P_{Loss1} = 3I_1^2 R_1$$

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

$$P_{Loss1} = 3\left(\frac{P_1}{\sqrt{3}\,V_1 \cos\phi}\right)^2 \times R_1$$

$$P_{Loss1} = \frac{P_1^2 R_1}{V_1^2 \cos^2\phi}$$

$$P_{Loss1} \propto \frac{R}{V_1^2} \propto \frac{1}{aV_2^2}$$

$$\Rightarrow aV^2 \propto \frac{1}{P_{Loss}}$$

$\Rightarrow aV^2 = \text{constant}$

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

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

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

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

In this efficiency is constant since same power loss.

02. Ans: (b)

Sol: Given data:

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

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

Power loss $P = I^2 R$

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

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

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.

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

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

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

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

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 mH/km increased 5%

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

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

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

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

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

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

$$244.69\ r_1 = d_1$$

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

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

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

$$322.14r_2 = d_2$$

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

$$= 0.3165\times 100$$

$$= 31.6\%$$

05. Ans: (b)

Sol: Given data:

d = 4;

(i) L_1 C_{n1}

After Transposition

$$GMD_1 = \sqrt[3]{4\times 4\times 4} = 4$$

(ii) L_2 C_{n2}

After Transposition

$$GMD_2 = \sqrt[3]{4\times 4\times 8} = 5.02\text{ m}$$

$GMD_1 < GMD_2$

$L_1 < L_2$

$C_{n1} > C_{n2}$

Resistances $R_1 = R_2$

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

$$\left[Z_{C_1} = \left(\frac{L_1}{Cn_1}\right)^{1/2}\right] < \left[Z_{C_2} = \left(\frac{L_2}{Cn_2}\right)^{1/2}\right]$$

$$\left[SIL_1 = \left(\frac{V^2}{Z_{C1}}\right)\right] > \left[SIL_2 = \left(\frac{V^2}{Z_{C2}}\right)\right]$$

06. Ans: (b)

Sol: Given data:

The impedance of a Transmission line

Z = 0.05+0.35Ω/phase/km

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

radius is doubled $r_2 = 2r_1$

$X_L = 0.35\ \Omega$/phase/km

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

l remain constant

$2\pi fL = 0.35$

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

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

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

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

$\therefore (z_2)_{new} = 0.0125 + j\,0.35\Omega$/km.

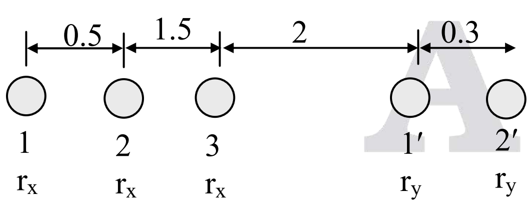
07. Ans: (c)

Sol: Given data:

$r_x = 0.03$m

$r_y = 0.04$m

$GMD_{system} = GMD_a.\ GMD_b$



$$GMD_a = \left(d_{11^1} \times d_{12^1} \times d_{21^1} \times d_{22^1} \times d_{31^1} \times d_{32^1}\right)^{1/6}$$

$= (4\times4.3\times3.5\times3.8\times2\times2.3)^{1/6}$

$= 3.189$m

$GMD_b = GMD_a = 3.189$

$\therefore GMD_{system} = \sqrt{GMD_a \times GMD_b}$

$= 3.189$ m.

$(\text{Self GMD})_{system}$

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

$\text{selfGMD}_a =$

$$= \left(r_x' \times 0.5 \times 2 \times r_x' \times 0.5 \times 1.5 \times r_x' \times 0.5 \times 2\right)^{1/9}$$

$$= (0.7788^3 \times (0.03)^3 \times (0.5)^3 \times 2^2)^{1/9} = 0.276\text{m}$$

$\text{SelfGMD}_b\ \left(r_y' \times 0.3 \times r_y' \times 0.3\right)^{1/4}$

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

$= 0.096$m

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

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

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

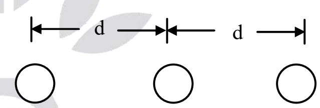
$L = 11.93 \times 10^{-7}$ H/m

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

Sol: Given data:

r = 1 cm

L = 1.2 mH/km



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

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

d = 2.49 m

09. Ans: 3.251 nF/km

Sol: Given data:

f = 50Hz, d = 0.04m, r = 0.02m

V = 132kV

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ell n\left(\frac{GMD}{GMR}\right)}$$

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

$$= 9.75 nF/km$$

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

$$\Rightarrow 3.251 nF/km$$

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

Sol: Given data:

Self GMD = kR

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

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

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

$$kR = 1.914\,R$$

$$k = 1.914$$

2.3 Steady state performance analysis Of Transmission lines

01. Ans: (c)

Sol: Given data:

A = D = 0.936 + j0.016 = 0.936∠0.98°,

B = 33.5 + j138 = 142.0∠76.4°,

C = (–5.18 + j914) × 10^{-6},

V_r = 50 MW, p.f = 0.9 lag,

V_S (L-L) = ?

$$V_{S\,ph} = A\ V_{r\,ph} + B\ I_{r\,ph}$$

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

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

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

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

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

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

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

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

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

02. Ans: (c)

Sol: Given data:

Load delivered at nominal rating

V_{rl} = 220 kV

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

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

03. Ans: (c)

Sol: Given data:

A = D = 0.95∠1.27 ; B = 92.4∠76.87

C = 0.006∠90° ; $V_S = V_r$ = 138 kV

R, Y are neglected

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

In nominal-π ⇒ B = Z

$Z = 92.4\angle 76.87° = 21+j90\Omega$

$X = 90\ \Omega$

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

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

Sol: Given data:

$A = 0.977\angle 0.66$

$B = 90.18\angle 64.12°$

$V = 132$ kV

AD-BC = 1

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

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

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

$$= \frac{0.9545\angle 1.32-1`}{90.18\angle 64.12°}$$

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

$I_S = CV_r + BI_r$

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

$P = 3V_L I_L \cos\phi$

$$P = 3\times\frac{132\times 74.184\cos(902-0.66)}{3\times 0.97}$$

$P = 81.04$kW

05. Ans: (b)

Sol: Given data:

Complex power delivered by load:

$S = V\ I^*$

$= (100\angle 60°)\ (10\angle 150°)$

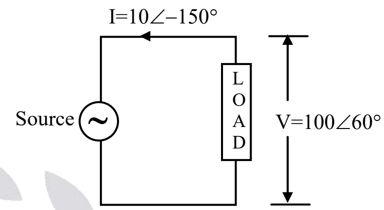
$= 1000\angle 210$

$= -866.6 - j\ 500$ VA

Complex power absorbed by load

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

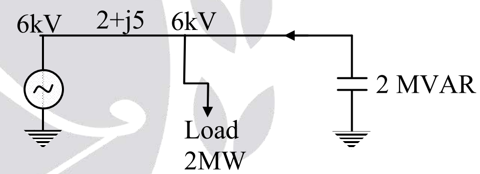
$\therefore$ Ans: (b) i.e., load absorbs both real and reactive power.



06. Ans: 0.936 lag

Sol: Given data:

Short transmission line having impedance = 2 + j5 Ω



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

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

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

$\text{Cos}(68.28-\delta) = 0.6705$

$\delta = 20.309°$

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

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

$- 1.24$ MW

$\therefore -1.24 + 2 = Q_c$

$Q_c = 0.7524$ MW

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

$$= 0.9359 \text{ lag}$$

$$\simeq 0.936 \text{ lag}$$

07. Ans: (a)

Sol: Given data:

f = 50 Hz

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

L = C

Velocity of wave

$$V = \frac{1}{\sqrt{LC}} = 3\times10^5$$

$$\frac{1}{\sqrt{LC}} = 3\times10^5$$

$$\frac{1}{C} = 3\times10^5$$

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

$$X = \frac{2\pi fL}{2}\times\ell$$

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

$$= 0.209$$

y = [2πfc] l

$$= 2\times\pi\times50\times\frac{10^{-5}}{3}\times400$$

$$= 0.418$$

08. Ans: (b)

Sol: Given data:

$V_s = V_r = 1$,

$X = 0.5$,

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

$$1 = \frac{1.0\times1.0}{0.5}\sin\delta$$

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

Reactive power

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

$$= \frac{1.0\times1.0}{0.5}\cos30 - \frac{1^2}{0.5}$$

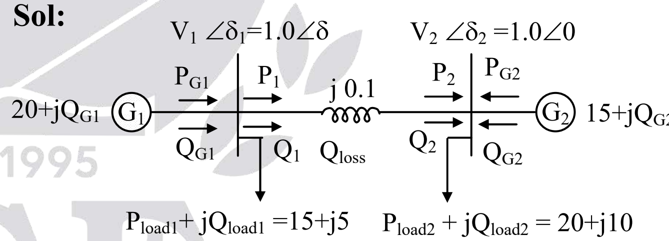
$$= \frac{\left(\frac{\sqrt{3}}{2}\right)}{\left(\frac{1}{2}\right)} - 2 = 1.732 - 2 = -0.268$$

But $Q_r + Q_C = 0$

$Q_C = -Q_r = 0.268$ p.u

09. Ans: (c)

Sol:



P_1 = Active power sent by bus (1)

$$= \frac{V_1V_2}{X_L}\sin(\delta_1-\delta_2)$$

P_2 = Active power received by bus (2)

$$= \frac{V_1V_2}{X_L}\sin(\delta_1-\delta_2)$$

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)

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

Active power balance at bus (1):

Active power balance at bus 2:

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

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

$$20 = P_1 + 15$$

$$P_2 + 15 = 20$$

$$P_1 = 5, P_2 = 5$$

$$\therefore P_1 = P_2 = \frac{V_1V_2}{X_L}\sin(\delta_1-\delta_2) = 5$$

$$\Rightarrow \quad \frac{1\times1}{0.1}\sin(\delta-0) = 5$$

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

$$\Rightarrow \quad \delta = 30°$$

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

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

$$= \frac{1}{0.1}\left[1-1\cos30^o\right]$$

$$= \frac{1}{0.1}\left[1\cos30^o-1\right]$$

$$= 1.34 \text{ pu}$$

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

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

$$= 1.34 - (-1.34)$$

$$= 2.68 \text{ pu}$$

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

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}=6.34pu, Q_{G2}=11.34pu, Q_{loss}=2.68pu

2.4. Transient Analysis & 2.5. Wave Traveling Analysis

01. Ans: (c)

Sol: Given data:

Let "l" be the total length of line

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

Total inductance of line = $\frac{0.045}{2\pi\times50}$

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

Total capacitance of line = $\frac{1}{2\pi\times50}$

Inductance/km = $\frac{0.045}{2\pi\times50\times l}$

Capacitance/km = $\frac{1.2}{2\pi\times50\times l}$

Velocity wave propagation

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

$$V = \frac{\ell}{\sqrt{\frac{0.045}{2\pi\times50\times l}\times\frac{1.2}{2\pi\times50\times l}}}$$

$$30\times10^5 = \frac{\ell}{7.4\times10^{-4}}$$

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

02. Ans: (c)

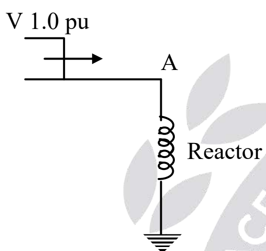
Sol: Since load impedance is equal to surge impedance, the voltage & current wave forms are not going to experience any reflection.

Hence reflection coefficient is zero.

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

03. Ans: (c)

Sol:



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

The Reactor is initially open circuit

$V_2 = V + V_1 = 1.0 + 1.0 = 2.0$ p.u

V_1 = reflected voltage

V_2 = Switched voltage

04. Ans: (b)

Sol: Given data:

V = 50 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

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

$V_2 = 20$ kV

05. Ans: (b)

Sol: Given data:

$L_{cable} = 0.185$ mH/km

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

$L_{Line} = 1.24$ mH

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

$$Z_{C\ (Cable)} = \sqrt{\frac{L}{C}}$$

$$= \sqrt{\frac{0.185 \times 10^{-3}}{0.285 \times 10^{-6}}}$$

$$= 25.4778\ \Omega$$

$$Z_{C\ (Line)} = \sqrt{\frac{L}{C}}$$

$$= \sqrt{\frac{1.24 \times 10^{-3}}{0.087 \times 10^{-6}}}$$

$$= 119.385\ \Omega$$

$$V_2 = 2V\left[\frac{Z_L}{Z_L + Z_C}\right]$$

$$= 2 \times 110\,\text{kV}\left[\frac{119.385}{119.385 + 25.4778}\right]$$

$$= 181.307 \text{ kV}$$

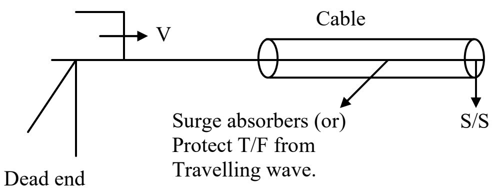
06. Ans: (d)

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

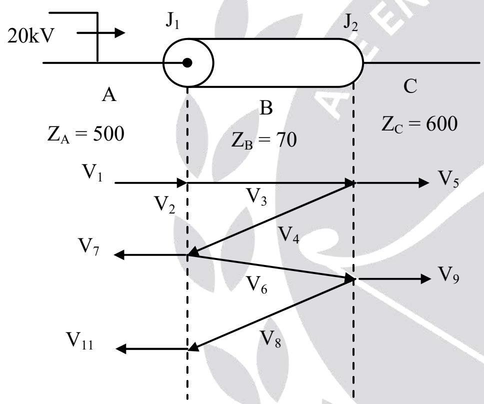
$V_{(Line)} = 3 \times 10^8$

$V_{(Cable)} = \dfrac{3\times10^8}{\sqrt{\varepsilon_r}}\, m/s$

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

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

Sol:



DC (or) step voltage

($\because$ line is of infinite length)

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

$$= 2\times20\,k\times\frac{70}{70+500}$$

$V_3 = 4.91$ kV

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

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

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

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

08. Ans: (d)

Sol: Given data

$V_6 = 2.93$

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

$= 6.8$ kV

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

$$= 2\times2.93\times\frac{600}{670} = 5.25V$$

2.6. Voltage Control

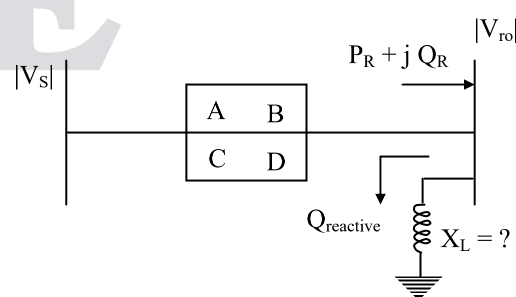
01. Ans: (a)

Sol: Given data:

$A = D = 0.9\angle0°$

$B = 200\angle90°\ \Omega$

$C = 0.95 \times 10^{-3}\angle90°$



Without shunt reactor

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

By adding shunt reactor

$\left|V_{r_0}\right| = |V_S|$

$P_R = 0$ (no load)

$Q_R = Q_{reactor}$

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

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

At $\left|V_{r_0}\right| = |V_S|$

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

To get δ at $(\left|V_{r_0}\right| = |V_S|)$

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

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

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

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

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

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

$X_L = 2000\ \Omega$ or $2\ k\Omega$

02. Ans: (d)

Sol: Given data:

$P = 2000$

$Q = 2000 \text{ Tan } (36.86)$

$= 2000(0.749) = 1499.46 kW$

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

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

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

$= 3000 + j499.46$

$$\cos\phi = \frac{3000}{3041.29} \times 100\% = 0.986 lag$$

03. Ans: (a)

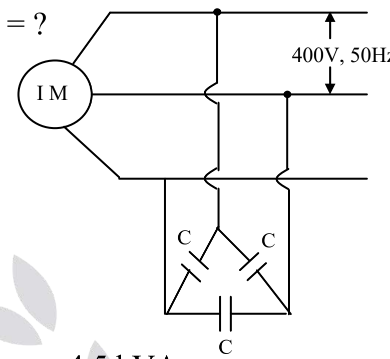
Sol: Given data:

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 kVA

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

P_1 = Real power drawn by IM

$= P_{IM}$

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

$= 4.5 \times 0.6$ kW

$P_1 = 2.7$ kW

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

$= 1.575$ kVAr

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

$= 0.525$ kVAr

Reactive power supplied $= \dfrac{V_S^2}{X_C} = 525$

$(400)^2 (2\pi\times50)C = 525$

$C = 10.1\ \mu F$

04. Ans: (c)

Sol: Given data $A = 0.85 \angle 5°$

$\alpha = 5°$

$B = 200 \angle 75°$ $\beta = 75°$

Power demand by the load = 150 MW at upf

$P_D = P_R = 150$ MW $Q_D = 0$

Power at receiving end

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

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

$\delta = 28.46°$

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

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

$= -27.56$ MVAR

In order to maintain 275 kV at receiving end $Q_R = -27.56$ MVAR must be drawn along with the real power.

So $-27.56 + Q_C = 0$

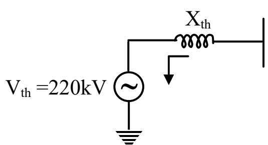
$Q_C = 27.56$ MVAR

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

05. Ans: (c)

Sol: Given data:

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



To boost the voltage 4 kV shunt capacitor is used.

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

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

$$X_\Omega = X_{pu}\times\frac{(kV_{base})^2}{MVA_{base}}$$

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

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

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

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

$$Q_{sh\,Ind} = \frac{2\,k\times 220\,k}{48.4} = 9.09\,MVAr$$

06. Ans: (d)

Sol: Given data:

$V_2 = 1.1\ V_1$

$F_2 = 0.9f_1$

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

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

Then reactive power absorbed

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

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

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

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

$= 134.4$ MVAr

07. 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.

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

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

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

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

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

$= 2725 \times 10^6 = 2725\text{MW}.$

08. Ans: (b)

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

kVAR demand of Load

$(Q_1) = \frac{200\times10^3}{0.8} \times \sin(\cos^{-1} 0.8)$

$\therefore Q_1 = 150$ 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 capacitor bank = $\frac{3V_{ph}^2}{X_{C_{ph}}} = 150$ kVAR

$\frac{3\times(11000)^2}{X_{C_{ph}}} = 150\times10^3$

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

$\frac{1}{2\pi fC} = 2420\Omega$

$C = \frac{1}{2\pi\times50\times2420}$

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

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

09. Ans: (c)

Sol: Given Data:

Let the initial power factor angle = ϕ_1

After connecting a capacitor, the power factor angle = ϕ_2

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

$= 14.07°$

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

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

$\phi_1 = 36.89°$

$\cos\phi_1 = 0.8$ lag

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

10. 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.

2.7. Under ground cables

01.

Sol: Given data:

$L = 5$ km

$C = 0.2$ μF/km

$E_r = 3.5$ core d = 1.5 cm,

r = 0.75 cm

V = 66 kV, 50Hz = f

D = ?

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

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

$$C_{Ph} = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln(D/d)} F/M$$

$$C = 0.2\times10^{-6}\times10^{3}$$

$$C = 0.2\times10^{-3}$$

$$0.2\times10^{-3} = \frac{2\pi\times8.854\times10^{-12}\times3.5}{\ln(\frac{D}{d})}$$

$$ln\left(\frac{D}{d}\right) = \frac{2\pi\times8.854\times10^{12}\times3.5}{\left(0.2\times10^{-3}\right)}$$

$$= 9.731\times10^{13}$$

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

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

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

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

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

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

E_{rms} = 90.413 kV/cm

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

$= 4.146 \times 5$

$= 20.73$A

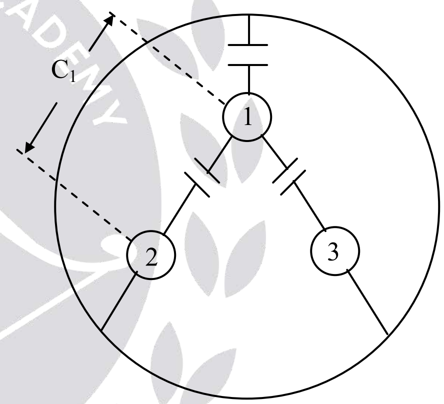
02. Ans: (b)

Sol: Given data

:

V = 11 kV; C_1 = 0.6 μF; C_2 = 0.96 μF

(i)



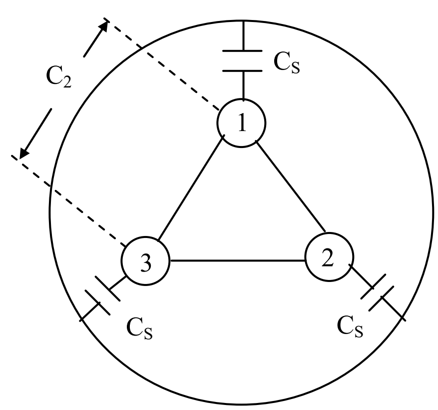
C_1 = 0.6 μF (given)

From network

$C_1 = C_S + 2\ C_C$

$\Rightarrow C_S + 2\ C_C = 0.6$ μF …….. (1)

(ii)



$C_2 = 0.96\ \mu F$ (given)

From network

$C_2 = 3\,C_S \Rightarrow 0.96\ \mu F$

$C_S = 0.32\ \mu F$

From (1)

$0.32 + 2\,C_C = 0.6$

$C_C = 0.14\ \mu F$

Effective capacitance from core to neutral

$C/ph = C_S + 3\,C_C$

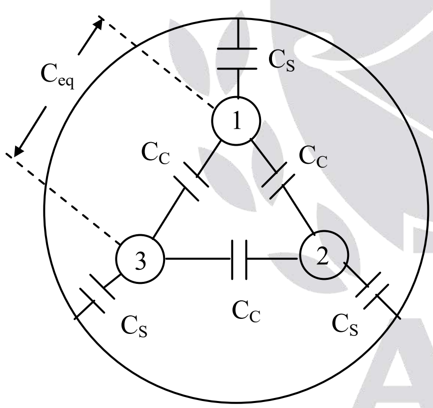
$= 0.32 + 3\times0.14 = 0.74\ \mu F$

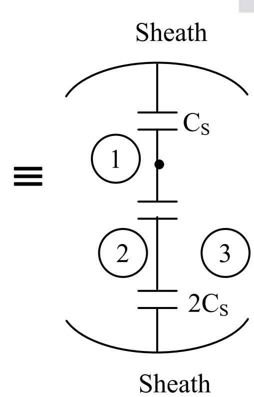
03. Ans: (b)

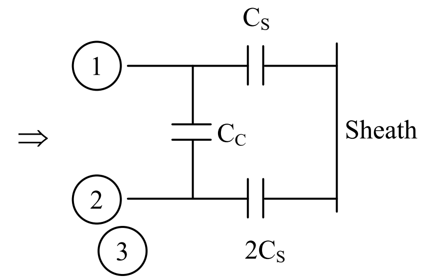
Sol: Given data:

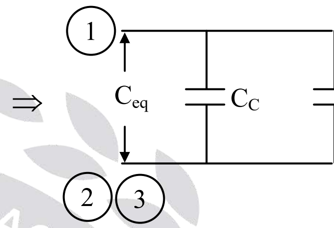
$C_c = 0.5\ \mu F$

$C_s = 0.3\ \mu F$









$$\frac{(C_s)(2C_s)}{C_s+2C_s} = \frac{2}{3}C_s$$

$$\therefore\ C_{eq} = \frac{2}{3}C_s + C_c$$

$$= 2\times0.5 + \frac{2}{3}\times0.3$$

$$= 1.2\ \mu F$$

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

Sol: Given data

L = 40 km

3-core ground cable = 12.77kVAr/km

f = 50Hz

Dielectric material is 0.025

$\cos\phi = 0.025$

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

$\phi = 88.56$

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

$$P = \frac{3\times12.77\times40}{\operatorname{Tan}(88.56)}$$

$= 38.32$ kW

05. Ans: (a)

Sol: Given data:

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

f = 50 Hz

V = 11 kV

$C/ph = C_2 + 3C_1$

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

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

$\therefore$ Perphase 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 ; 3-ϕ;

V = 400 kV; η = 80%

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

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

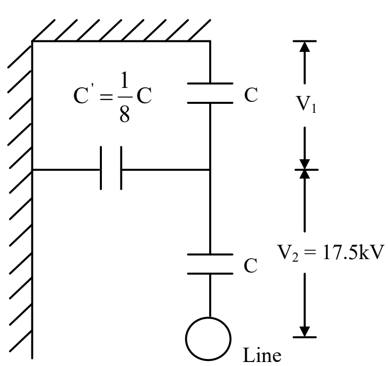
$$\therefore\ V_{20} = \frac{25}{\sqrt{3}}\text{ kV}$$

02. Ans: (b)

Sol: Given data:

V_2 = 17.5 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 kV

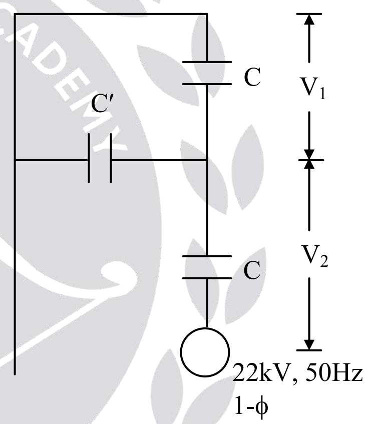
$V = V_1 + V_2$ = 33.05 kV

03. Ans: (b)

Sol: Given data:

V = 22 kV

f = 50 Hz



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

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

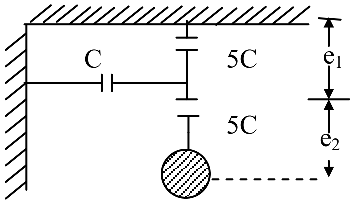
04. Ans: (b)

Sol: Given data:

f = 50 Hz

V = 11 kV

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



$e_2 = e_1 (1 + K)$

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

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

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

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

$e_1 = 2.8867 \cong 2.89$ kV

$e_2 = e_1 (1 + K)$

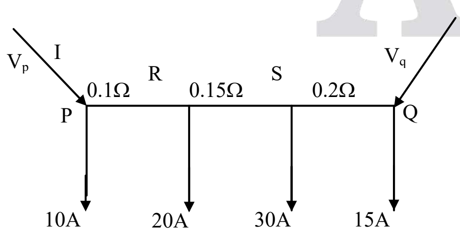
$= 2.8867 \times 1.2$

$= 3.46$ kV.

2.10. Distribution Systems

01. Ans: (a)

Sol: Given data:



Let "V_D" be the drop of voltage in line

Applying KVL,

$V_P - V_D - V_Q = 0$

$V_P - V_Q = V_D$

$V_D = V_p - V_Q = 3V$

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

$\therefore\ V_D = 8.77$

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

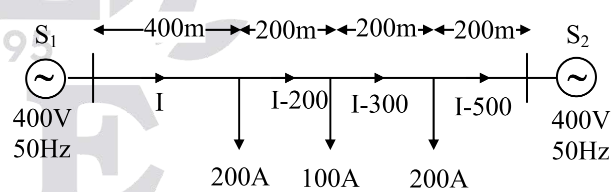
$V_Q = V_P - 3 = 225.7V.$

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 rΩ /m (reactance is neglected).



KVL From S_1 and S_2 is given as

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

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

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

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

$1000\,I = 200000$

$I = \frac{200000}{1000} \Rightarrow I = 200\,A$ as I = 200 A, Contribution to load at point P from source S_1 is 0A from source S_2 is 100 A.

03 Ans: $V_s = 271.04\angle 2.78°$, pf = 0.74 (lag)

Sol: Given Data:

$V_r = 220$

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

$= 129.9\angle -39.98$

$V_s = V_r + \Delta V$

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

$= 52.45\angle -14.33$

$V_s = 220\angle° + 52.45\angle 14.33$

$= 271.12\angle 2.74$

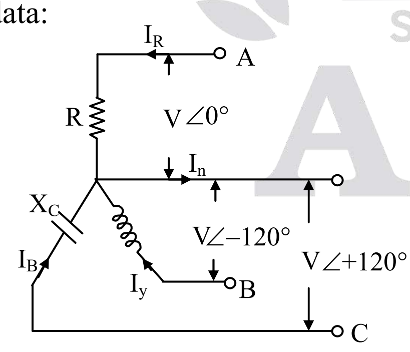
P.F.= cos (angle between V_s and I_{sc})

$= \cos(42.72)$

$= 0.734$ lag

04. Ans: (b)

Sol: Given data:



$$I_R + I_y + I_B = I_n = 0$$

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

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

$$+ V\omega C\angle +120\angle +90$$

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

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

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

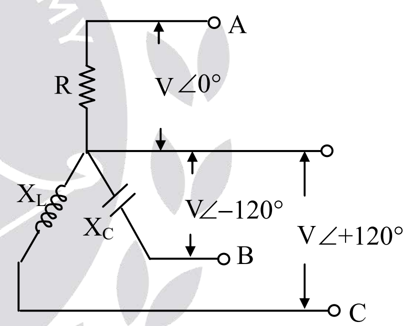
$$\omega = \frac{1}{\sqrt{LC}} \quad \text{.............. (i)}$$

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

$L = 72.9$ mH

$C = 139.02$ μF

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



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

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

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

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

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

3. PU System, Symmetrical Components & Fault Analysis

01. Ans: (b)

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

$= j0.18$ p.u

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

$= j\ 0.27$ p.u

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

$X_l = j150 \times \frac{200}{(220)^2}$

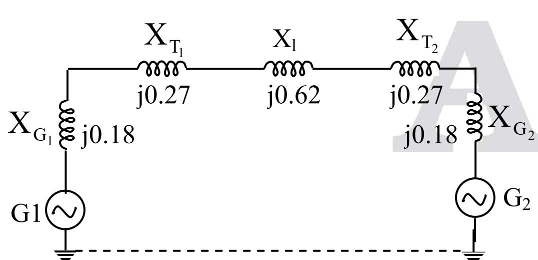
$= j0.62$ p.u.

$X_{T_2} = X_{T_1}$

$= j0.27$ P.u

$X_{G_2} = j\ 0.09 \times \left(\frac{200}{100}\right)\left(\frac{25}{25}\right)^2$

$= j\ 0.18$ p.u.



02. Ans: (a)

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

$$Z_{P.unew} = Z_{P.uold} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{kV_{b\ old}}{kV_{b\ new}}\right)^2$$

$$= 0.72 \times \frac{20}{10} \times \left(\frac{69}{13.8}\right)^2$$

$= 36$ p.u

03. Ans:

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:

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

Transformer:

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

Transmission line:

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

Motor 1:

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

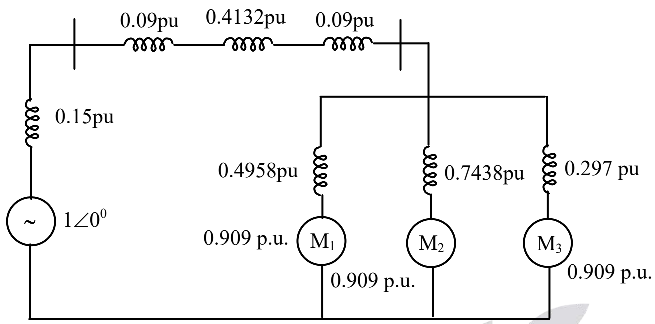
Motor 2:

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

Motor 3:

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

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



04. Ans: (d)

Sol: Given data:

$E_a = 10\angle 0°V$

$E_b = 10\angle -90°V$

$E_c = 10\angle 120°V$,

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

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

$$I_b = \frac{E_b}{X_b} = \frac{10\ \angle -90^0}{j3} = 3.33\angle -180^0$$

$$I_c = \frac{E_c}{X_c} = \frac{10\ \angle 120^0}{j4} = 2.5\angle 30^0$$

Positive sequence current,

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

Where $a = 1\angle 120^o$

$$I_1 = \frac{1}{3}(5\ \angle -90^o + 1\angle\ 120^o \times 3.33\ \angle -180^o + 1\ \angle 240^o \times 2.5\ \angle 30^o)$$

$$= 3.510\ \angle -81^o$$

05. Ans: $I_{a1} = 7.637\ \angle -79.1$ kA

Sol: Given data:

$I_a = 10\angle 30°$, $I_c = 15\angle -30°$, $I_b = ?$

$I_a + I_b + I_c = 0$

$I_b = -[I_a + I_c]$

$= -[10\angle 30° + 15\angle -30°]$

$= -21.79\angle 173.41°$

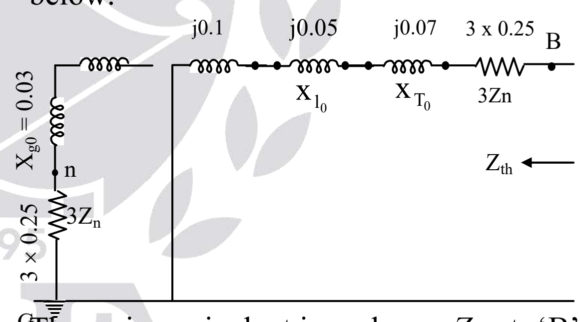
$$I_{a1} = \frac{1}{3}[I_a + K\,I_b + K^2\,I_c]$$

$$I_{a1} = \frac{1}{3}\left[\begin{array}{c} 10\angle 30^\circ + 1\angle 120^\circ \times 21.79\angle 173.41^\circ \\ +1\angle 240^\circ \times 15\angle -30^\circ \end{array}\right]$$

$I_{a1} = 7.637\ \angle -79.1$ kA

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

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

$$1.0 = \frac{3E_{R_1}}{X_1 + X_2 + X_0 + 3X_n}$$

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

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

$X_n = 0.75$ p.u

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

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

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

(ii) $V_n = 1905$ volts

Sol: Given data:

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

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

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

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

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

$V_n = 3I_{R0}\,X_n = 3\times5\times0.05 = 0.75$p.u

$$V_n = 0.75\times\frac{6.6\times10^3}{\sqrt{3}} = 2858\text{volts}$$

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

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

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

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

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

$V_n = 3I_{R0}\,X_n = 3\times3.33\times0.05 = 0.5$ p.u

$$V_n = 0.5\times\frac{6.6\times10^3}{\sqrt{3}} = 1905\text{Volts}$$

09. Ans: | I_f | = 8.39∠–47.83 pu.

Sol: Given data:

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

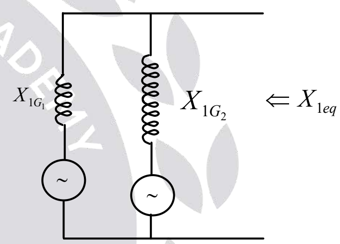


Fig.(a)

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

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).

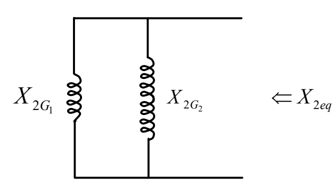


Fig (b)

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

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

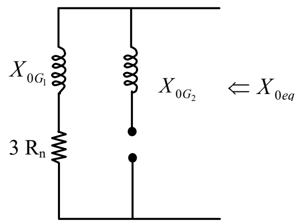


Fig.

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 × 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 p.u.)

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

$|I_f|$ = 8.39 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

$$Z_1 = Z_{l_1} + Z_{g_1}$$

$$Z_2 = Z_{l_2} + Z_{g_2}$$

$$I_{a_1} = \frac{E_a}{Z_0 + Z_1 + Z_2 + 3Z_n}$$

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

For L–G fault

= – j1.12 (pu)

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

= 1750 Amp

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

= – j 5897.6A

Neutral voltage $V_N = I_f.Z_n$

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

= 0.1089Ω

V_N = 5897.6 × 0.1089

= 642.2 volts

11. Ans: 7 kA

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

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

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

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

12. Ans: V_{AB} =13.33 kV

Sol: Given data:

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

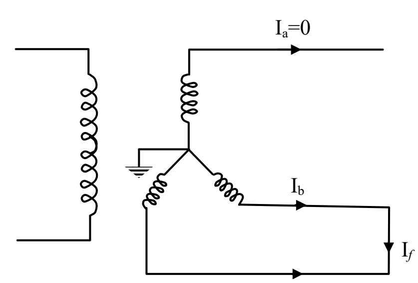


Figure (a)

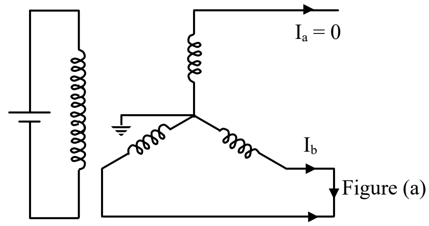


Figure (a)

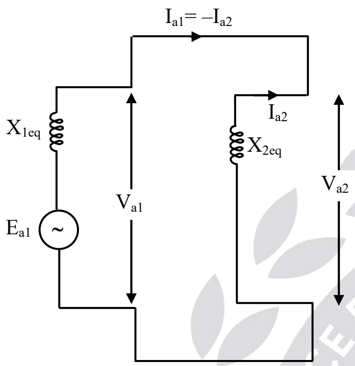


Figure (b) Sequence Network with respective Fig.(a)

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 pu.)

Positive sequence current

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

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

$= 2j$ pu.

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

$\therefore I_{a0} = 0.$

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

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

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

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

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

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

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

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

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

$= 3.464$ 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,

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

$= 3.464 \times 1093.4$

$= 3787.5$A.

$V_{a1} = E_a - I_{a1} X_{1eq}$

$= 1 + j0 - (-2j)(j0.2)$

$= 1 - 0.4 = 0.6$ p.u.

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

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

For Phase 'a',

$V_a = V_{a1} + V_{a2} + V_{a0} \qquad (\because V_{a0} = 0)$

$= 2V_{a1} = 2 \times 0.6 = 1.2$ pu.

For Phase 'b',

$V_b = V_{a0} + \lambda^2 V_{a1} + \lambda V_{a2}$

$= (k^2 + k) V_{a1} \qquad (\because V_{a1} = V_{a2})$

$= (-0.5 - 0.8667j) + (-0.5 + 0.8667j) V_{a1}$

$= -0.6$ pu.

But we know that $V_b = V_c$

$\therefore V_b = V_c = -0.6$

Line voltages, $V_{ab} = V_a - V_b$

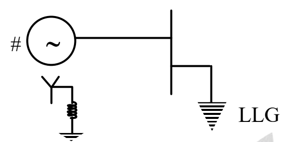
$= 1.2 - (0.6) = 1.8$ p.u.

$V_{bc} = V_b - V_c = 0$ p.u.

$$V_{ca} = V_c - V_a$$
$$= -0.6 - (1.2) = 1.8 \text{ p.u.}$$
$$V_{ab} = 1.8 \times \frac{13.2}{\sqrt{3}} = 13.33 \text{ KV},$$

13. Ans: $I_f = 4.8$ p.u

Sol: Given data:



Prefault voltage $= \dfrac{13.9}{13.2} = 1.05$

Current through ground = Fault current

$I_f = 3\, I_{a0}$

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

$$I_{a1} = \frac{E_{a1}}{X_1 + \dfrac{X_2\,X_0}{X_2 + X_0}}$$

$$= \frac{1.05}{0.2 + \left[\dfrac{0.2\times(3\times0.05+0.08)}{0.2+(3\times0.05+0.08)}\right]}$$

$= 3.42$

Substitute I_{a1} value in equation (1)

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

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

$$I_{f\,amp} = 4.77\left[\frac{15}{\sqrt{3}\times13.2}\right]\text{kA}$$

$\simeq 3.13$ kA

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

Sol: Given data:

The rating each generator 20 MVA, 6.6 kV, $X_1 = X_2 = 0.12$ pu,

$X_0 = 0.05$ pu

$X_n = 0.05$

The sequence reactance $X_1 = X_2 = 0.1$ pu

$X_0 = 0.3$ pu

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

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

$X_{0eq} = X_0 + 3X_n + X_0$

$= j0.05 + 3(j0.05) + j0.3 = j0.5$

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

$$= \frac{1.0}{0.16 + \dfrac{0.16\times0.5}{0.66}} = \frac{1.0}{0.2812}$$

$$I_{R1} = 3.55\text{p.u} = 3.55\times\frac{20}{\sqrt{3}\times6.6} = 6.22\text{kA}$$

15. Ans: (c)

Sol: Equivalent reactance seen from the fault point

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

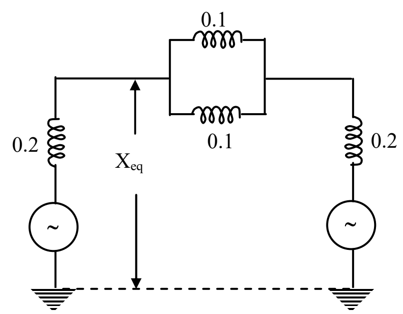
$= j0.12214$

Fault level current $= 1/X_{(PU)} = 1/j0.12214$

$= -j8.1871$

16. Ans: (c)

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



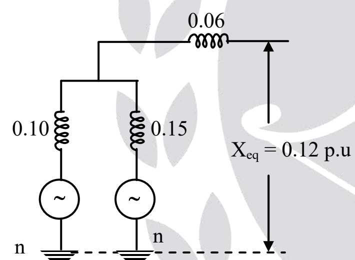
$$X_{G_2}\ \text{New} = 0.16\left[\frac{1000}{800}\right] = 0.2$$

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

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

17. Ans: (b)

Sol:



X_{G_2} New on 15 MVA Base

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

$$I_f = \frac{E_{R_1}}{X_{eq}} = \frac{1}{0.12} = 8.33\ \text{p.u}$$

$$I_{fG_2} = 8.33\left[\frac{0.1}{0.25}\right] = 3.33$$

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

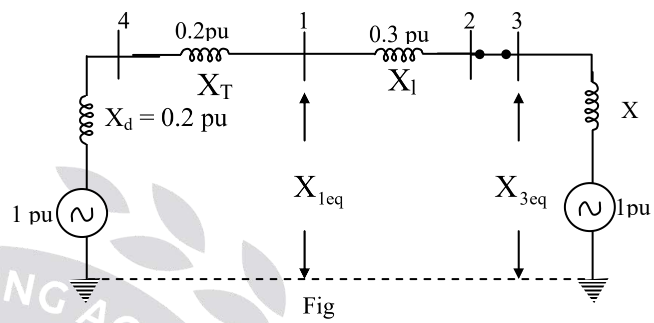
$$I_{fG_1} = 8.33 - 3.33 = 5$$

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

18. Ans: I_f =11.43 pu

Sol: Given data:

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



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}) = 1pu.

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

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

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

$\therefore X = 0.1$p.u

To find fault level at bus '3':

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

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

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

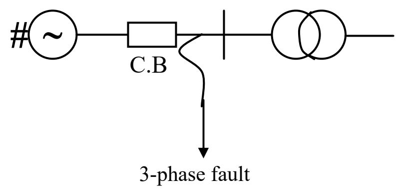
$$= \frac{0.7\times 0.1}{0.8} = 0.0875\ \text{pu}$$

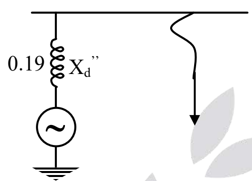
$$\therefore\ \text{Fault current}\,(I_{f_3}) = \frac{V_{th}}{X_{3eq}}$$

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

19. Ans: (c)

Sol:





For a 3-phase fault

Fault current $I_f = \dfrac{E_{R_1}}{X_{1eq}}$

where, $E_{R_1} = V_{th} = 1.0$ p.u, $X_{1eq} = X_d''$

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

$$I_{base} = \frac{110\times10^6}{\sqrt{3}\times11\times10^3} = 5773.5\text{A}$$

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

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

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_{S_1}.

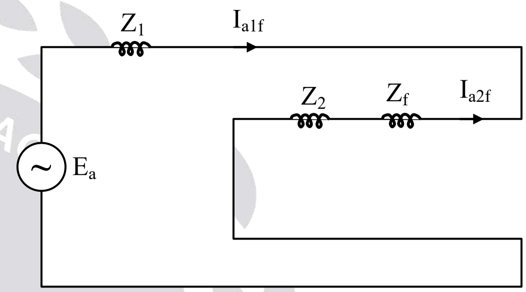
In phasor diagram current $\bar{I}_3, \bar{I}_4$ are almost 90° lead with respect to V_{S_2}.

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'.

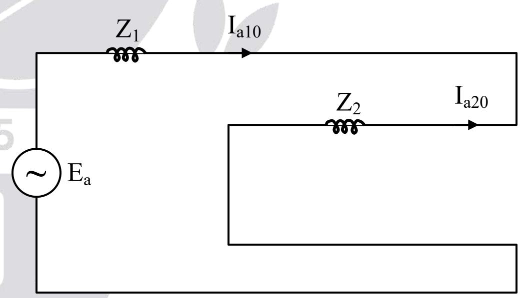
21. Ans: (a)

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



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

$$I_{f1} = kI_f$$

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

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

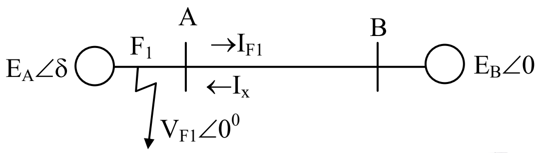
$$Z_1 + Z_2 = kZ_1\, kZ_2 + kZ_f$$

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

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

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}

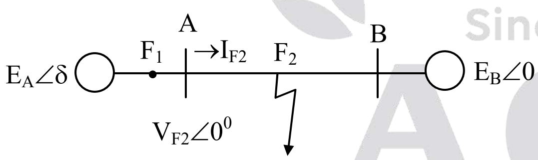
I_x fault current will be $I_x\angle-90^0$

$I_{F1} = -I_x = (1\angle180^0)\, I_x\angle-90^0$

$I_{F1} = I_x\angle 90$

$\rightarrow V_{F1}$ 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 $\overline{I_{F2}}$ is also $\angle-90$

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

4. Power Systems Stability

01. Ans: (i) 180 MJ (ii)23.54k N-m (iii) 184.9 Elec.deg/sec^2

Sol: Given data:

H = 9 kW – sec/kVA

K.E = stored?

(i) Inertia constant

$$H = \frac{\text{K.E stroed}}{\text{rating of the machine}}$$

K.E stored = H × S

= 9 × 20 MVA

= 180 MW – sec ⇒ 180 MJ

(ii) Accelerating torque T_a = ?

$P_a = T_a\omega$ $\qquad$ $T_a = \dfrac{P_a}{\omega}$

$P_a = P_s - P_e$

$P_s = 26800 \times 0.735 = 1998$ kW

$P_a = 19698 - 16000 = 3698$ kW

$$T_a = \frac{3698}{\frac{2\pi\times1500}{60}} = 23.54 \text{ kN – m.}$$

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

$$M = \frac{SH}{\pi f} = \frac{180}{180\times50} = 0.02$$

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

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

02. Ans: (c)

Sol: Given data:

$N_s = 3000$,

f = 60 Hz,

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

$H = \dfrac{\frac{1}{2} I\omega_s^2}{S}$ due to moment of Inertia, there is no sudden change in angular velocity

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

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

= 6.152 MJ/MVA

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

03. Ans: (d)

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

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

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

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

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

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

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

04. Ans: f_n =1.53 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.

$\therefore \sin\delta_0 = loading$

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

$\delta_0 = 36.86$

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

where E = no-load voltage,

V = load voltage

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

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

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

where S = Rating of the machine,

f = frequency,

Inertia constant , H = 3 MW-sec/MVA

(∵ 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,

$$f_n = \left\{\left(\frac{dPe}{d\delta}\right)_{=\delta 0} \Big/ M\right\}^{1/2}$$

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

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

05. Ans: 12.7

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

$P_s = P_e = 60$MW

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

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

$$= \frac{(\Delta t)^2}{2} = \frac{60-0}{\frac{5H}{180f}} \times \frac{(0.1)^2}{2}$$

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

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

$\delta = 10+2.7=12.7°$

06. Ans: 27 deg

Sol: Given data:

E = 1.1pu   V = 1.0pu

Assuming inertia constant (H) = 1pu

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

X= j.015+ j.015 = j0.30pu

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

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

δ =15.82°

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

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

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

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

Rotor angle $\delta_1 = \delta_0 + \Delta\delta_1$

= 15.82+11.26

= 27deg

07. Ans: δ_{cr} = 70.336°

Sol: Given data:

$\delta = 30°$, $P_{m2} = 0.5$, $P_{m2} = 1.5$, $P_s = 1.0$

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

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

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

δ_{max} = 180 – 41.80 = 138.18

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

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

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

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

= $\cos^{-1}$ [1.887 – 1.5505]

= $\cos^{-1}$ [0.3365] = 70.336°.

08. Ans: δ_{cr} = 55°

Sol: Given data:

$P_s = 1.0$ p.u

$P_{m1} = 1.8$ p.u

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

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

X_{3eq} = 1.0 p.u

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

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

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

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

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

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

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

P_{m3} = 1.245

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

δ_0 = 35.17° = 0.614 rad

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

= 126.56° = 2.208 rad

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

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

δ_{cr} = 51.82° ≃ 55°

09. Ans: δ_c = 65°

Sol: Given data:

$P_s = P_{e1} = 1.0$

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

$P_{m1} = 2.2$

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

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

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

$$= 27° \times \frac{\pi}{180} = 0.471$$

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

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

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

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

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

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

$$= \cos^{-1}[0.423] = 65°$$

10. Ans: δ_c = 84°

Sol: Given data:

$P_s = P_{e_1} = 1.0$

$P_{e_1} = 2.2\sin\delta$

$P_{m_1} = 2.2$

$P_{e_2} = 0, P_{m_2} = 0$

$P_{m_3} = P_{m_1} = 2.2$

$\delta_0 = 27°$

δ_0(rad) = 0.471

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

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

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

$\delta_c = 84°$

11. Ans: 0.20682 sec

Sol: Given data:

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

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

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

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

$$= 0.20682\,\text{sec}$$

12. Ans: Permissible increase = 60.34°

Sol: Given data:

$P_S = 2.5$ p.u.

$P_{max1} = 5.0$ p.u.

$\therefore$ Before fault $\dfrac{d\delta}{dt} = 0$, $\delta = \delta_0$, $P_a = 0$

$P_s = P_{e1}$

$$P_s = P_{max1}\sin\delta_0 \Rightarrow \delta_0 = \sin^{-1}\left[\frac{P_s}{P_{max1}}\right]$$

$$\delta_0 = \sin^{-1}\left[\frac{2.5}{5}\right]$$

$$\delta_0 = 30° \Rightarrow 0.523\text{ rad}$$

$P_{max2} = 2$ p.u.

$P_{max3} = 4$ p.u.

$$\delta_{max} = 180° - \sin^{-1}\left[\frac{P_s}{P_{max3}}\right]$$

$$= 180 - \sin^{-1}\left[\frac{2.5}{4}\right]$$

$$= 180 - 36.68$$

$\delta_{max} = 141.32° \Rightarrow 2.4664$ rad

$$\cos\delta = \frac{P_s[\delta_{max}-\delta_0]\times\dfrac{\pi}{180°}+P_{max_3}.\cos(\delta_{max})-P_{max_2}\cos(\delta_0)}{P_{max_3}-P_{max_2}}$$

$$= \frac{2.5[141.32-30]\times\dfrac{\pi}{180}+4.\cos(141.32)-2\cos(30°)}{4-2} =$$

$$\frac{4.84+(-3.122)-1.73}{2}$$

$\text{Cos}\,\delta_c = -6\times10^{-3}$

$\delta_c = \text{Cos}^{-1}(-6\times10^{-3}) \Rightarrow 90.34°$

Permissible increases $= \delta_c - \delta_0$

$= 90.34° - 30°$

$= 60.34°$

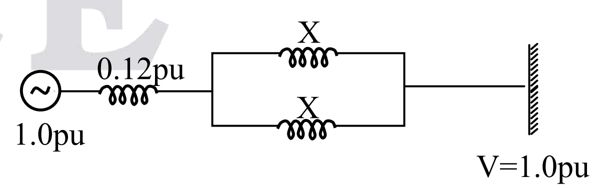
13. Ans: (d)

Sol: Given data:

V = 1.0pu

$\chi_T = 0.12$pu

|E| = 1.0pu



when one of the double circuit tripped, then

$$P_{m_2} = \frac{1\times1}{0.12+x}$$

$$= \frac{1}{0.2} = 5\text{pu}$$

14. Ans: (c)

Sol: Before fault

Mechanical input to alternator

(P_s) = electrical output (P_e) = 1.0 P.u.

Given $\delta = 30^0$, $V = 1.0$ P.u

During fault

$$X_{eq} = \frac{1}{0.8}\text{pu}$$

$E = 1.1$ p.u, $V = 1.0$ P.u

'δ' value cannot change instantaneously.

$\therefore$ Initial accelerating power

$$(P_a) = P_s - P_e$$

$$P_a = 1.0 - \frac{1.1\times1.0}{\left(\frac{1}{0.8}\right)}\sin 30^0$$

$$P_a = 0.56 \text{ P.u}$$

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: $Y_{11} = y_{13} + y_{12}$

$= (j\,0.2)^{-1} + (j\,0.5)^{-1} = -j\,7$

$Y_{22} = y_{21} + y_{23}$

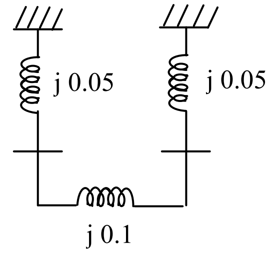
$= (j\,0.5)^{-1} + (j\,0.25)^{-1} = -\,j\,6$

$Y_{33} = y_{31} + y_{32}$

$= (j\,0.2)^{-1} + (j\,0.25)^{-1} = -j\,9$

03. Ans: (a)

Sol:



$Y_{22} = Y_{11} = (j0.05)^{-1} + (j0.1)^{-1} = -\,j\,30$

$Y_{12} = Y_{21} = -(j0.1)^{-1} = j10$

04. Ans: (b)

Sol: Given data:

We know that

$Y_{22} = y_{21} + y_{22} + y_{23}$

$Y_{21} = -y_{21}$ $\quad Y_{23} = -y_{23}$

From the data, $Y_{22} = -18$, $Y_{21} = 10$,

$Y_{23} = 10$

$Y_{22} = ?$

$-18 = (-10) + y_{22} + (-10)$

$\Rightarrow y_{22} = 20 - 18$

Shunt Susceptance, $y_{22} = 2$.

05. Ans: Y''_{13} = j0.8

Sol: $$Y_{Bus} = j\begin{bmatrix} -14.4 & 10 & 5 \\ 10 & -11.5 & 2.5 \\ 5 & 2.5 & -6.3 \end{bmatrix}$$

$$Y_{11} = \frac{Y'_{12}}{2} + \frac{Y'_{13}}{2} + Y_{12} + Y_{31} = -14.4$$

$Y_{12} = -\,Y_{12} = j10$

$Y_{23} = -\,Y_{23} = j2.5$

$Y_{31} = -\,Y_{31} = j5$

$Y'_{12} + Y'_{31} = 2[-\,j14.4 + j10 + j5]$

$= j1.2$ ………..(1)

Similarly

$Y'_{12} + Y'_{23} = 2[-j11.5 + j10 + j2.5]$

$= j2$ ………..(2)

$Y'_{23} + Y'_{31} = 2[j(5 + 2.5 - 6.3)]$

$= j2.4$ ……….(3)

$Y'_{12} + Y'_{31} = j1.2$ ………(1)

Subtracting (2) and (3)

$Y'_{12} + Y'_{23} - Y'_{23} - Y'_{31} = j2 - j2.4$

$\Rightarrow Y'_{12} - Y'_{31} = -j0.4$ ………(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: $z_{12} = j0.001 \times 100 = j\ 0.1$

$y_{12} = -j10$

$z_{13} = j0.001 \times 200 = j0.2$

$y_{13} = -j5$

$y_{23} = j0.001 \times 250 = j0.25$

$y_{23} = -j4$

$y^1_{12} = j0.0016 \times 100 = j0.16$

$y^1_{13} = j0.0016 \times 200 = j0.32$

$y^1_{23} = j0.0016 \times 250 = j0.4$

$Y_{11} = y_{12} + y_{13} + \frac{y^1_{12}}{2} + \frac{y^1_{13}}{2}$

$= -j10 - j5 + j0.08 + j0.16$

$= -j\ 14.76$

$Y_{22} = y_{12} + y_{23} + \frac{y^1_{12}}{2} + \frac{y^1_{23}}{2}$

$- j10 - j4 + j0.08 + j0.2$

$= -j13.72$

$Y_{33} = y_{13} + y_{23} + \frac{y^1_{13}}{2} + \frac{y^1_{23}}{2}$

$- j15 - j4 + j0.16 + j0.2$

$= -j8.64$

$Y_{12} = -y_{12} = j10 + Y_{13} = -y_{13} = j5, Y_{23} = -y_{23} = j4$

$y_{BUS} = j\begin{bmatrix} -14.76 & 10 & 5 \\ 10 & -13.72 & 4 \\ 5 & 4 & -8.64 \end{bmatrix}$

07. Ans: $Y_{bus} = j\begin{bmatrix} -29.76 & 20 & 10 \\ 20 & -27.72 & 8 \\ 10 & 8 & -17.64 \end{bmatrix}$

Sol: $z_{12} = j0.0005 \times j0.05$

$y_{12} = -20j$

$y_{13} = j0.0005 \times 200 = j0.1$

$y_{13} = -j10$

$z_{23} = j0.0005 \times 250 = j0.125$

$y_{23} = -j8$

$y'_{12} = j0.0016 \times 100 = j0.16$

$y'_{13} = j0.0016 \times 200 = j0.32$

$y'_{23} = j0.0016 \times 250 = j0.4$

$Y_{11} = y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2}$

$= -j20 - j10 + j0.08 + j0.16$

$= -j29.76$

$Y_{22} = y_{12} + y_{23} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2}$

$= -j10 - j8 + j0.16 + j0.2$

$= -j17.64$

$Y_{12} = -y_{12} = j20$; $Y_{13} = -y_{13} = j10$;

$Y_{23} = -y_{23} = j8$

$$y_{BUS} = j\begin{bmatrix} -29.76 & 20 & 10 \\ 20 & -27.72 & 8 \\ 10 & 8 & -17.64 \end{bmatrix}$$

$$Y_{BUS} = j\begin{bmatrix} -14.88 & 10 & 5 \\ 10 & -13.86 & 4 \\ 5 & 4 & -8.82 \end{bmatrix}$$

08. Ans: $Y_{bus} = j\begin{bmatrix} -14.88 & 10 & 5 \\ 10 & -13.86 & 4 \\ 5 & 4 & -8.82 \end{bmatrix}$

Sol: $z_{12} = 0.001 \times 100 = j0.1$

$y_{12} = -j10$

$z_{13} = j0.001 \times 200 = j0.2$

$y_{13} = -j5$

$z_{23} = j0.001 \times 250 = j0.25$

$y_{23} = -j4$

$y'_{12} = j0.0008 \times 100 = j0.08$

$y'_{13} = j0.0008 \times 200 = j0.16$

$y'_{23} = j0.0008 \times 250 = j0.2$

$$Y_{11} = y_{12} + y_{13} + \frac{y'_{12}}{2} + \frac{y'_{13}}{2}$$

$= -j10 - j5 + j0.04 + j0.08$

$= -j14.88$

$$Y_{22} = y_{12} + y_{23} + \frac{y'_{12}}{2} + \frac{y'_{23}}{2}$$

$= -j10 - j4 + j0.04 + j0.1$

$= -13.86$

$$Y_{33} = y_{13} + y_{23} + \frac{y'_{13}}{2} + \frac{y'_{23}}{2}$$

$= -j5 - j4 + j0.04 + j0.1$

$= -j8.82$

$Y_{12} = -y_{12} = j10;$

$Y_{13} = -y_{13} = j5;$

$Y_{23} = -y_{23} = j4$

09. Ans: 3500 (3500 to3500)

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

$Q_2 \text{ min} \le Q_2 \le Q_2 \text{ max}$

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 busses = 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

= (npq) + (npq + npv)

= 150 + 150+32 = 332

13. Ans: (c)

Sol: Given,

$P = 1.4\sin\delta + 0.15\sin 2\delta$ ……….(1)

Initial guess $\delta_0 = 30° = \dfrac{\pi}{6}$

$P = 0.8$ pu

From (1),

$f(\delta) = P - 1.4\sin\delta - 0.15\sin 2\delta$

$f'(\delta) = -1.4\cos\delta - 0.3\cos 2\delta$

$f(\delta_0) = 0.8 - 1.4\sin 30° - 0.15\sin(2\times 30°)$

$= -0.0299$

$f'(\delta_0) = -1.4\cos 30° - 0.3\cos(2\times 30°)$

$= -1.2124 - 0.15 = -1.3624$

According to Newton Raphson method,

$$\delta_{n+1} = \delta_n - \frac{f(\delta_n)}{f'(\delta_n)}$$

$$\delta_1 = \delta_0 - \frac{f(\delta_0)}{f'(\delta_0)}$$

$$\delta_1 = \frac{\pi}{6} - \frac{(-0.0299)}{(-1.3624)}$$

$\delta_1 = 0.5016$ rad

$\delta_1 = 28.74°$

6. Load Frequency Control

01. Ans: (c)

Sol: Given data:

Nominal frequency is 60 Hz,

Regulation is 0.1.

When load of 1500 MW,

The regulation $= \dfrac{0.1\times 60}{1500}$

$= \dfrac{6}{1500}\ \text{Hz/MW}$

02. Ans: (a)

Sol: Given data:

D = 2, R = 0.025,

We know that Change in load

$\Delta P_D = -\left(D + \dfrac{1}{R}\right)\Delta f$,

where Δf = change in frequency

$= D + \dfrac{1}{R} \Rightarrow 2 + \dfrac{1}{0.025} = 42\ \text{MW/Hz}$

$\therefore$ AFRC = 42 MW/Hz

03. Ans: (b)

Sol: Given data:

f = 50 Hz, generator rating = 120 MVA

Generator frequency decreases 0.01

$$\frac{\Delta f}{f} = \frac{0.06X}{120}$$

$$\Rightarrow X = \frac{0.01}{50} \times \frac{120}{0.06} = 0.4\,MW$$

04. Ans: (c)

Sol: Given data:

The energy stored at no load = 5×100

= 500 MJ

Before the steam valves open the energy lost by the rotor = $25 \times 0.6 = 15$ MJ

As a result of this there is reduction in speed of the rotor and,

$\therefore$ reduction in frequency

$$f_{new} = \sqrt{\frac{500-15}{500}} \times 50$$

= 49.24Hz

05. Ans: (c)

Sol: $$\%\ \text{regulation} = \frac{\frac{\Delta f}{f}}{\frac{\Delta p}{p}} = \frac{\frac{50-48}{50}}{\frac{100}{100}} \times 100$$

$$= \frac{2}{50} \times 100 = 4\%$$

7. Circuit Breakers

01. Ans: (a)

Sol: Given data:

$L = 15 \times 10^{-3}$ H

$C = 0.002 \times 10^{-6}$ 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 kHz

02. Ans: (b)

Sol: Given data:

$I = 10$ A, $C = 0.01 \times 10^{-6}$ F,

L = 1 H

$$\frac{1}{2} L i^2 = \frac{1}{2} C V^2 \Rightarrow L\, i^2 = C\, V^2$$

$$V = i\sqrt{\frac{L}{C}} = 10\left[\sqrt{\frac{1}{0.01 \times 10^{-6}}}\right] = 100\ \text{kV}$$

03. Ans: (a)

Sol: Given data:

Maximum voltage across circuit breakers contacts at current zero point = Maximum value of Restriking voltage (V_{max})

$V_{rmax} = 2$ ARV

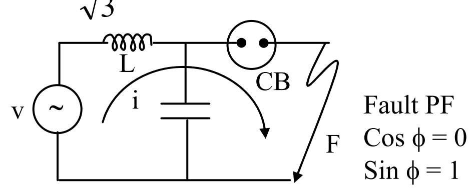
ARV = $K_1 K_2 K_3 V_{max} \sin\phi$

$K_1 = 1 \rightarrow$ No Armature reaction

$K_2 = 1 \rightarrow$ Assuming fault as grounded fault

$K_3 = 1 \rightarrow$ ARV/phase

$$V_{max} = \frac{17.32}{\sqrt{3}} \times \sqrt{2}$$



$$V_{r\,max} = 2\left[1 \times 1 \times 1 \times \frac{17.32}{\sqrt{3}} \times \sqrt{2} \times 1\right]$$

= 28.28kV

04. Ans: (d)

Sol: Making current = 2.55 × I_B

$$= 2.55\left[\frac{2000}{\sqrt{2}\times 25}\right] = 144.25 \text{ kA}$$

05. Ans: (a)

Sol: For 1-ϕ, breaking current = $\left[\frac{2000\,\text{MVA}}{25\,\text{kV}}\right]$

= 80 kA

Making current = 2.55[80 kA]

= 204 kA

06. Ans: (c)

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)

Sol: A.R.V = $K_1K_2\, V_m \sin\phi$

K_1 – first pole clearing factor

K_1 = 1.5 (LLL fault)

K_2 – Due to armature reaction

K_2 = 1 (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

$$V_m = \frac{132\text{kV}}{\sqrt{3}} \times \sqrt{2}$$

$$\text{A.R.V} = 1.5 \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times \sin 36.86$$

= 96.7kV

8. Protective Relays

01. Ans: (d)

Sol: Relay current setting = 50% × 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

$$= 0.2 \times \frac{5}{1} = 1\text{A}$$

But for a line to line fault, $I_{R_2} = -I_{R_1}$

And fault current $(I_f) = \sqrt{3}\, I_{R_2}$

$$= \sqrt{3} \times 1 = 1.732\text{A}$$

∴ Minimum fault current required

= 1.732 A.

03. Ans: (a)

Sol: From figure, it is clear that zone 2 of relay1 and relay 2 are overlapped. If there is a fault in overlapped section (line2), the fault should be clear by relay 2. Hence zone 2 operating time of relay2 must be less than zone1 operating time.($TZ2_{R1} > TZ2_{R2}$)

04. Ans: (b)

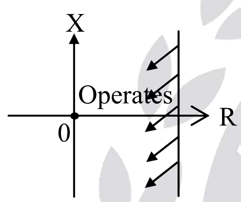
Sol: $\frac{I_2}{i_2}$; $I_2 = 400 \times \frac{11}{66} = \frac{400}{6} = 66.66$

$$i_2 = \frac{5}{\sqrt{3}} = 2.88$$

$$\frac{I_2}{i_2} = 23:1$$

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

Relay current setting = 50% of 5A

= 0.5 ×5A

= 2.5A

$$PSM = \frac{\text{Primary current (fault current)}}{\text{Relay current setting} \times \text{CT ratio}}$$

$$= \frac{1000}{2.5 \times 80} = 5$$

The operating time from given table at PSM 5 is 1.4 the operating time for TMS of 0.5 will be

0.5×1.4 = 0.7 sec

07. Ans: (b)

Sol: $T_{max} \propto \cos(\theta - \tau)$

When $\cos(\theta - \tau) = 1$, $T_{max} = 10$

$\tau = 90°$

Impedance of relay $0.1 + j0.1 = 0.1414\angle 45°$

$\theta = 45°$

Operating torque $\frac{T_1}{T_{max}} = \frac{\cos(45-90)}{1}$

$$\frac{T_1}{10} = \frac{\cos(-45)}{1}$$

$T_1 = 7.07$ N-m.