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POWER SYSTEMS

Volume-1 : Study Material with Classroom Practice Questions

Power Systems

(Solutions for Volume-1 Class Room Practice Questions)

02. 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)

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

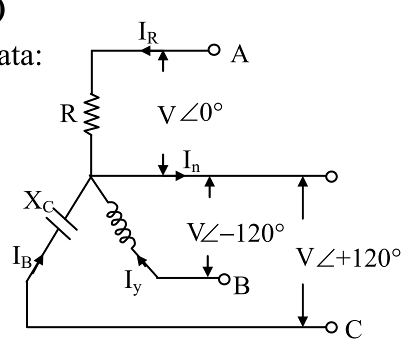
$$a = \frac{K}{(V\cos\phi)^2}$$

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

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

03. Ans: (b)

Sol: Given data:



$I_R + I_y + I_B = I_n = 0$

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

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

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

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

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

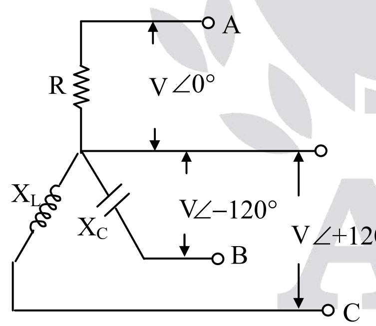
$\omega = \frac{1}{\sqrt{LC}}$ .... (i)

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

$L = 72.9$ mH

$C = 139.02\ \mu$F

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



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

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

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

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

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

04. 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)

05. Ans: 31.6%

Sol: Given data:

L_n = 1.10 mH/km increased 5%

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

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

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

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

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

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

$244.69\ r_1 = d_1$

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

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

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

$322.14r_2 = d_2$

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

$= 0.3165 \times 100$

$= 31.6\%$

06. 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

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

$GMD_1 < GMD_2$

$L_1 < L_2$

$C_{n1} > C_{n2}$

Resistances $R_1 = R_2$

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

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

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

07. Ans: (b)

Sol: Given data:

The impedance of a Transmission line

$Z = 0.05+20.35\Omega$/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

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

l remain constant

$2\pi fL = 0.35$

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

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

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

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

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

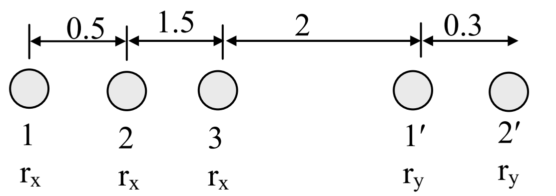
08. Ans: (c)

Sol: Given data:

$r_x = 0.03$m

$r_y = 0.04$m

$GMD_{system} = GMD_a.\ GMD_b$



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

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

$= 3.189\text{m}$

$GMD_b = GMD_a = 3.189$

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

$= 3.189$ m.

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

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

$\text{selfGMD}_a =$

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

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

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

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

$= 0.096\text{m}$

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

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

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

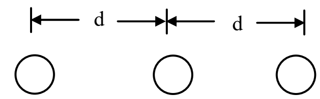
$L = 11.93\times10^{-7}$ H/m

09. Ans: d = 3.74 m

Sol: Given data:

r = 1.5cm

L = 1.2 mH/km



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

$$0.2\ell n\left(\frac{1.2599\,d}{0.7788 \times 0.015}\right) = 1.2$$

d = 3.74 m

10. Ans: 3.251 nF/km

Sol: Given data:

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

v = 132kV

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

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

= 9.75nF/km

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

$\Rightarrow 3.251\text{nF/km}$

11. Ans: 1.914

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:

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

$B = 33.5 + j138 = 142.0\angle 76.4°$,

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

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

V_S (L-L) = ?

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

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

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

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

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

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

$$= 133.24\angle 7.7°\text{ kV}$$

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

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

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

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:

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

$C = 0.006\angle 90°$; $V_S = V_r = 138$ 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

Sol: Given data:

$A = 0.977\angle 0.66$

$B = 90.18\angle 64.12°$

$V = 132$ kV

AD-BC = 1

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

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

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

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

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

$I_S = CV_r + BI_r$

$$5.62\times10^{-4}\angle 90\times\frac{132\times10^3}{\sqrt{3}}$$

$P = 3V_LI_L\cos\phi$

$$P = 3\times\frac{132\times74.184\cos(902-0.66)}{3\times0.97}$$

$P = 81.04\text{kW}$

05. Ans: (b)

Sol: Given data:

Complex power delivered by load:

$S = V\,I^*$

$= (100\angle60°)\,(10\angle150°)$

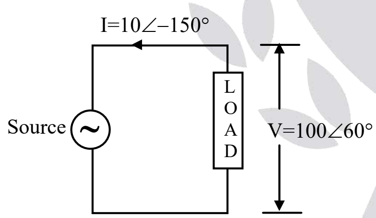
$= 1000\angle210$

$= -866.6 - j\,500$ VA

Complex power absorbed by load

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

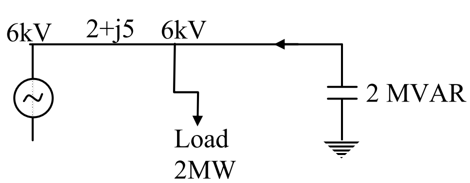
$\therefore$ Ans: (b) i.e., load absorbs both real and reactive power.



06. Ans: 0.936 lag

Sol: Given data:

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



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

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

$$2\times10^6 = \frac{36\times10^6}{\sqrt{29}}[\cos(68.2-\delta)-\cos(68.2)]$$

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

$\delta = 20.309°$

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

$$= \frac{36\times10^6}{\sqrt{29}}[\sin(68.2-20.309)-\sin 68.2]$$

-1.24 MW

$\therefore -1.24 + 2 = Q_c$

$Q_c = 0.7524$ MW

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

$= 0.9359$ lag

$\simeq 0.936$ lag

07. Ans: (a)

Sol: Given data:

$f = 50$ Hz

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

$L = C$

Velocity of wave

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

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

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

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

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

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

$$= 0.209$$

$y = [2\pi fc]\, l$

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

$$= 0.418$$

08. Ans: (b)

Sol: Given data:

$V_s = V_r = 1$,

$X = 0.5$,

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

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

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

Reactive power

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

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

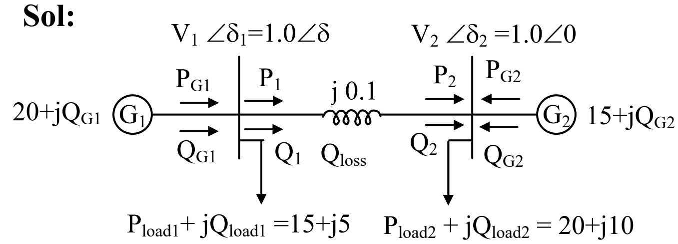
$$= \frac{\left(\frac{\sqrt{3}}{2}\right)}{\left(\frac{1}{2}\right)} - 2 = 1.732 - 2 = -0.268$$

But $Q_r + Q_C = 0$

$$Q_C = -Q_r = 0.268 \text{ p.u}$$

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)

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

Active power balance at bus (1):

Active power balance at bus 2:

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

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

$$20 = P_1 + 15$$

$$P_2 + 15 = 20$$

$$P_1 = 5$$

$$P_2 = 5$$

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

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

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

$$\Rightarrow \delta = 30°$$

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

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

$$= \frac{1}{0.1}\left[1 - 1\cos 30^o\right]$$

$$= \frac{1}{0.1}\left[1\cos 30^o - 1\right]$$

= 1.34 pu

= –1.34 pu

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

= 1.34 – (–1.34)

= 2.68 pu

Q_{loss} = 2.68 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 pu

Q_{G2} = 11.34 pu

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

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. = 2πfL

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

Total susceptance of line = 1.2p.u = 2πfC

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

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

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

Velocity wave propagation

$$(V) = \frac{1}{\sqrt{\left(\frac{L}{km}\right)\left(\frac{C}{km}\right)}}$$

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

$$30\times 10^5 = \frac{1}{7.4\times 10^{-4}}$$

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

02. Ans: (c)

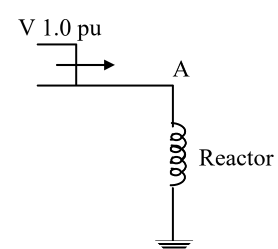
Sol: Since load impedance is equal to surge impedance, the voltage & current wave forms are not going to experience any reflection.

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

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

$$= \sqrt{\frac{0.185\times10^{-3}}{0.285\times10^{-6}}}$$

$= 25.4778\ \Omega$

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

$$= \sqrt{\frac{1.24\times10^{-3}}{0.087\times10^{-6}}}$$

$= 119.385\ \Omega$

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

$$= 2\times110\,\text{kV}\left[\frac{119.385}{119.385+25.4778}\right]$$

$= 181.307$ kV

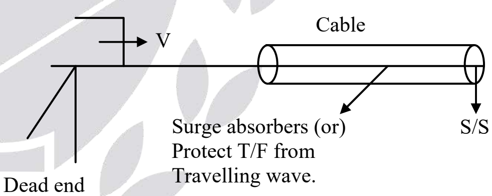
06. Ans: (d)

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

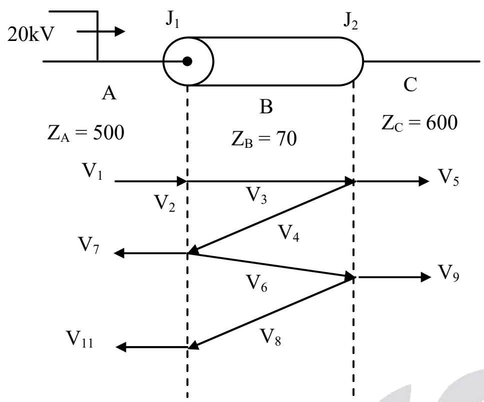
$V_{(Line)} = 3 \times 10^8$

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

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

07. Ans: 2.93 kV

Sol:



DC (or) step voltage

($\because$ line is of infinite length)

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

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

$V_3 = 4.91$ 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

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

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

2.6. Voltage Control

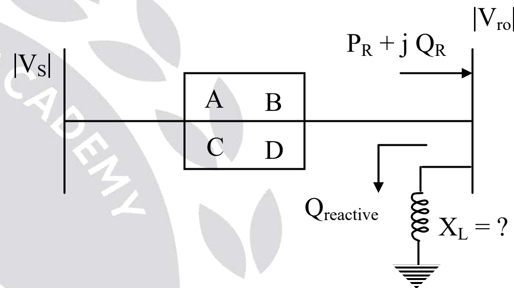
01. Ans: (a)

Sol: Given data:

$A = D = 0.9\angle 0°$

$B = 200\angle 90°\ \Omega$

$C = 0.95\times 10^{-3}\angle 90°$



Without shunt reactor

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

By adding shunt reactor

$|V_{ro}| = |V_S|$

$P_R = 0$ (no load)

$Q_R = Q_{reactor}$

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

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

At $|V_{ro}| = |V_S|$

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

To get δ at ($|V_{ro}| = |V_S|$)

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

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

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

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

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

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

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

02. Ans: (d)

Sol: Given data:

$P = 2000$

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

$= 2000(0.749) = 1499.46 kW$

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

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

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

$= 3000 + j499.46$

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

03. Ans: (a)

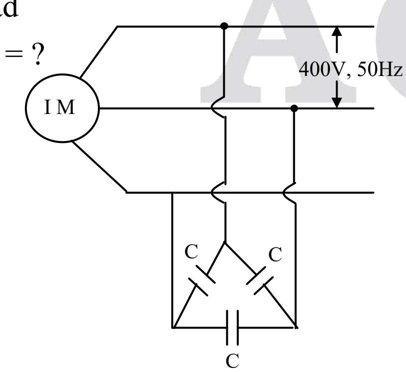
Sol: Given data:

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

i/p = 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

$$Q_{S/ph} = \frac{1.575}{3} \text{kVAr} = 0.525 \text{kVAr}$$

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

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

$C = 10.1\ \mu F$

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 $-27.56 + Q_C = 0$

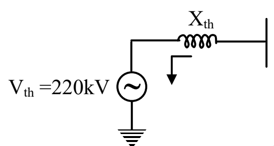
Q_C = 27.56 MVAR

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

05. Ans: (a)

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.

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

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

06. Ans: (d)

Sol: Given data:

$V_2 = 1.1\ V_1$

$F_2 = 0.9f_1$

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

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

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

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

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

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) = $\dfrac{V^2}{Z_c}$

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

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

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

$$= 2725 \times 10^6 = 2725MW.$$

08. Ans: (b)

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

kVAR demand of Load

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

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

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

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

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

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

$$= 1.3153\ \mu F$$

$$\approx 1.316\ \mu F$$

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

$$4\times10^6(\tan\phi_1 - \tan 14.07) = 2\times10^6$$

$$\phi_1 = 36.89°$$

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

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

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

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

$E_{rms} = 90.413$ kV/cm

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

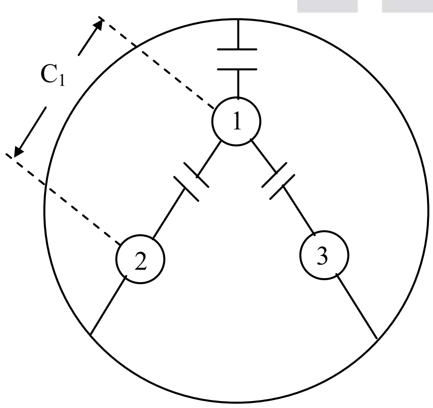
$= 4.146 \times 5 = 20.73$A

02. Ans: (b)

Sol: Given data:

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

(i)



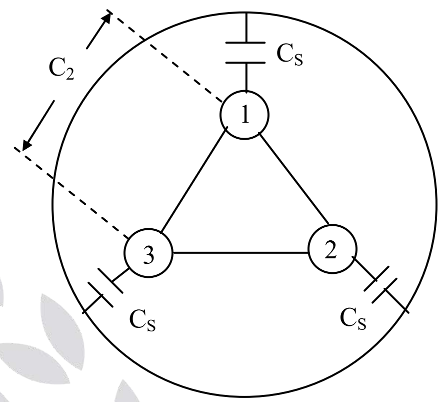
$C_1 = 0.6\ \mu F$ (given)

From network

$C_1 = C_S + 2\ C_C$

$\Rightarrow C_S + 2\ C_C = 0.6\ \mu F$ …….. (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

$C/ph = C_S + 3\ C_C$

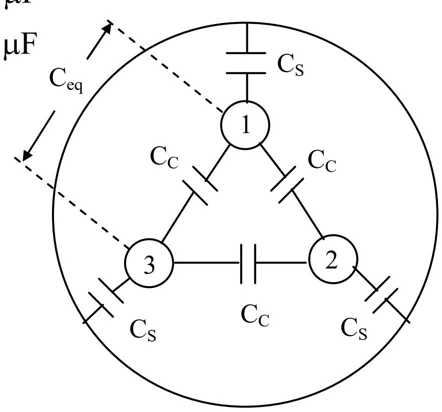
$= 0.32 + 3\times0.14 = 0.74\ \mu F$

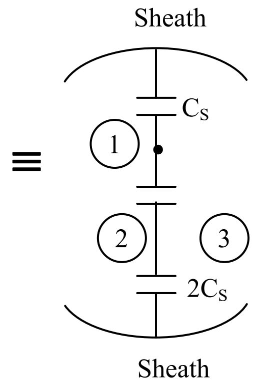
03. Ans: (b)

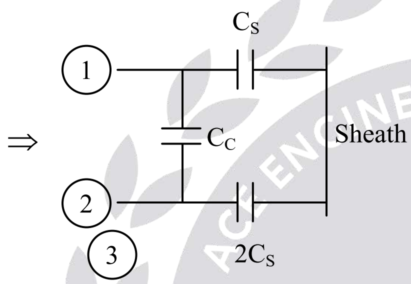
Sol: Given data:

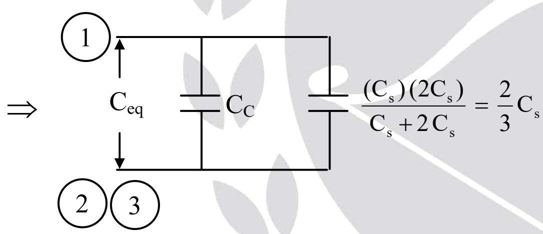
$C_c = 0.5\ \mu F$

$C_s = 0.3\ \mu F$









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

$$= 2\times0.5 + \frac{2}{3}\times0.3 = 1.2\,\mu F$$

04. Ans: 38.32kW

Sol: Given data

L = 40 km

3-core ground cable = 12.77kVAr/km

F = 50Hz

Dielectric material is 0.025

$\cos\phi = 0.025$

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

$\phi = 88.56$

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

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

$= 38.32$ kW

05. Ans: (a)

Sol: Given data:

$C_1 = 0.2\times10^{-6}$ F

$C_2 = 0.4\times10^{-6}$ F

f = 50 Hz

V = 11 kV

$C/ph = C_2 + 3C_1$

$= 0.4\times10^{-6} + 3\times0.2\times10^{-6}$

$= 1\times10^{-6} = 1\mu F.$

$\therefore$ Perphase charging current $= V_{ph}\,\omega C_{ph}$

$$= \frac{11}{\sqrt{3}}\times10^{3}\times2\pi\times50\times1\times10^{-6} = 2\text{ A.}$$

2.8. Overhead line Insulators

01. Ans: (d)

Sol: Given data:

n = 20 ; 3-ϕ ;

400 kV ; $\eta = 80\%$

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

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

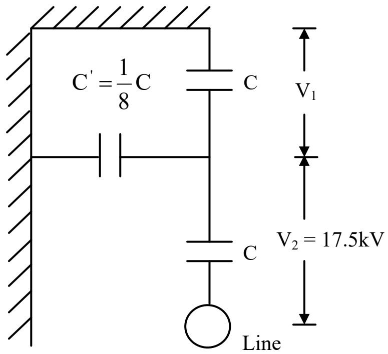
$$\therefore\ V_{20} = \frac{25}{\sqrt{3}}\text{ kV}$$

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

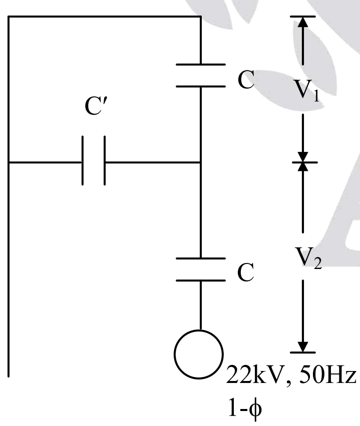
$V = V_1 + V_2 = 33.05$ kV

03. Ans: (b)

Sol: Given data:

V = 22 kV

f = 50 Hz



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

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

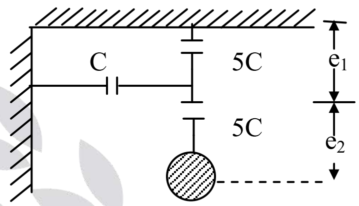
04. Ans: (b)

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

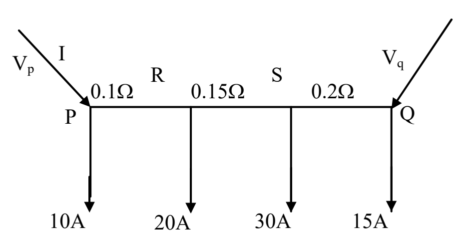
$e_2 = e_1\ (1 + K) = 2.8867 \times 1.2$

$= 3.46$ 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 $V_D = (I-10)0.1+(I-30)0.15+(I-60)0.2$

$3 = 0.45I - 17.5$

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

$\therefore V_D = 35.55\times0.1+15.55\times0.15+14.45\times0.2$

Here we have to take magnitude only

$\therefore V_D = 8.77$

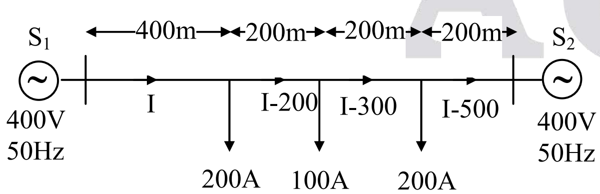
$\therefore V_P = 220 + 8.77 = 228.7V$

$V_Q = V_P - 3 = 225.7V.$

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

$V_{S1} - V_{S2} = I(400r) + (I-200)(200r) + (I-300)(200r) + (I-500)(200r)$

$0 = 400I + 200I - 200\times200 + 200I - 300\times200 + 200I - 500\times200$

$1000I = 200000$

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

Contribution to load at point P from source S_1 is 0A from source S_2 is 100 A.

03 Ans: $V_s = 271.04\angle2.78°$, pf = 0.74 (lag)

Sol: Given Data:

$V_r = 220$

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

$= 129.9\angle-39.98$

$V_s = V_r + \Delta V$

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

$= 52.45\angle-14.33$

$V_s = 220\angle° + 52.45\angle14.33$

$= 271.12\angle2.74$

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

= Cos (42.72)

= 0.734 lag

3 . PU System, Symmetrical Components & Fault Analysis

01.

Sol: Given data,

Synchronous generator (or) synchronous motor

$Z'' \rightarrow$ sub transient impedance

$Z' \rightarrow$ transient impedance

$Z \rightarrow$ Steady state

Generator:

$$X_{pu\,(new)} = 0.2\times\frac{100}{40}\times\left(\frac{25}{33}\right)^2 = 0.28$$

Transformer 1:

$$X_{pu\,(new)} = 0.15\times\frac{100}{40}\left(\frac{33}{33}\right)^2$$

$$= 0.375$$

Overhead transmission line:

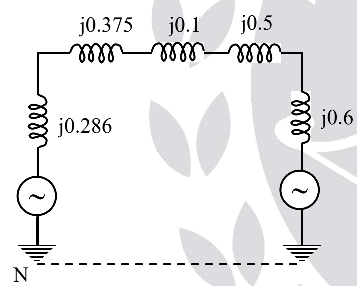
$$X_{pu} = 50\times\frac{100}{(200)^2} = 0.1$$

Transformer 2:

$$X_{pu(new)} = 0.15\times\frac{100}{30}\times\left(\frac{220}{220}\right)^2 = 0.5$$

Motor:

$$X_{pu\,new} = 0.3\times\frac{100}{50}\left(\frac{11}{11}\right)^2 = 0.6$$



02. 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:

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

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:

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

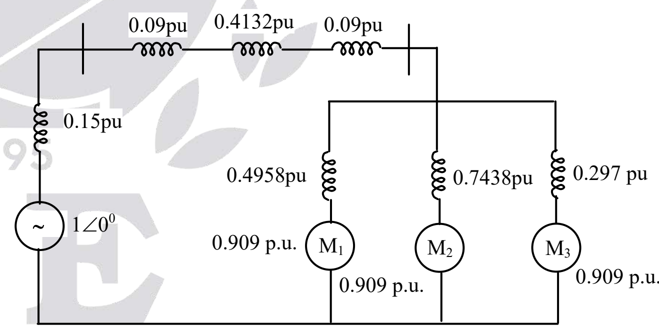
Motor 2:

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

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.



03. Ans: (c)

Sol: Given data

$I_a = 1\angle{-90°}$p.u

$I_{b_2} = 4\angle{-150°}$ p.u

$I_{c_0} = 3\angle 90°$ p.u

magnitude of phase current I_b in p.u = ?

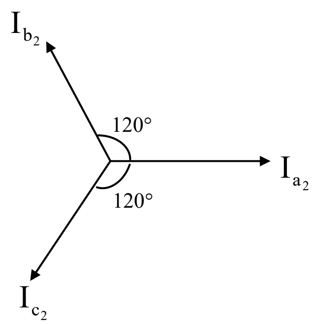
$|I_b| = ?$

$$I_b = I_{b_0} + I_{b_1} + I_{b_2}$$

$$I_a = I_{a_0} + I_{a_1} + I_{a_2}$$

$$I_{b_2} = \alpha . I_{a_2}$$

$$I_{a_2} = \frac{I_{b_2}}{\alpha}$$



$$I_a = I_{a_0} + I_{a_1} + I_{a_2}$$

$$I_{a_1} = I_a - \left(I_{a_0} + I_{a_2}\right)$$

$$= I_a\left(I_{a_0} + \left(\frac{I_{b_2}}{\alpha}\right)\right)$$

$$1\angle -90^\circ - \left[3\angle 90^\circ + \frac{4\angle -150^\circ}{1\angle 120^\circ}\right]$$

$$I_{a_1} = 8\angle -90^\circ \text{p.u}$$

$$I_{b_1} = \alpha^2 I_{a_1}$$

$= 1(1\angle 240^\circ)\,(8\angle -90^\circ)$

$= 8\angle 150^\circ$p.u

$I_b = 3\angle 90^\circ + 8\angle 150^\circ + 4\angle -150^\circ$

$= 11.53\angle 154.3$

04. Ans: 9.8∠0°

Sol: Given data:

$I_a = 10\angle 0^\circ$ A; $I_b = 10\angle 230$ A;

$I_c = 10\angle 130^\circ$A

$K = 1\angle 120^\circ$; K^2

$= 1\angle 240^\circ$

Positive sequence component

$$= \frac{1}{3}\left[I_a + KI_b + K^2 I_c\right]$$

$$= \frac{1}{3}[10\angle 0^\circ + 1\angle 120^\circ \times 10\angle 230^\circ + 1\angle 240 \times 10\angle 130^\circ]$$

$= 9.8\angle 0^\circ$

05. Ans: I_{a1} = 23.53 kA

Sol: Given data:

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

$I_a + I_b + I_c = 0$

$I_c = -[I_a + I_b]$

$= -[10\angle 30^\circ + 15\angle -30^\circ] = -150\angle 0^\circ$

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

$$I_{a1} = \frac{1}{3}\left[\begin{array}{r} 10\angle 30^\circ + 1\angle 120^\circ \times 15\angle 30^\circ \\ +1\angle 240^\circ \times -150\angle 0^\circ \end{array}\right]$$

$I_{a1} = 23.53$ kA

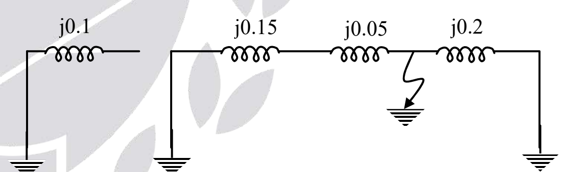
06. Ans: (b)

Sol: Given data:

$X_{G_0} = 0.1$

$X_{T_0} = 0.05$

$X_0 = 0.15$



$Z_{th} = 0.2 \| 0.2$

$$\Rightarrow \frac{0.2 \times 0.2}{0.2 + 0.2} = j0.1 \text{ p.u}$$

07. Ans: (c)

Sol: Given data:

100 MVA, 20 kV

$X_d'' = X_1 = X_2 = 0.2$

$X_0 = 0.05$

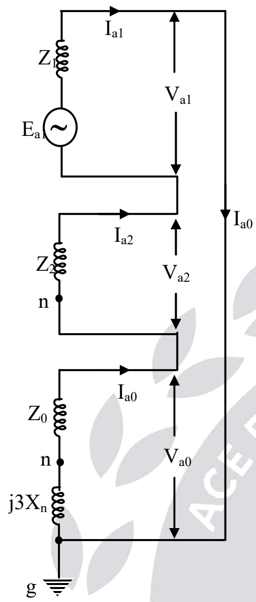
Prefault voltage, $E_{a1} = 1$ p.u

$Z_1 = j\,0.2$

$Z_2 = j\,0.2$

$Z_0 = j\,0.05$

Solid L-G fault $\rightarrow Z_f = 0$



$$I_{a1} = \frac{E_{a1}}{Z_0 + Z_1 + Z_2 + j3X_n}$$

$$X_n\,(p.u) = X_n\,(\Omega) \times \frac{MVA_{base}}{(kV_{base})^2}$$

$$= 0.32 \times \frac{100}{20^2} = 0.08 \text{ p.u}$$

$$I_{a0} = \frac{1}{j0.05 + j0.2 + j0.2 + 3 \times 0.08}$$

$= -j\,1.449$ p.u

$I_f = 3\,I_{a0}$

$= 3\,(-j1.449)$

$= -j\,4.347$ p.u

$$I_{base} = \frac{100\,M}{\sqrt{3} \times 20\,K}$$

$I_f\,(kA) = -j\,4.347 \times I_{base}$

$= 12.5$ kA

08. Ans: (b)

Sol: Given data:

$MVA_b = 15$ MVA

$kV_b = 11$ kV

$Z_1 = j1.5\ \Omega$

$Z_2 = j0.8\ \Omega$

$Z_0 = j0.3\ \Omega$

$$X_1 = 1.5\left[\frac{15}{121}\right] = 0.185 \text{ p.u}$$

$$X_2 = 0.8\left[\frac{15}{121}\right] = 0.099 \text{ p.u}$$

$$X_0 = 0.3\left[\frac{15}{121}\right] = 0.0371 \text{ p.u}$$

$$I_f = \frac{3 \times E_{R_1}}{X_1 + X_2 + X_0}$$

$$I_f = \frac{3}{0.185 + 0.099 + 0.0371} = 9.342 \text{ p.u}$$

$$I_{f\ actual} = 9.342 \times \frac{15 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 7.35 \text{ kA}$$

09. 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

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

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

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

$X_n = 0.75$ p.u

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

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

10. Ans:(i) $I_{R1} = 9.54\text{kA}$ **;(ii)** $V_{R0} = 4.0\text{kV}$ **]**

Sol: Given data:

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

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

$= 0.05 + 3(0.05) + 3(0.05) = 0.35$

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

$$= \frac{1.0}{0.1 + 0.1 + 0.35} = \frac{1.0}{0.55} = 1.81\text{p.u}$$

(i) $I_{R1} = 1.81 \times \dfrac{100}{\sqrt{3}\times 11} = 9.54\text{kA}$

(ii) $V_{R0} = -I_{R0}\,X_{0eq}$

$= 1.81\angle{-90^\circ} \times 0.35\angle 90^\circ$

$= 0.6335\text{p.u}$

$$V_{R0} = 0.6335 \times \frac{11}{\sqrt{3}} = 4.0\text{kV}$$

11. Ans: (i) $V_n = 2858\text{Volts}$

(ii) $V_n = 1905\text{Volts}$

Sol: Given data:

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

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

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

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

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

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

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

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

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

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

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

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

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

12. Ans: | I_f | = 2.926 pu.

Sol: Given data:

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

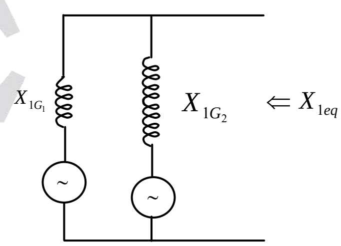


Fig.(a)

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

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).

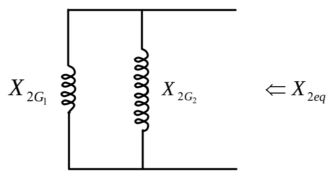


Fig (b)

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

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).

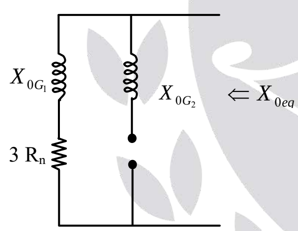


Fig.

$\therefore$ X_{0eq} = j0.1 + (3 × 0.33) = 0.99 + 0.1j

Now all values are in p.u. ,then

$$R_{pu} = 2\times\frac{20}{11^2} \Rightarrow 0.33\,pu.$$

For LG Fault, Fault current

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

$$I_f = \frac{3\times1}{j0.09+j0.075+j0.1+0.99}$$

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

$$= \frac{3}{0.99+j0.265}$$

$= 2.827 - j0.756$

$|I_f| = 2.926$ pu.

13. 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)

$$I_B \text{ (Base Current)} = \frac{20\times10^6}{\sqrt{3}\times6.6\times10^3}$$

= 1750 Amp

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

$= -$ j 5897.6A

Neutral voltage $V_N = I_f.Z_n$

$$\text{where } Z_n = Z_B\times0.05 = \frac{(6.6)^2}{20}\times0.05$$

= 0.1089Ω

V_N = 5897.6 × 0.1089

= 642.2 Volts

14. Ans: 7 kA

Sol: Given data:

$X_1 = X_2 = j0.1$, $X_f = j0.05$

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

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

$$I_{fault} = \frac{20\times10^3}{\sqrt{3}\times6.6}\times = 7\,\text{kA}$$

15. Ans: $I_F = 7.57\text{kA}$

Sol: $X_{1eq} = \frac{0.15\times0.1}{0.25}$

$X_{2eq} = x_{1eq} = 0.06$

$$I_F = \frac{\sqrt{3}E_{R1}}{X_{1eq}+X_{2eq}}$$

$$= 1.732\times\frac{1.0}{0.06+0.06} = 14.43$$

$$I_F = 14.43\times\frac{30}{\sqrt{3}\times33} = 7.57\text{kA}$$

16. 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)

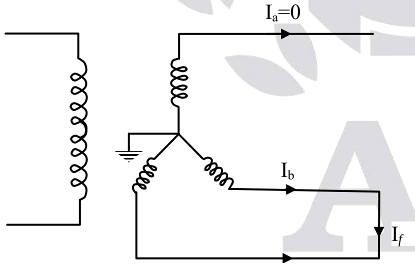


Figure (a)

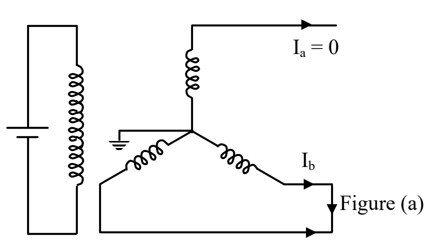


Figure (a)

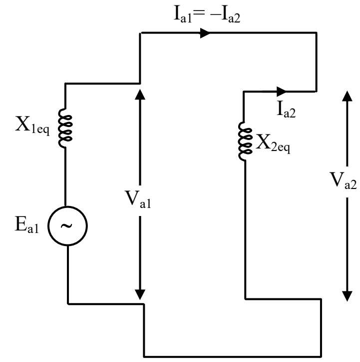


Figure (b) Sequence Network with respective Fig.(a)

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) = $|I_b|$ = $|I_c|$

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

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

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

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

= – j1.732 I_{a1}

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

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

$\therefore$ Fault current (I_f) = $|I_b|$ = $|I_c|$= 3.464 pu.

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

$$= \frac{25\times10^6}{\sqrt{3}\times13.2\times10^3} = 1093.4\text{A}$$

$\therefore$ Fault current in amps,

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

$= 3.464\times1093.4$

$= 3787.5$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',

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

$= 2V_{a1} = 2\times0.6 = 1.2$ 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.

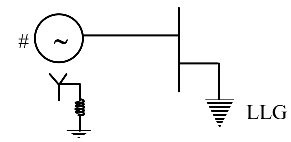
$V_{ca} = V_c - V_a$

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

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

17. Ans: I_f = 4.8 p.u $I_{f\ amp}$ = 3.13 kA

Sol: Given data:



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

Current through ground = Fault current

$I_f = 3\,I_{a0}$

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

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

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

$= 3.42$

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

$$I_{f\ amp} = 4.77\left[\frac{15}{\sqrt{3}\times13.2}\right]\text{kA} \simeq 3.13\ \text{kA}$$

18. Ans: $I_{R1} = 6.22$kA

Sol: Given data:

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

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

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

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

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

$$= \frac{1.0}{0.16 + \dfrac{0.16\times 0.5}{0.66}} = \frac{1.0}{0.2812}$$

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

19. Ans: (c)

Sol: Equivalent reactance seen from the fault point

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

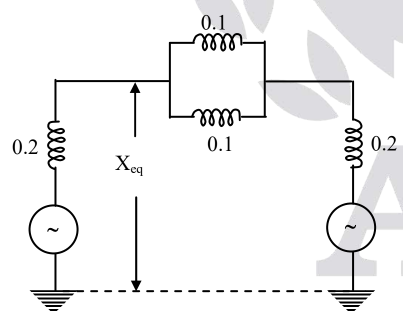
$$= j0.12214$$

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

$= -j8.1871$

20. Ans: (c)

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



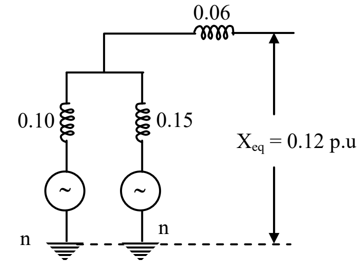
$$X_{G_2}\text{ New} = 0.16\left[\frac{1000}{800}\right] = 0.2$$

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

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

21. Ans: (b)

Sol:



X_{G_2} New on 15 MVA Base

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

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

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

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

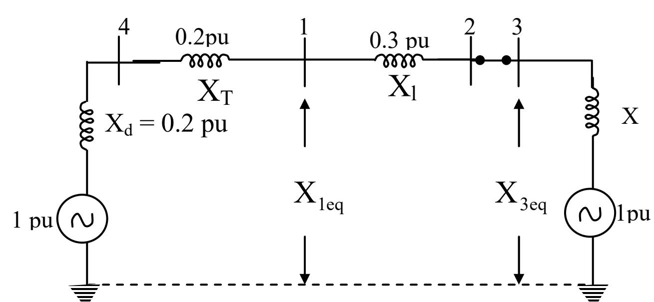
$$I_{fG_1} = 8.33 - 3.33 = 5$$

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

22. 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.

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

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

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

$\therefore X = 0.1\text{p.u}$

To find fault level at bus '3':

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

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

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

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

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

$$= \frac{1.0}{0.0875}$$

$= 11.43$ pu

4. Power System Stability

01. Ans: 23.54k N-m

Sol: Given data:

H = 9 kW – sec/kVA

K.E = stored?

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

K.E stored = H × S

= 9 × 20 MVA

= 180 MW – sec $\Rightarrow$ 180 MJ

Accelerating torque T_a = ?

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

$P_a = P_s - P_e$

$P_s = 26800 \times 0.735 = 1998$ kW

$P_a = 19698 - 16000 = 3698$ kW

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

02. Ans: (c)

Sol: Given data:

$N_s = 3000$,

f = 60 Hz,

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

$$H = \frac{\frac{1}{2} I\omega_s^2}{S}$$ 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: 40 MJ/MVA

Sol: Given data:

Generator A
$n = 4$
$H_{eq} = 9 \times 4$
$=36$ J/MVA
$H_{A\,New} = \frac{36\times100}{150}$
$= 24$

Generator B
$n = 3$
$H_{eq} = 4 \times 3$
$= 12$J/MVA
$H_{B\,New} = \frac{12\times200}{150}$
$= 16$

$H_{eq} = H_{Anew} + H_{BNew}$
$= 24 + 16 = 40$ MJ/MVA

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

where E = no-load voltage,
V = load voltage

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

$$\Rightarrow \frac{1.1\times1}{(0.3+0.2)}\cos 36.86 = 1.76$$

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

where S = Rating of the machine,
f = frequency,

Inertia constant , H = 3 MW-sec/MVA

(∵ Assume rating of machine 1 pu.)

$$= \frac{1\times3}{\pi\times50} \Rightarrow \frac{3}{50\pi}$$

The natural frequency of oscillation at 60% loading,

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

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

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

05. Ans: (i) KE = 800 MJ;
(ii) α = 337.5 elec.deg/sec^2
(iii) Δδ = 6.75 elec.degree/sec^2

Sol: Given data:

$p = 4$, $f = 50$Hz, $G = 100$ MVA, $H = 8$ sec

(i) K.E Stored $GH = 100\times8 = 800$ MJ

(ii) $m\frac{d^2\delta}{dt^2} = p_a$

$p_a = p_s - p_e = 80 - 50 = 30$

$m\frac{d^2\delta}{dt^2}$(accelecation)

$$\frac{d^2\delta}{dt^2} = \frac{30}{m}$$

$$M = \frac{GH}{180f} = \frac{800}{180\times50} = 0.088$$

$$\frac{d^2\delta}{dt^2} = \frac{30}{0.0888} = 337.5 \text{ Elec.degree/s}^2$$

$= 337.5 \times \frac{2}{p}$ mech deg/ s^2

$= 337.5 \times \frac{2}{4} = 168.7$ mech deg /s^2

$= 168.7 \times \frac{\pi}{180}$ mech deg/ s^2

$= 2.94$ mech rad/s^2

(iii) 10 cycles- Acceleration maintained constant mean $\frac{d^2\delta}{dt^2}$ constant change in angle after 10 sec

$$\frac{d^2\delta}{dt^2} = \alpha$$

α = 337.5 elec. degree/sec^2

$$\frac{d\delta}{dt} = \alpha t$$

$$\delta = \frac{1}{2}\alpha +^2 + k_1$$

Before giving distance, at t=0 $\delta = \delta_0$

$$\delta_0 = \frac{1}{2} \times \alpha(0)^2 + k_1$$

$$k_1 = \delta_0$$

$$\delta(t) = \frac{1}{2}\alpha t^2 + \delta_0$$

$$10\text{cycles } t = \frac{10}{50} = 0.2 \text{ sec}$$

$$\delta(t) = \frac{1}{2}\alpha t^2 + \delta_0$$

$$\delta(0.2) = \frac{1}{2}\alpha t^2 + \delta_0$$

$$\delta(0.2) = \frac{1}{2} \times 337.5 \times (0.2)^2$$

= 6.74 elec. degree/sec^2

Speed of the motor at end of the 10cycles.

Before disturbances speed $(N_s) = \frac{120f}{p}$

$$= \frac{120 \times 50}{4}$$

Speed of the 10 cycle = 1500

$$N(t) = N_0 + \frac{dN}{dt} \times t \qquad (N_0 = N_S)$$

$$= 1500 + \frac{dN}{dt} \times 0.2 \text{ .... (1)}$$

$$\frac{d\omega}{dt} = \frac{d^2\delta}{dt^2} = \alpha$$

$$\frac{d}{dt}\left(\frac{2\pi N}{60}\right) = \alpha$$

$$\frac{dN}{dt} = \frac{60\alpha}{2\pi} \qquad \frac{d^2\delta}{dt^2} = \alpha = 2.97$$

$$\frac{60 \times 2.97}{2\pi} = 9.5 \times 2.97 = 28.36 \text{ .... (2)}$$

Equation (2) substitute equation (1)

N(t) $= 1500 + 28.36 \times 0.2$

N(t) = 1505.67 rpm

06. Ans: 27 deg

Sol: Given data:

E = 1.1pu V = 1.0pu

Assuming inertia constant (H) = 1pu

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

$$X = j.015 + j.015 = j0.30\text{pu}$$

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

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

$\delta = 15.82°$

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

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

$$\alpha(0_+) = \frac{0.5}{1.11\times10^{-4}} = 4504 \text{ deg/sec}^2$$

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

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

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

$$\delta_c = \cos^{-1}\left[\frac{1.0(2.41-0.523)+1.5\cos138.18-0.5\cos30°}{1.5-0.5}\right]$$

$$= \cos^{-1}\left[\frac{1.00\times1.887+1.5\times-0.7452-0.5\times\frac{\sqrt{3}}{2}}{1}\right]$$

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

$= \cos^{-1}$ [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} = 1.736 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}

$$\therefore P_{m2} = 1.736\times\frac{0.72}{3.0} = 0.416$$

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

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

$$\delta_{cr}\ \cos^{-1}\left[\frac{1.0(2.208-0.614)+1.245\cos126.56-0.416\cos35.17}{1.245-0.416}\right]$$

δ_{cr} = 51.82° $\simeq$ 55°

09. Ans: δ_{cr} = 88°

Sol: Given data:

$P_s = 0.4\ P_{m1}$

$X_2 = 6\ X_1$ $\qquad P_{m2} = P_{m1}\times\frac{X_1}{X_2}$

$P_{m3} = 0.8\ P_{m1}$ $\quad = P_{m1} \times 0.167$

$$\delta_0 = \sin^{-1} 0.8\left(\frac{P_s}{P_{m1}}\right) = \sin^{-1}(0.4) = 23.578°$$

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

$$= 180 - \sin^{-1}\left(\frac{0.4\,P_{m1}}{0.8\,P_{m1}}\right) = 150°$$

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

$$\cos^{-1}\left[\frac{0.4Pm_l(150 - 23.578)\times\frac{\pi}{4} + 0.8P_{ml}\cos 150 - 0.167P_{ml}\cos 23.578}{0.8P_{ml} - 0.167P_{ml}}\right]$$

$\delta_{cr} = 88°$

10. Ans: $\delta_c = 65°$

Sol: Given data:

$P_s = P_{e1} = 1.0$

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

$P_{m1} = 2.2$

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

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

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

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

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

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

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

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

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

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

$$= \cos^{-1}[0.423] = 65°$$

11. Ans: $\delta_c = 84°$

Sol: Given data:

$P_S = P_{e_1} = 1.0$

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

$P_{m_1} = 2.2$

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

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

$\delta_0 = 27°$

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

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

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

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

$\delta_c = 84°$

12. Ans: $\delta_c = 79.77°$

Sol: Given data:

$P_s = P_{e_1}$

$P_{e_1} = 2\sin\delta$

$P_{m_1} = 2\text{p.u}$

$\delta_0 = 30°$, $\delta_{0(rad)} = 0.523$

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

$$P_{m_3} = P_{m_1} = 2.0$$

$$\delta_m = 180 - \delta_0 = 150$$

$$\delta(\text{rad}) = 150 \times \frac{\pi}{180} = 2.61$$

$$\delta_c = \cos^{-1}\left[\frac{(2.61 - 0.523) + 2.0\cos(150)}{2.0}\right]$$

$$\delta_c = \cos^{-1}\left[\frac{2.61 - 0.523 - 1.732}{2.0}\right] \cong 80°$$

13. Ans: $\delta_c = 87.7°$

Sol: Given data:

$$P_s = P_{e_1} = 1.0$$

$$P_{m1} = \frac{1.0 \times 1.2}{0.5} = 2.4$$

$$P_{m_2} = 0, P_{m_3} = P_{m_1} = 2.4$$

$$\delta_0 = \sin^{-1}\left(\frac{1.0}{2.4}\right) = 24.6° = 0.43$$

$$\delta_m = 180 - \sin^{-1}\left(\frac{1.0}{2.4}\right) = 180 - 24.6 = 155.4$$

$$\delta_m = 155.4 \times \frac{\pi}{180} = 2.71$$

$$\delta_c = \cos^{-1}\left[\frac{1.0(2.71 - 0.43) + 2.4\cos(155.4)}{2.4}\right]$$

$$= 87.7°$$

14. Ans: 0.20682 sec

Sol: Given data:

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

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

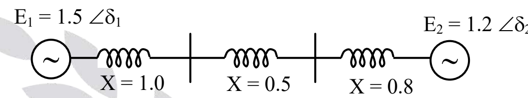
$$t_c = \sqrt{\frac{2 \times SH\,(\delta_L - \delta_0)}{\pi f(P_s)}}$$

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

$$= 0.20682 \text{ sec}$$

15. Ans: $P_e = 0.3307$ pu

Sol:



$$P_e = \frac{E_1E_2}{X_{eq}}\sin(\delta_1 - \delta_2)$$

$$P_e = \frac{1.5 \times 1.2}{2.3}\sin 25°$$

$$= 0.3307 \text{ p.u}$$

16. Ans: Permissible increase = 60.34°

Sol: Given data:

$P_S = 2.5$ p.u.

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

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

$$P_s = P_{e1}$$

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

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

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

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

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

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

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

$$= 180 - 36.68$$

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

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

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

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

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

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

Permissible increases $= \delta_c - \delta_0$

$= 90.34° - 30°$

$= 60.34°$

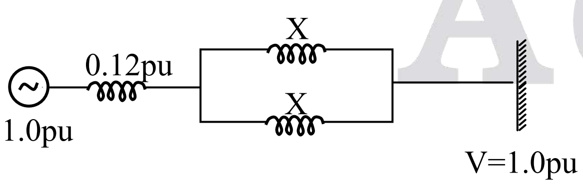
17. Ans: (d)

Sol: Given data:

V = 1.0pu

$\chi_T = 0.12$pu

|E| = 1.0pu



when one of the double circuit tripped, then

$$P_{m_2} = \frac{1\times1}{0.12 + x} = \frac{1}{0.2} = 5\text{pu}$$

18. 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.

∴ Initial accelerating power

$(P_a) = P_s - P_e$

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

$P_a = 0.56$ 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: $Y_{11} = y_{13} + y_{12}$

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

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

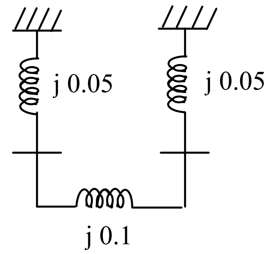
$= (j\ 0.5)^{-1} + (j\ 0.25)^{-1} = -j\ 6$

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

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

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

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

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

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

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

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

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

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

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

$= j1.2 \;\ldots\ldots\ldots.(1)$

Similarly

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

$= j2 \;\ldots\ldots\ldots.(2)$

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

$= j2.4 \;\ldots\ldots\ldots(3)$

$Y'_{12} + Y'_{31} = j1.2 \;\ldots\ldots\ldots(1)$

Subtracting (2) and (3)

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

$\Rightarrow Y'_{12} - Y'_{31} = -j0.4 \;\ldots\ldots\ldots(4)$

Solving equation (1) & (4) we get

$Y''_{13} = j0.8$

06. Ans: (i) $$Y_{bus} = j\begin{bmatrix} -14.76 & 10 & 5 \\ 10 & -13.72 & 4 \\ 5 & 4 & -8.64 \end{bmatrix}$$

(ii) $$Y_{bus} = j\begin{bmatrix} -29.76 & 20 & 10 \\ 20 & -27.72 & 8 \\ 10 & 8 & -17.64 \end{bmatrix}$$

(iii) $$Y_{bus} = j\begin{bmatrix} -14.88 & 10 & 5 \\ 10 & -13.86 & 4 \\ 5 & 4 & -8.82 \end{bmatrix}$$

Sol: (i) $z_{12} = j0.001 \times 100 = j\,0.1$

$y_{12} = -j10$

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

$y_{13} = -j5$

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

$y_{23} = -j4$

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

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

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

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

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

$= -j\ 14.76$

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

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

$= -j13.72$

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

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

$= -j8.64$

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

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

(ii) $z_{12} = j0.0005 \times j0.05$

$y_{12} = -20j$

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

$y_{13} = -j10$

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

$y_{23} = -j8$

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

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

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

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

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

$= -j29.76$

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

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

$= -j17.64$

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

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

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

(iii) $z_{12} = 0.001 \times 100 = j0.1$

$y_{12} = -j10$

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

$y_{13} = -j5$

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

$y_{23} = -j4$

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

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

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

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

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

$= -j14.88$

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

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

$= -13.86$

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

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

$= -j8.82$

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

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

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

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

07. Ans: (b)

Sol: Given data:

$y_{31} = y_{13} = -j5$

$y_{23} = y_{32} = -j5$

$Y_{11} = y_{11} + y_{13} = -j5$

$Y_{22} = y_{22} + y_{23} = -j5$

$Y_{12} = Y_{21} = 0$

$Y_{13} = Y_{31} = -y_{13} = j5$

$Y_{23} = Y_{32} = -y_{23} = j5$

$Y_{33} = y_{13} + y_{23} = -j5 - j5 = -j10.$

18. 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

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

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

$\Rightarrow X = \dfrac{0.01}{50}\times\dfrac{120}{0.06} = 0.4\text{ MW}$

04. Ans: (c)

Sol: Given data:

The energy stored at no load $= 5\times 100$

$= 500$ 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

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

$= 49.24$Hz

05. Ans: (c)

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

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

7. Circuit Breakers

01. Ans: (a)

Sol: Given data:

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

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

$f_r = \dfrac{1}{2\pi\sqrt{LC}}$

$= \dfrac{1}{2\pi\sqrt{15\times10^{-3}\times0.002\times10^{-6}}}$

$= 29$ kHz

02. Ans: (b)

Sol: Given data:

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

$L = 1$ H

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

$V = i\sqrt{\dfrac{L}{C}} = 10\left[\sqrt{\dfrac{1}{0.01\times10^{-6}}}\right] = 100$ 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

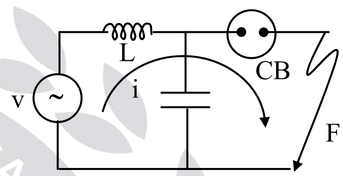
$ARV = K_1 K_2 K_3 V_{max} \sin\phi$

$K_1 = 1 \rightarrow$ No Armature reaction

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

$K_3 = 1 \rightarrow$ ARV/phase

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



Fault PF
$\cos\phi = 0$
$\sin\phi = 1$

$V_{r\,max} = 2\left[1\times1\times1\times\dfrac{17.32}{\sqrt{3}}\times\sqrt{2}\times1\right]$

$= 28.28$kV

04. Ans: (d)

Sol: Making current $= 2.55 \times I_B$

$= 2.55\left[\dfrac{2000}{\sqrt{2}\times25}\right] = 144.25$ kA

05. Ans: (a)

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

$= 80$ kA

Making current = 2.55[80 kA] = 204 kA

06. Ans: (c)

Sol: $R = 0.5\sqrt{\dfrac{L}{C}} = 0.5\sqrt{\dfrac{25\text{mH}}{0.025\mu\text{H}}} = 500\,\Omega$

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

$\cos\phi = 0.8 \Rightarrow \phi = 36.86^o$

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: (b)

Sol: ARC is initiated at the instant of contact separation due to high field gradient (or) field ionization properties of the Arc is column of ionized gases.

09. Ans: (b)

Sol: High resistance method of Arc interruption, it is resistance is increased as to reduce the current to a value insufficient to maintain the arc. When current is interrupted the energy associated with its magnetic field appears in the form of electrostatic energy. A high voltage appears across the contact of circuit breaker. If this voltage is very high and more than with standing capacity of the gap between the contacts, the Arc will strike again.

10. Ans: (d)

Sol: When interrupting a low inductive current (shunt reactor (or) magnetizing current of Transformer) the current become abruptly zero well before natural zero instant this phenomenon known as current chopping. A current chopping phenomenon is very severe during the interruption of low magnetizing current.

8. Protective Relays

01. Ans: (d)

Sol: Relay current setting = 50% × 5

$\Rightarrow 0.5\times5 \Rightarrow 2.5$

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

$$= \frac{2000}{\frac{400}{5}\times0.5\times5} = 10$$

02. Ans: (c)

Sol: The minimum value of current required for relay operation is the plug setting value of current.

$\therefore$ 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 $(I_f) = \sqrt{3}\, I_{R_2}$

$$= \sqrt{3}\times1 = 1.732\text{A}$$

$\therefore$ Minimum fault current required

= 1.732 A.

03. Ans: (a)

Sol: From figure, it is clear that zone2 of relay1 and relay2 are overlapped. If there is a fault in overlapped section (line2), the fault should be clear by relay2. Hence zone2 operating time of relay2 must be less than zone1 operating time.($TZ2_{R1} > TZ2_{R2}$)

04. Ans: (b)

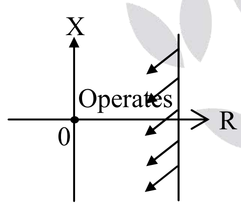
Sol: $\frac{I_2}{i_2}$; $I_2 = 400 \times \frac{11}{66} = \frac{400}{6} = 66.66$

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

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

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

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

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

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

08. Ans: (c)

Sol: Mho relay is selected for long Transmission line should be less affected due to power swings. Impedance of long line is very high effect of ARC resistance.

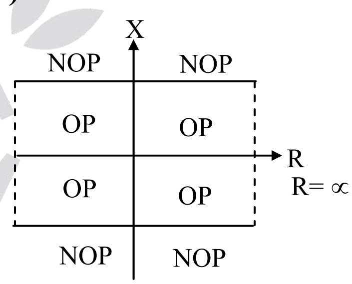
09. Ans: (a)

Sol: The angle between voltage coil voltage and voltage coil current is adjusted with the help of phase shifting network so it is possible to adjust the maximum torque angle.

$\theta_V = 45°$, maximum torque angle $\gamma = 45°$, the relay operated torque is 70.7% of maximum torque.

10. Ans: (a)

Sol:



The operation of relay depends only on reactance seen by the relay. Reactance relay is not affected due to Arc resistance, occupies more space on RX diagram.