ELECTRICAL ENGINEERING

GATE | PSUs

POWER SYSTEMS

Volume - I : Study Material with Classroom Practice Questions

Power Systems

2. Transmission & Distribution

2.1 Basic Concepts & 2.2 Transmission Line Constants:

01. Ans: n^2

Sol: 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: we know that $P = VI\cos\phi$

$$I = \frac{P}{(V\cos\phi)} \quad \text{.........} (1)$$

Power loss $P = I^2 R$

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

$$a = I^2 \frac{\rho\ell}{P} \quad \text{..........} (2)$$

Substitute eq (1) in eq. (2)

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

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

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

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

($\because$ volume $\propto$ area)

03. Ans: (b)

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

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

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

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

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

04. Ans: The incremental distance is **31.6%**

Sol: Given data:

L_n = 1.10 mH/km increased 5%

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

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

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

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

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

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

$244.69\ r_1 = d_1$

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

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

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

$322.14 r_2 = d_2$

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

$= 0.3165 \times 100$

$= 31.6\%$

05. Ans: (b)

Sol: (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 $R_1 = R_2$

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

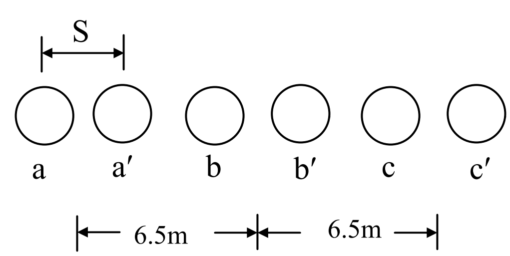
$$\left[Z_{C_1} = \left(\frac{L_1}{Cn_1}\right)^{1/2}\right] < \left[Z_{C_2} = \left(\frac{L_2}{Cn_2}\right)^{1/2}\right]$$

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

06. Ans: (d)

07. Ans: (d)

Sol:



S = 40 cm, r = 1.5 cm

$$C/ph = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left[\frac{GMD}{Self\ GMD}\right]} F/m$$

By neglecting 'S'

$$GMD = \sqrt[3]{6.5\times 6.5\times 13} = 8.18\, m$$

$$\text{Self GMD} = \sqrt{r \times S}$$

$$= \sqrt{1.5 \times 40} = 7.74 \text{ cm}$$

$$C/ph = 11.9 \times 10^{-12} \text{ F/m}$$

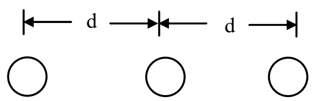
$$= 11.9 \times 10^{-9} \text{ F/km}$$

$$= 11.9 \times 10^{-3} \ \mu\text{F/km}$$

$$= 0.0119 \ \mu\text{F/km}$$

08. Ans: d = 2.4 m

Sol:



r = 1.5cm

L = 1.2 mH/km

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

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

d = 2 × 1.2 = 2.4 m

09. Ans: 4.875 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

$$\text{Interline capacitance} = \frac{C}{2} = \frac{9.75}{2}$$

⇒ 4.875 nF/km

2.3 Steady state performance analysis of Transmission lines

01. Ans: (c)

Sol: V_S (L-L) = ?

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

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

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

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

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

$$V_{S\,ph} = (0.936\angle 0.98)\left(\frac{220k}{\sqrt{3}}\right)$$

$$+ (142\angle 76.4)(145.7\angle -25.84)$$

$$= 133.24\angle 7.7° \text{ kV}$$

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

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

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

02. Ans: (c)

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

$C = 0.006\angle 90°$; $V_S = V_r = 138$ 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: 81.04kW

Sol: Given data

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 = 81.04kW

05. Ans: (b)

Sol: Complex power delivered by load:

$S = V I^*$

$= (100\angle 60°)(10\angle 150°)$

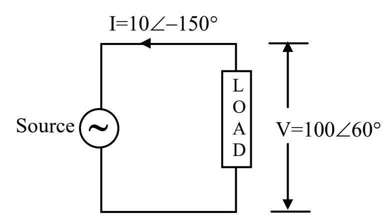
$= 1000\angle 210$

$= -866.6 - j\,500$ VA

Complex power absorbed by load

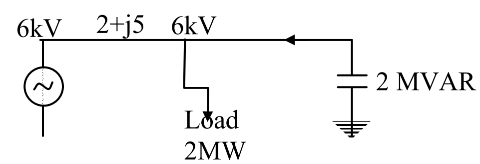
$S_{load} = 866.6 + j\,500$ VA

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



06. Ans: 0.936 lag

Sol:



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

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

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

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

$\delta = 20.309°$

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

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

-1.24 MW

$\therefore -1.24 + 2 = Q_c$

$Q_c = 0.7524$ MW

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

$= 0.9359$ lag

$\simeq 0.936$ lag

07. Ans: (a)

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

$L = C$

Velocity of wave

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

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

$$\frac{1}{C} = 3\times10^5 \Rightarrow C = \frac{10^5}{3}$$

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

$$= 2\pi 50\times\frac{10^{-5}}{3}\times400 = 0.209$$

y = [2πfc] *l*

$$= 2\times\pi\times50\times\frac{10^{-3}}{3}\times400 = 0.418$$

2.4. Transient Analysis & 2.5. Wave Traveling Analysis

01. Ans: (c)

Sol: Velocity wave propagation

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

Let "l" be the total length of line

Total reactance of line = 0.045p.u. = 2πfL

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

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

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

Inductance/km = $\frac{0.045}{2\pi\times50\times1}$

Capacitance/km = $\frac{1.2}{2\pi\times50\times1}$

$$V = \frac{1}{\sqrt{\frac{0.045}{2\pi\times50\times1}\times\frac{1.2}{2\pi\times50\times1}}}$$

$$30\times10^5 = \frac{1}{7.4\times10^{-4}}$$

∴ Length of the line (l) = 222km

02. Ans: (c)

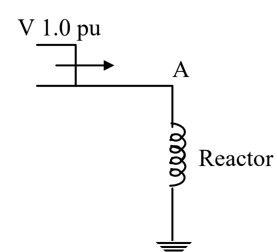
Sol: Since load impendence is equal to surge impedance, the voltage & current wave forms are not going to experience any reflection.

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

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

$= 25.4778\ \Omega$

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

$$= \sqrt{\frac{1.24\times10^{-3}}{0.087\times10^{-6}}} = 119.385\ \Omega$$

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

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

$= 181.307$ kV

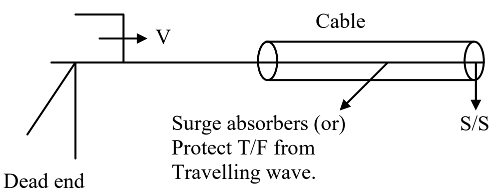
06. Ans: (d)

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

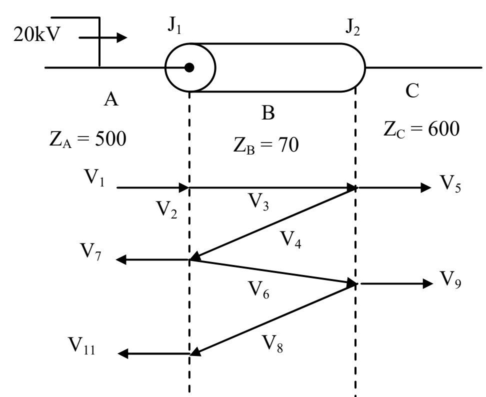
$V_{(Line)} = 3 \times 10^8$

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

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

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

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

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

$$= 3.88 \text{ kV}$$

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

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

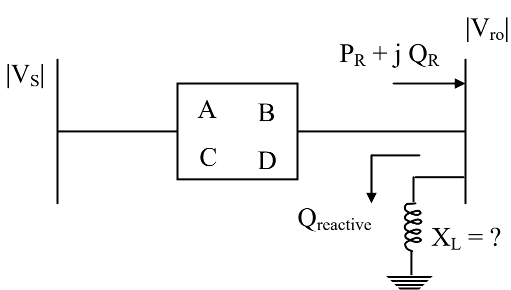
2.6. Voltage Control

01. Ans: (a)

Sol: $A = D = 0.9\angle 0°$

$B = 200\angle 90°\ \Omega$

$C = 0.95\times 10^{-3}\angle 90°$



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_{Total}) for 2 – induction (I) motor is

$P = 2000$

$Q = 2000\tan(36.86)$

$= 2000(0.749) = 1499.46$kW

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

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

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

$= 3000 + j499.46$

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

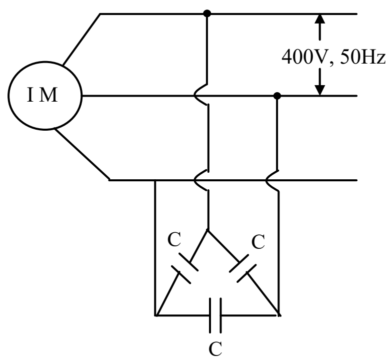
03. Ans: (a)

Sol: 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

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

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

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

$C = 10.1\ \mu F$

04. Ans: (c)

Sol: Given data A = 0.85 ∠ 5°

$\alpha = 5°$

B = 200 ∠ 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.

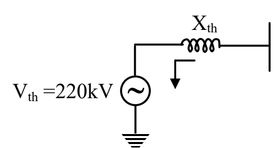
So – 27.56 + Q_C = 0

Q_C = 27.56 MVAR

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

05. Ans: (a)

Sol:



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

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

$V_2 = 1.1\ V_1$

$F_2 = 0.9 f_1$

Then reactive power absorbed

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

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

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

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

$= 134.4$ MVAr

07. Ans: (c)

Sol: 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.

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

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

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

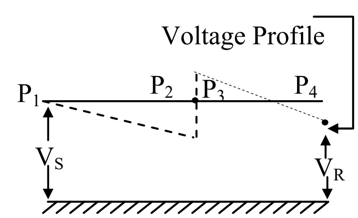
$$\frac{(SIL)_2}{(SIL)_1} = \frac{Z_{c1}}{Z_{c2}}$$

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

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

08. Ans: (c)

Sol: The voltage profile for the given line is shown in fig.



09. Ans: (d)

2.7. Under ground cables

01.

Sol: 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 = 3.9707cm

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

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

$E_{rms} = 90.413$ kV/cm

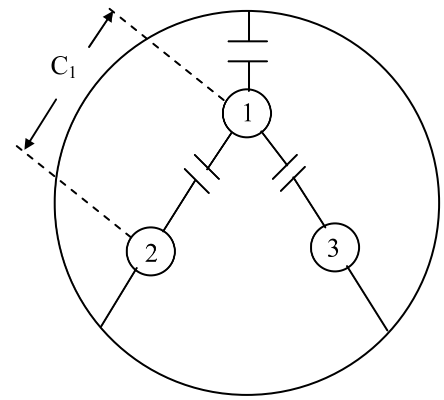
(c) At charging current = $I_C \times l$

$= 4.146 \times 5 = 20.73$A

02. Ans: (b)

Sol:

(i)



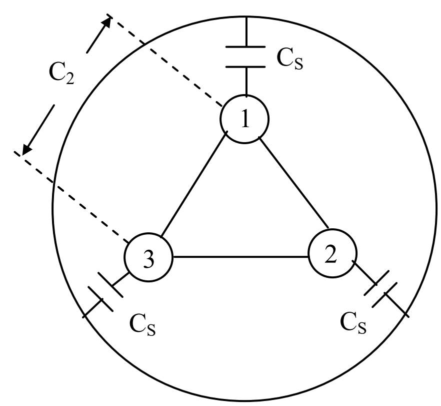
$C_1 = 0.6$ μF (given)

From network

$C_1 = C_S + 2\,C_C$

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

(ii)



$C_2 = 0.96$ μF (given)

From network

$C_2 = 3\,C_S \Rightarrow 0.96$ μF

$C_S = 0.32$ μF

From (1)

$0.32 + 2\,C_C = 0.6$

$C_C = 0.14$ μF

Effective capacitance from core to neutral

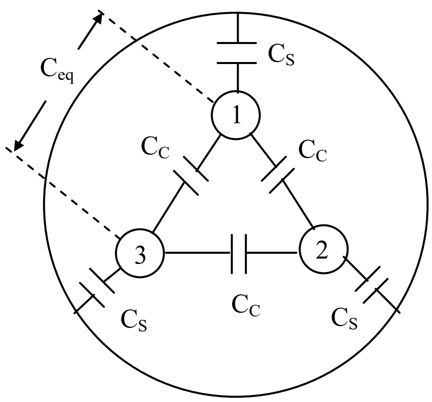
$C/ph = C_S + 3\,C_C$

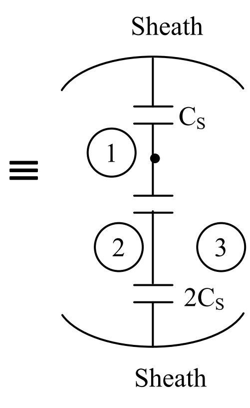
$= 0.32 + 3\times0.14 = 0.74\ \mu F$

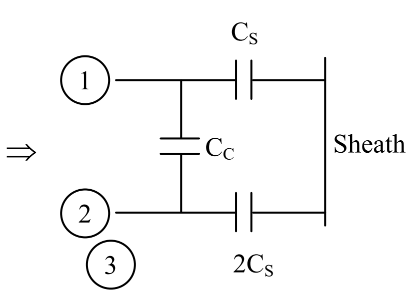
03. Ans: (b)

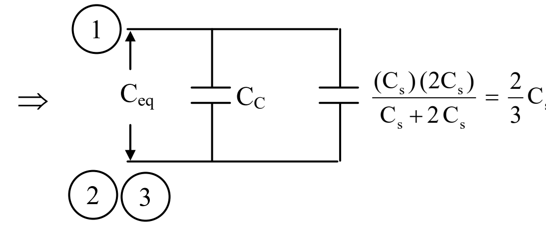
Sol: $C_c = 0.5\ \mu F$

$C_s = 0.3\ \mu F$









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

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

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: $C/ph = C_2 + 3C_1$

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

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

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

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

2.8. Overhead line Insulators

01. Ans: (d)

Sol: n = 20 ; 3-ϕ ;

400 kV ; η = 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)

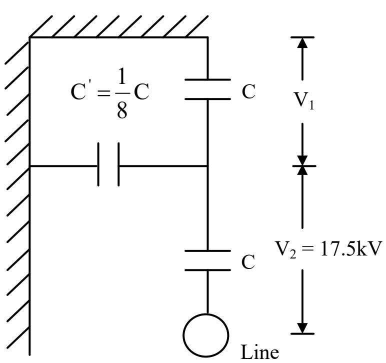
Sol: $V_1 + V_2 = V$

$V_2 = (1 + K) V$

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

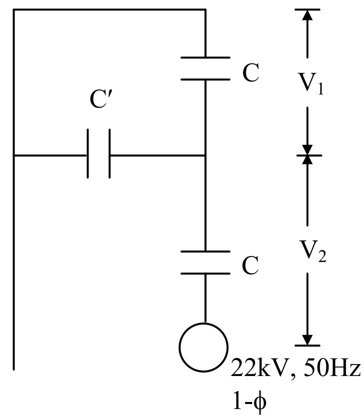
$V_1 = 15.55$ kV

$V = V_1 + V_2 = 33.05$ kV



03. Ans: (b)

Sol:

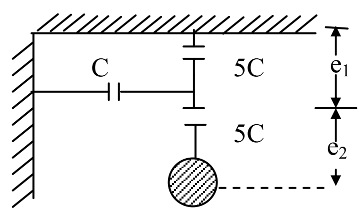


$$\eta_{string} = \frac{V_1 + V_2}{2V_2} = \frac{V_1 + (1+K)V_1}{2 \times V_1(1+K)}$$

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

04. Ans: (b)

Sol:



$e_2 = e_1 (1 + K)$

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

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

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

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

$e_1 = 2.8867 \cong 2.89$ kV

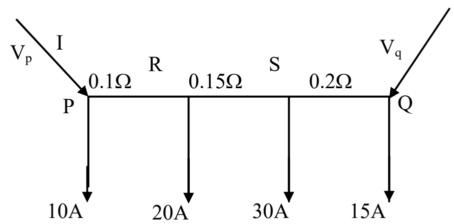
$e_2 = e_1 (1 + K) = 2.8867 \times 1.2$

$= 3.46$ kV.

2.10. Distribution Systems

01. Ans: (a)

Sol:



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

$3 = 0.45I - 17.5$

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

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

Here we have to take magnitude only

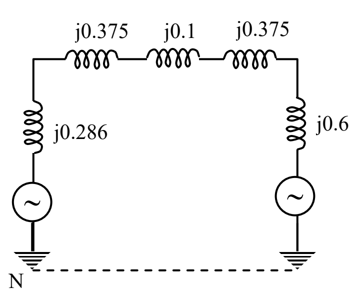
$\therefore V_D = 8.77$

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

$V_Q = V_P - 3 = 225.7V.$

3. PU System, Symmetrical Components & Fault Analysis

01.



02. Ans: Gen: X(pu) = 0.2 ;

T/F 1: X(pu) = 0.085

Tr.line: X(pu) = 0.181;T/F 2 : X_{New}(pu) = 0.091

M_1 : X_{New}(pu) = 0.2744

M_2 : X_{New}(pu) = 0.548

Sol: Choose 300 MVA, 20 kV as base value:

(1) Gen = 300 MVA, 20 kV, X = 0.2 p.u

(2) Transformer T_1:

$$Z_{T1} = 0.1\times\frac{300}{350}\times\left(\frac{20\,kV}{20\,kV}\right)^2$$

$$= 0.0857 \text{ p.u}$$

(3) Transmission line :

The base voltage of transmission line,

$$20\times\frac{230}{20} = 230\,V$$

transmission line reactance

$X = 0.5\ \Omega/km$

$X_T = 0.5\times 64 = 32\ \Omega,$

$$X_{Tp.u} = \frac{32\times300}{(230)^2} = 0.1815\,p.u$$

(4) Transformer T_2:

Transformation ratio T_2

$$= \frac{127\times\sqrt{3}}{13.2} = \frac{220}{13.2}$$

3-ϕ MVA rating of T_2 = 100×3

= 300 MVA

$$Z_{T2} = 0.1\times\left(\frac{220}{230}\right)^2\times\frac{300}{300}$$

$$= 0.0915 \text{ p.u}$$

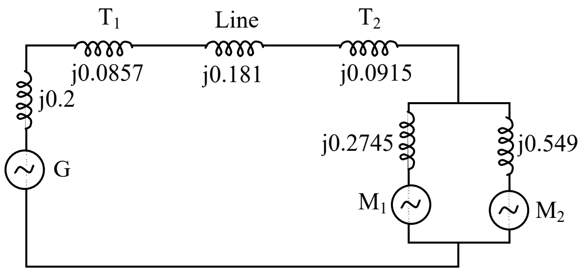
Base voltage on motors $= 230\times\dfrac{13.2}{220}$

= 13.8 volt

$$Z_{m1} = 0.2 \times \left(\frac{13.2}{13.8}\right)^2 \times \frac{300}{200} = 0.274\,\text{p.u}$$

$$Z_{m2} = 0.2 \times \left(\frac{13.2}{13.8}\right)^2 \times \frac{300}{100} = 0.549\,\text{p.u}$$

p.u reactance diagram



03. Ans: (c)

Sol: Given data

$I_a = 1\angle{-90°}$p.u

$I_{b_2} = 4\angle -150^\circ$ p.u

$I_{c_0} = 3\angle 90^\circ$ p.u

magnitude of phase current I_b in p.u = ?

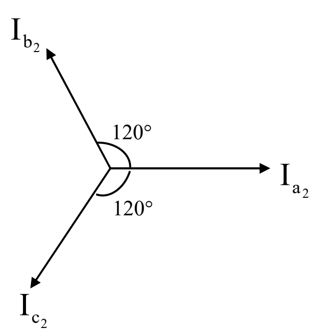
$|I_b| = ?$

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

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

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

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



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

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

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

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

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

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

$= 1(1\angle 240°)\ (8\angle{-90°})$

$= 8\angle 150°$p.u

$I_b = 3\angle 90° + 8\angle 150° + 4\angle{-150°}$

$= 11.53\angle 154.3$

04. Ans: I_{a1} = 23.53 kA

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

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

$I_a + I_b + I_c = 0$

$I_c = -[I_a + I_b]$

$= -[10\angle 30° + 15\angle{-30°}] = -150\angle 0°$

$$I_{a1} = \frac{1}{3}\begin{bmatrix} 10\angle 30^\circ + 1\angle 120^\circ \times 15\angle 30^\circ \\ +1\angle 240^\circ \times -150\angle 0^\circ \end{bmatrix}$$

I_{a1} = 23.53 kA

05. Ans: 7 kA

Sol: $I_{a1} = \dfrac{E}{Z_1 + Z_2 + Z_f}$

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

$I_{fault} = \dfrac{20\times 10^3}{\sqrt{3}\times 6.6} \times 4 = 7$ kA

06. Ans: (c)

Sol: 100 MVA, 20 kV

$X_d'' = X_1 = X_2 = 0.2$

$X_0 = 0.05$

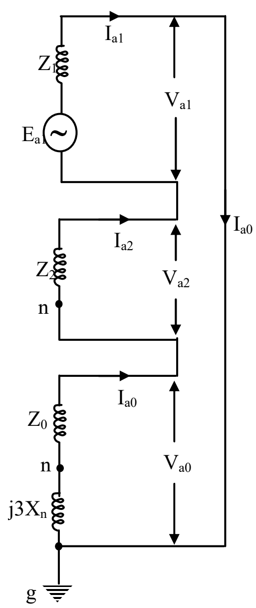
Prefault voltage, E_{a1} = 1 p.u

Z_1 = j 0.2

Z_2 = j 0.2

$Z_0 = j\,0.05$

Solid L-G fault → $Z_f = 0$



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

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

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

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

$= -\,j\,1.449$ 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

07. Ans: (b)

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

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

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

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

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

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

08. Ans: (b)

Sol: 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

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

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

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

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

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

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

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

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

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

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

$= 1.81\angle -90° \times 0.35\angle 90°$

$= 0.6335\text{p.u}$

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

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

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

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

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

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

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

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

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

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

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

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

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

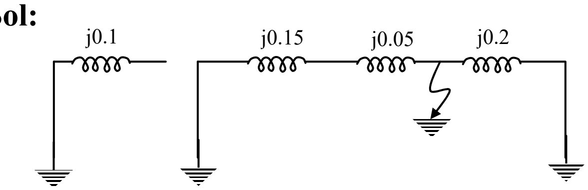
$I_{R0} = I_{R1} = \frac{E_{R1}}{X_{1eq} + X_{2eq} + X_{0eq}} = \frac{1.0}{0.3} = 3.33$

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

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

11. Ans: (b)

Sol:



$Z_{th} = 0.2||0.2 \Rightarrow \frac{0.2\times0.2}{0.2+0.2} = j0.1\text{ p.u}$

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

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

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

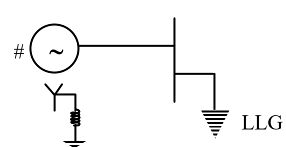
$I_F = \frac{\sqrt{3}E_{R1}}{X_{1eq} + X_{2eq}}$

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

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

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

Sol:



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

Current through ground = Fault current

$I_f = 3\ I_{a0}$

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

$$I_{a1} = \frac{E_{a1}}{X_1+\dfrac{X_2X_0}{X_2+X_0}}$$

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

$= 3.42$

Substitute I_{a1} value in equation (1)

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

$I_f = 3\ I_{a0} = 3\times1.59 = 4.77 \simeq 4.8$ p.u

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

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

Sol: $X_{1eq} = \dfrac{j0.12}{2}+j0.1 = j0.16$

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

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

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

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

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

$$= \frac{1.0}{0.2812}$$

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

15. Ans: (c)

Sol: Equivalent reactance seen from the fault point

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

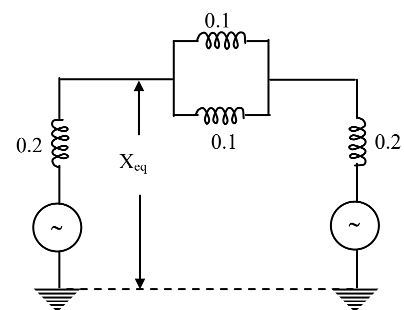
$= j0.12214$

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

= –j8.1871

16. Ans: (c)

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



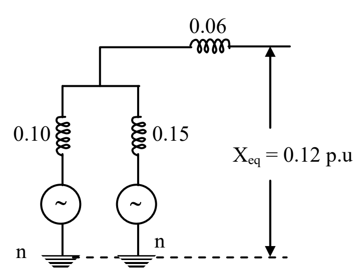
$$X_{G_2}\text{ New} = 0.16\left[\frac{1000}{800}\right] = 0.2$$

$$X_{eq} = \frac{0.2\times0.25}{0.45} = \frac{1}{9}$$

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

17. Ans: (b)

Sol:



X_{G_2} New on 15 MVA Base

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

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

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

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

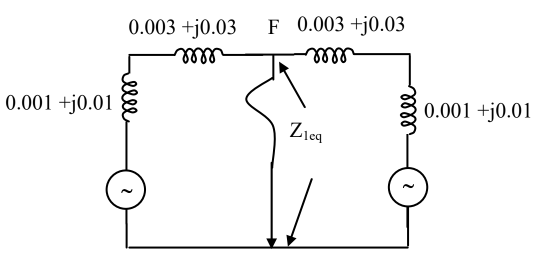
$$I_{fG_1} = 8.33 - 3.33 = 5$$

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

18. Ans: (a)

Sol: For a 3-phase fault

Fault current (I_f) = $\frac{E_{R_1}}{Z_{1\,eq}}$



Z_{1eq} = (0.004 + j 0.04) || (0.004 + j 0.04)

Z_{1eq} = 0.002 + j 0.02 p.u

E_{R_1} = V_{th} = 1.0 p.u

[∵ pre-fault voltage not specified]

$$\therefore I_f = \frac{1.0}{0.002 + j0.02} = 49.75\angle -84.289^\circ$$

$$I_{f\,base} = \frac{100\times 10^6}{\sqrt{3}\times 400\times 10^3} = 144.3\text{A}$$

$$\therefore I_{f\,actal} = I_{f\,p.u.} \times I_{f\,base}$$

$$= 49.75 \times 144.3 = 7.18 \text{ kA.}$$

$$= I_X = \frac{7.18}{2} = 3.59$$

19. Ans: (c)

Sol: For single line to ground fault

$$I_f = \frac{3E_{R_1}}{X_{1eq} + X_{2eq} + X_{0eq}}$$

Given that

$X_{2eq} = X_{1eq}$ & $X_{oeq} = 3\,X_{1eq}$

$$I_f = \frac{3E_{R_1}}{5X_{1eq}}$$

$$I_f = \frac{3\times 1.0}{5\times(0.002 + j0.02)}$$

I_f = 29.85 ∠– 84.289° p.u.

$$I_f = \frac{29.85\angle -84.289^\circ}{2} \text{ p.u}$$

$$I_x = 14.93$$

20. Ans: (i) I_{R1} = 4.77 kA, (ii) I_F = 35 kA, (iii) i = 56 kA, (iv) 49.5 kA, (v) i = 5.6pu, (vi) interrupting capacity = 560

Sol: (i) $I_{R1} = \frac{1.0}{1.1} = 0.91\text{p.u}$

$$= 0.9\times\frac{100}{\sqrt{3}\times 11} = 4.77\text{kA}$$

(ii) $I_F = I_{R1} = \frac{1.0}{0.15} = 6.67\text{p.u}$

$$= 6.67\times 5.24 = 35\text{kA}$$

(iii) i = I_F ×1.6=35×1.6=56kA

(iv) i = j2 ×I_{RMS} = 1.414 ×35=49.5kA

(v) $i = \frac{E_{R1}}{X_{1eql}} = \frac{1.0}{0.25} \times 1.4 = 4 \times 1.4 = 5.6\text{p.u}$

$i = 5.6 \times 5.24 = 29.34\text{kA}$

(vi) interrupting capacity

$= 3 \times \frac{11}{\sqrt{3}} \times 29.34 = 560$

21. Ans: $\overline{V}_t$ **= 0.9727 ∠8.287° p.u ;**

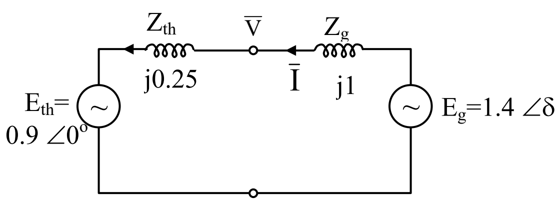
P = 0.5038 p.u., Q = 0.319 p.u.

Sol: Power system network represented as thevenins model with

$E_{th} = 0.9\ \angle 0^o$ p.u., $Z_{th} = 0.25\ \angle 90^o$ p.u.

Generator, $E_g = 1.4\ \angle 30^o$ p.u.

$Z_g = 1\ \angle 90^o$ p.u.



Current, $\bar{I} = \frac{E_g - E_{th}}{Z_{th} + Z_g}$

$= 0.613\ \angle -24.05^o$ p.u.

Bus voltage, $\overline{V}_t = E_g - Z_g.\bar{I}$

$= 1.4\angle 30^o - (1\angle 90^o)\ (0.613\ \angle -24.05^o)$

$= 0.9727\ \angle 8.287^o$ p.u

Complex power transferred to system at the bus

$s = \overline{V}_t.\bar{I}^*$

$= (0.9727\angle 8.287^o)\ (0.613\angle 24.05^o)$

$= 0.5038 + j0.319$

P = 0.5038 p.u., Q = 0.319 p.u.

4. Power System Stability

01. Ans: 23.54k N-m

Sol: Given that

H = 9 kW – sec/kVA

K.E = stored?

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

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

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

02. Ans: (c)

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

$H = \frac{\frac{1}{2} I \omega_s^2}{S}$ 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:

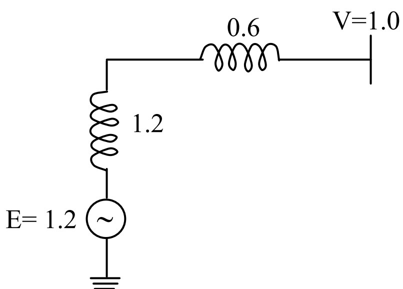
Generator A
n = 4
$H_{eq} = 9 \times 4$
=36 J/MVA
$H_{A\,New} = \frac{36 \times 100}{150}$
= 24

Generator B
n = 3
$H_{eq} = 4 \times 3$
= 12J/MVA
$H_{B\,New} = \frac{12 \times 200}{150}$
= 16

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

04. Ans: f_n = 0.63 Hz

Sol:



Frequency of oscillations.

$$K = \pm\left[\frac{1}{m}\left[\frac{\partial Pe}{\partial \delta}\right]_{\delta 0}\right]^{1/2}$$

$$\left.\frac{\partial P_e}{\partial \delta}\right|_{\delta=\delta_0} = \frac{EV}{X_{eq}}\cos\delta_0 \Rightarrow \frac{1.2 \times 1}{1.8}\cos(53.13°)$$

= 0.4

X_{eq} = 1.8

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

$= \sin^{-1}(0.8) = 53.13°$.

$$M = \frac{SH}{\pi f}$$

$$M = \frac{1 \times 4}{\pi \times 50} \Rightarrow 0.02546$$

$$f_n = \pm\left[\frac{1}{0.02546} \times 0.4\right]^{1/2}$$

f_n = 3.96 rad/sec

f_n = 0.63 Hz

05. (i) KE = 800 MJ ;(ii) α = 337.5 elec.deg/sec^2
(iii) $\Delta\delta$ = 6.75 elec.degree/sec^2

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

(i) K.E Stored GH=$100 \times 8 = 800$ 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)

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

$$M = \frac{GH}{180f} = \frac{800}{180 \times 50} = 0.088$$

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

$= 337.5 \times \frac{2}{p}$ 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.

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

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

Speed of the 10 cycle = 1500

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

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

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

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

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

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

Equation (2) substitute equation (1)

N(t) = 1500 + 28.36 × 0.2

N(t) = 1505.67 rpm

06. Ans: δ_{cr} = 70.336°

Sol: δ = 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°.

07. Ans: δ_{cr} = 55°

Sol: Given that 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}

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

$P_{m3} = 1.245$

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

$\delta_0 = 35.17° = 0.614$ rad

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

$= 126.56° = 2.208$ rad

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

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

$\delta_{cr} = 51.82° \simeq 55°$

08. Ans: $\delta_{cr} = 88°$

Sol: Given that

$P_s = 0.4\ P_{m1}$

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

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

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

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

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

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

$$\cos^{-1}\left[\frac{0.4Pm_1(150 - 23.578) \times \frac{\pi}{4} + 0.8P_{ml}\cos 150 - 0.167P_{ml}\cos 23.578}{0.8P_{ml} - 0.167P_{ml}}\right]$$

$\delta_{cr} = 88°$

09. Ans: $\delta_c = 65°$

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

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

$P_{m1} = 2.2$

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

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

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

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

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

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

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

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

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

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

$$= \cos^{-1}[0.423] = 65°$$

10. Ans: δ_c = 84°

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

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

$$P_{m_1} = 2.2$$

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

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

$$\delta_0 = 27°$$

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

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

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

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

$$\delta_c = 84°$$

11. Ans: δ_c = 79.77°

Sol: $P_s = P_{e_1}$

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

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

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

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

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

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

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

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

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

12. Ans: δ_c = 87.7°

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

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

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

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

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

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

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

$$= 87.7°$$

13. Ans: (a)

Sol: $P_{m1} = P_{m3} = 2.5$ pu

$P_{m2} = 0$

$P_s = 1.0$ pu

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

$$= \sin^{-1}\left(\frac{1}{2.5}\right) = 23.57° = 0.411\,\text{rad}$$

$$\delta_{max} = 180 - \delta_0 = 156.43 = 2.73\text{ rad}$$

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

$$= \cos^{-1}\left[\frac{1(2.73-0.411)+2.5\cos 156.43}{2.5}\right]$$

$= 89.27°$

14. Ans: (d)

Sol: $t_C = \sqrt{\frac{2M(\delta_C-\delta_0)}{P_s}} = \sqrt{2\times\frac{SH(\delta_C-\delta_0)}{\pi f(P_s)}}$

$$= \sqrt{2\times\frac{1\times 6}{3.14\times 50}\times(89.27-23.57)\times\frac{\pi}{180}}$$

$= 0.290$ sec $\simeq 0.292$ sec.

15. Ans: 0.20682 sec

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

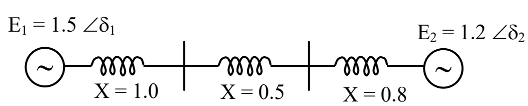
$$t_c = \sqrt{\frac{2\times SH(\delta_L-\delta_0)}{\pi f(P_s)}}$$

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

$= 0.20682$ sec

16. Ans: $P_e = 0.3307$ pu

Sol:



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

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

$= 0.3307$ p.u

17. Ans: Permissible increase = 60.34°

Sol: Given $P_S = 2.5$ p.u.

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

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

$P_s = P_{e1}$

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

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

$\delta_0 = 30° \Rightarrow 0.523$ 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

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

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

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

$\cos\delta_c = -6\times10^{-3}$

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

Permissible increases $= \delta_c - \delta_0$

$= 90.34° - 30°$

$= 60.34°$

5. Load Flow Studies

01. Ans: (a)

Sol: $Y_{23} = j10\,;\ y_{23} = -Y_{23} = -j10$

$$z_{23} = \frac{1}{y_{23}} = j0.1$$

02. Ans: (c)

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

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

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

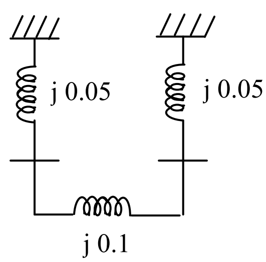
$= (j\,0.5)^{-1} + (j\,0.25)^{-1} = -j\,6$

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

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

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

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

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

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

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

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

$= j1.2$ ………..(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

$Y_{31} = j0.8$

06. Ans: The reactance = j0.4

07. 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) $z_{12} = j0.001\times100 = j\,0.1$

$y_{12} = -j10$

$z_{13} = j0.001\times200 = j0.2$

$y_{13} = -j5$

$y_{23} = j0.001\times250 = j0.25$

$y_{23} = -j4$

$y^1_{12} = j0.0016\times100 = j0.16$

$y^1_{13} = j0.0016\times200 = j0.32$

$y^1_{23} = j0.0016\times250 = j0.4$

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

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

$= -j\,14.76$

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

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

$= -j13.72$

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

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

$= -j8.64$

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

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

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

$y_{12} = -20j$

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

$y_{13} = -j10$

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

$y_{23} = -j8$

$y'_{12} = j0.0016\times100 = j0.16$

$y'_{13} = j0.0016\times200 = j0.32$

$y'_{23} = j0.0016\times250 = j0.4$

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

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

$= -j29.76$

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

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

$= -j17.64$

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

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

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

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

$y_{12} = -j10$

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

$y_{13} = -j5$

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

$y_{23} = -j4$

$y'_{12} = j0.0008\times100 = j0.08$

$y'_{13} = j0.0008\times200 = j0.16$

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

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

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

$$= -j14.88$$

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

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

$$= -13.86$$

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

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

$$= -j8.82$$

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

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

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

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

08. Ans: (b)

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

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

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

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

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

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

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

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

6. Load frequency control

01. Ans: (c)

Sol: 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: We know that Change in load

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

where Δf = change in frequency

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

$\therefore$ AFRC = 42 MW/Hz

03. Ans: (b)

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

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

04. Ans: (c)

Sol: 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

$$f_{new} = \sqrt{\frac{500-15}{500}} \times 50 = 49.24\text{Hz}$$

05. Ans: (c)

Sol: $\% \text{ regulation} = \dfrac{\frac{\Delta f}{f}}{\frac{\Delta p}{p}}$

$$= \frac{\frac{50-48}{50}}{\frac{100}{100}} \times 100$$

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

7. Circuit breakers

01. Ans: (a)

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

$$= \frac{1}{2\pi\sqrt{15\times10^{-3}\times0.002\times10^{-6}}} = 29 \text{ kHz}$$

02. Ans: (b)

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

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

03. Ans: (a)

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

V_{rmax} = 2 ARV

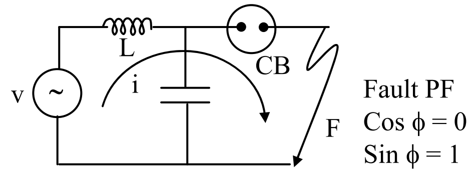
ARV = K_1 K_2 K_3 V_{max} sin ϕ

$K_1 = 1 \rightarrow$ No Armature reaction

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

$K_3 = 1 \rightarrow$ ARV/phase

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



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

= 28.28kV

04. Ans: (d)

Sol: Making current = 2.55 × I_B

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

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

07. Ans: (c)

Sol: A.R.V = K_1K_2 V_m sinϕ

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

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

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

$$= 96.7kV$$

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% $\times 5$

$\Rightarrow 0.5\times 5 \Rightarrow 2.5$

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

$$= \frac{2000}{\frac{400}{5}\times 0.5\times 5} = 10$$

02. Ans: (c)

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

$\therefore$ Minimum value of negative sequence

current required for relay operation

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

But for a line to line fault

$I_{R_2} = -I_{R_1}$

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

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

$\therefore$ 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)

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)

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.

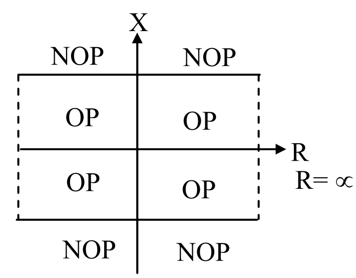
09. Ans: (a)

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.

θ_V = 45°, maximum torque angle γ = 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.