1 GEOMETRIC MEAN DISTANCE : $D_m = \sqrt[nm]{\prod_{i=1}^{n}\prod_{j=1'}^{m} D_{ij}}$; n - conductors in one bundle ; m - conductors remaining ;

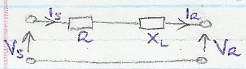
GEOMETRIC MEAN RADIUS : $D_s = \sqrt[n^2]{\prod_{i=1}^{n}\prod_{j=1}^{n} D_{ij}}$; *note D_{kk} where $k = 1, 2, \dots n$ has skin effect

RADIUS WITH SKIN EFFECT : $r' = r\, e^{\left(-k_s \frac{\mu_r}{4}\right)}$; k_s - L/L_0 skin effect correction ; r - actual radius

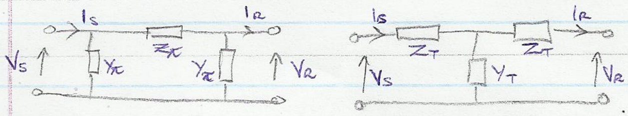
GEOMETRIC MEAN RADIUS FOR CAPACITANCE : $D_{eq} = D_s$ without the skin effect ie remove $\left[e^{-k\mu/4}\right]$

$L' = \frac{\mu_0}{2\pi} \ln\left[\frac{D_m}{D_s}\right] (H/m)$; $C' = \frac{2\pi\varepsilon_0}{\ln\left[\frac{D_m}{D_{eq}}\right]} [F/m]$; $R' = k_s \frac{\rho}{A}\ [\Omega/m]$; $A = \pi r^2$

3 SHORT LINES : $l < 50$; $R = R' l$; $X_L = \omega L' l$; $A = 1\angle 0$; $B = R + jX_L$



MEDIUM LINES : $50 < l < 200$



$Z_\pi = (R' + j\omega L') l$; $Y_\pi = \frac{(G' + j\omega C') l}{2}$

$Z_T = \frac{(R' + j\omega L') l}{2}$; $Y_T = (G' + j\omega C') l$

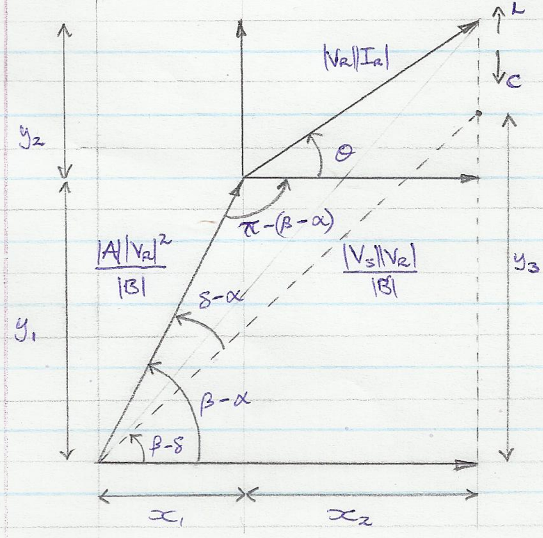
use $G' = 0$ infinite resistance w.r.t. ground

$A = 1 + Z_\pi Y_\pi$; $B = Z_\pi$

LONG LINES : $l > 200$ $\quad \gamma = \sqrt{(R' + j\omega L')(G' + j\omega C')}$; $Z_0 = \sqrt{\frac{(R' + j\omega L')}{(G' + j\omega C')}}$

$Z_\pi = Z_0 \sinh(\gamma l)$; $Y_\pi = \frac{\cosh(\gamma l) - 1}{Z_\pi}$; $Y_T = \frac{\sinh(\gamma l)}{Z_0}$; $Z_T = \frac{\cosh(\gamma l) - 1}{Y_T}$

$A = \cosh(\gamma l)$; $B = Z_0 \sinh(\gamma l)$



POWER FACTOR

$A = |A|\angle\alpha$; $B = |B|\angle\beta$; δ - load angle ; $\theta = \cos^{-1}\phi$

$x_1 = \frac{|A||V_R|^2}{|B|}\cos(\beta - \alpha)$; $x_2 = |V_R||I_R|\cos\theta$ POWER IN (W)

$y_1 = \frac{|A||V_R|^2}{|B|}\sin(\beta - \alpha)$; $y_2 = |V_R||I_R|\sin\theta$ POWER IN (VAR)

$y_3 = \sqrt{\left(\frac{|V_s||V_R|}{|B|}\right)^2 - (x_1 + x_2)^2}$; $(\beta - \delta) = \cos^{-1}\frac{(x_1 - x_2)}{\left(\frac{|V_s||V_R|}{|B|}\right)}$

COMPENSATION = $y_1 + y_2 - y_3$ - [VAR] (shunt)

SERIES COMPENSATON : $P_L = \frac{|V_s||V_R|}{\omega L} = \frac{|V_s||V_R|}{X_s}$; $X_s = \left(\omega L - \frac{1}{\omega C}\right) j$

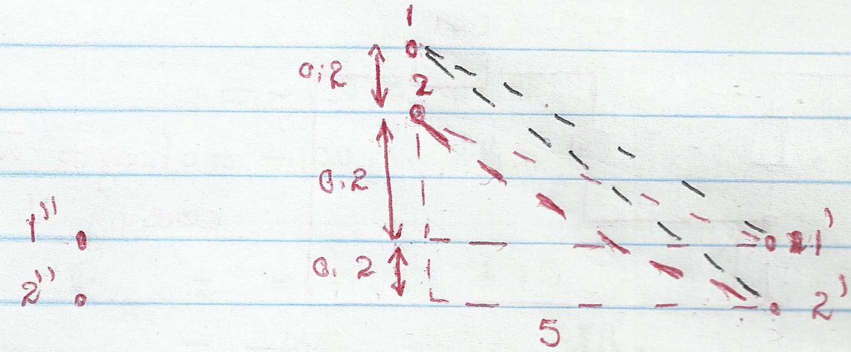
5 FAULT LEVEL = $\frac{MVA_{base}}{\text{total impedance [upstream]}}$ [MVA] ; FAULT CURRENT = $\frac{\text{MVA fault level}}{\sqrt{3}\, V_{base}\ (\text{@ fault point})}$ [A]

RATED CURRENT = $\frac{\text{rated MVA of transformer}}{\sqrt{3}\, V \text{ @ the bus}}$; CURRENT MULTIPLIER = $\frac{I\ \text{rated}}{I\ \text{pickup}}$

I pickup is the current @ which the IDMT Responds. ; $t = \frac{0{,}14}{I_{pu}^{0{,}02} - 1} \times$ time multiplier

$I_{pu} = \frac{I_{fault}}{I_{rated}}$;

(1)



$D_{11'} = 5.02 = D_{22'}$

$D_{12'} = 5.04$ $D_{21'} = 5.004$

~~$G.M.D = \sqrt[2\times4]{(5.02 \times 5.02 \times 5.004 \times 5.04)^2}$~~

$= 5.021\ m$

$D_{11''} = 10$, $D_{22''} = 10$

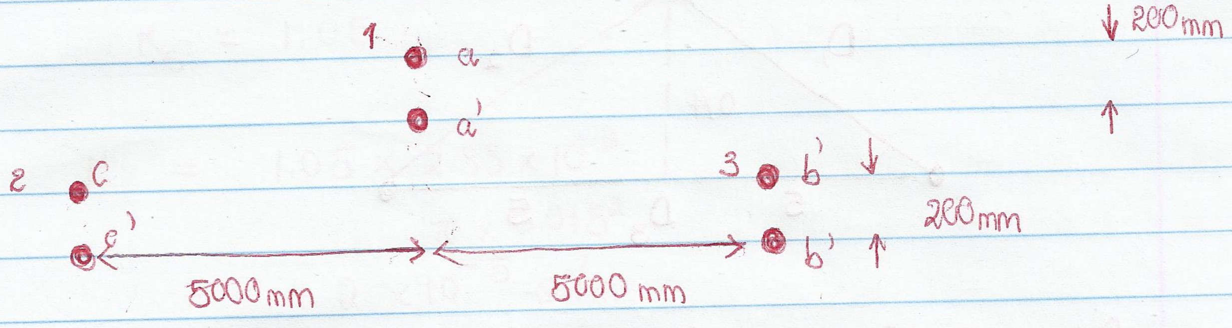
$D_{12''} = D_{21''} = 10.002$

$G.M.D = \sqrt[8]{5.02 \times 5.02 \times 5.04 \times 5.004 \times 10 \times 10 \times 10.002 \times 10.002}$

$= 7.086\ m.$

PtP 2012

1.



radius = 15mm

$G.M.R = \sqrt[n^2]{aa \times aa' \times a'a \times a'a'}$ or $\sqrt[4]{aa \times aa'}$

$aa' = a'a' = r\left(e^{-k_s \mu_r/4}\right)$

$m = \sqrt{\dfrac{2\pi(50) \times 4\pi \times 10^{-7}}{2.83 \times 10^{-8}}} = 118.11$ $\mu_r = 1$

$mr = 118.11 \times 0.015 = \underline{1.772}$

$K_s = 0.975$

$aa = a'a' = 0.015\ e^{-0.975/4}$

$= 0.0118\ m.$

$aa' = a'a = 0.2\ m$ #

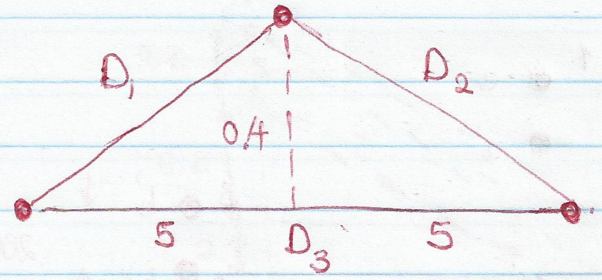
$GMR = \sqrt[4]{0.0118^2 \times 0.2^2}$

$= 0.0486\ m.$

Assuming distance btwn subconductors is << distance btwn conductors (phase)

$G.M.D = \sqrt[3]{D_1 D_2 D_3}$

3



$D_1 = 5.016\ m = D_2 \qquad D_3 = 10m.$

$$G.M.D = \sqrt[3]{5.016^2 \times 10} = 7.08\ m.$$

$$L' = 2 \times 10^{-7} \ln\left(\frac{7.086}{0.0486}\right)$$

$$= 9.96 \times 10^{-7}\ H/m.$$

$$C' = \frac{2\pi\varepsilon_0}{\ln\left(\frac{7.086}{D_{eq_{rc}}}\right)}$$

$D_{eq_{rc}}$: $aa = a'a' = 0.015 \cancel{e^{-1/4}}$ (no skin effect)

$= 0.\cancel{017}m$

$$D_{eq_{rc}} = \cancel{\sqrt[4]{0.017^2 \times 0.2^2}}$$

$= \cancel{0.0484\ m}.$

$$D_{eq_{rc}} = \sqrt[4]{0.015^2 \times 0.2^2}$$

$D_{eq_{rc}} = \cancel{0.448\ m}\ 0.0548\ m$

$\therefore C' = 1.115 \times 10^{-11}\ F/m.$

$C' = \cancel{20.1 \times 10^{-12}\ F/m}$

11.4 pF/m

$C' = \cancel{20.1\ pF/m}.$

$$R' = K_s \frac{\rho}{A}$$

$C' = 11.4\ PF$

$$K_s = 1.05$$

$$R' = \frac{1.05 \times 2.88 \times 10^{-8}}{\pi \times 0.015^2}$$

$$= 4.2 \times 10^{-5}\ \Omega/m$$

b) $$L' = 2 \times 10^{-7} \ln\left(\frac{D_m}{D_{eq}}\right)$$

~~For a~~ Conductor bundles ~~Deq~~ increase D_{eq} values wc in turn dt L'

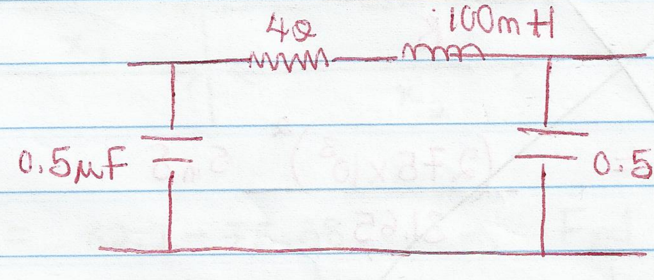
c) For a symmetrically spaced 3 ϕ conductor Geometry.

2 An overhead line has a higher $\frac{X}{R}$ ratio than similarly rated cable because there is flux cancellation in rated cables becoz ~~since~~ their spacing is small compared to overhead cables where there is small ~~Significant~~ flux cancellation due to a larger separation distance between phase conductors.

$$L = 2 \times 10^{-7} \ln\left(\frac{D_m}{D_{eq}}\right) \qquad (1)$$

From (1), D_m is >> D_{eq} ⇒ L is high. ⇒ X is high as well, compared to rated cables in wc D_m/D_{eq} is very small.

b)



$V = \cancel{200\,kV}\ 275\,kV$, $P_R = 300\,MW$; $pf = 0.94$ lagging

$A = 1 + Z_\pi Y_\pi$

$B = Z_\pi$

$Z_\pi = (R' + j\omega L')\,l = R'l + j\omega L'$

$= 4\Omega + j\ 100\,mH \times 2\pi f$

$= 4\Omega + j\,10\pi$

$= 4\Omega + j\,31.4\Omega$

$Y_\pi = \dfrac{(G' + j\omega C')l}{2} = \dfrac{G'l + j\omega C'l}{2}$ $(G=0)$

$= j\,\dfrac{2\pi(50) \times 0.5\times10^{-6}}{2}$

$= j\ 78.54 \times 10^{-6}\,\Omega$

$B = 4 + j\,31.4 = 31.65\angle 82.7^\circ$

$A = 1 + (31.65\angle 82.7^\circ)(78.54\times10^{-6}\angle 90)$

$= 1 + 2.49\times10^{-3}\angle 172.7$

$= 0.9975 + j\ 316\times10^{-6}$

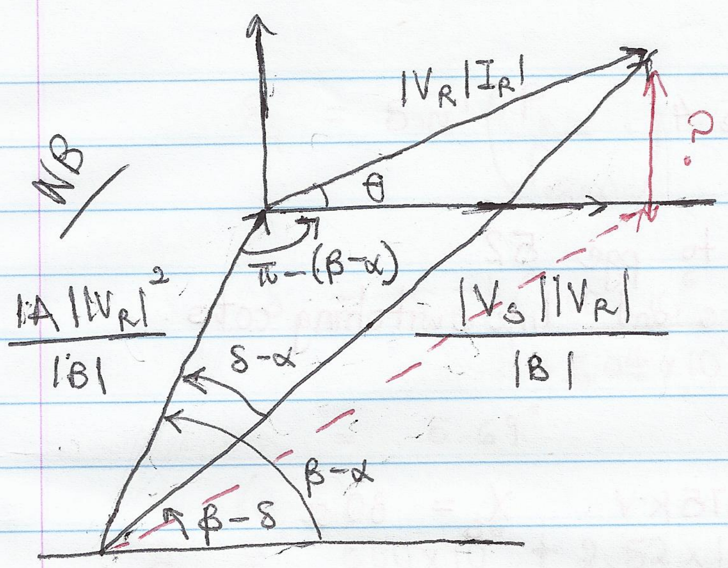
$= 0.9975\angle 0.018$

$V_S = AV_R + BI_R$

NB Load Real Power $= \dfrac{|V_S||V_r|}{B}\sin\delta$

$\left(\dfrac{300}{3}\right) = \dfrac{(275\times10^3)^2}{31.65}\sin\delta$

$\sin\delta = 41.9\times10^{-9}$



$$\theta = 19.95^\circ = \cos^{-1}(0.94)$$

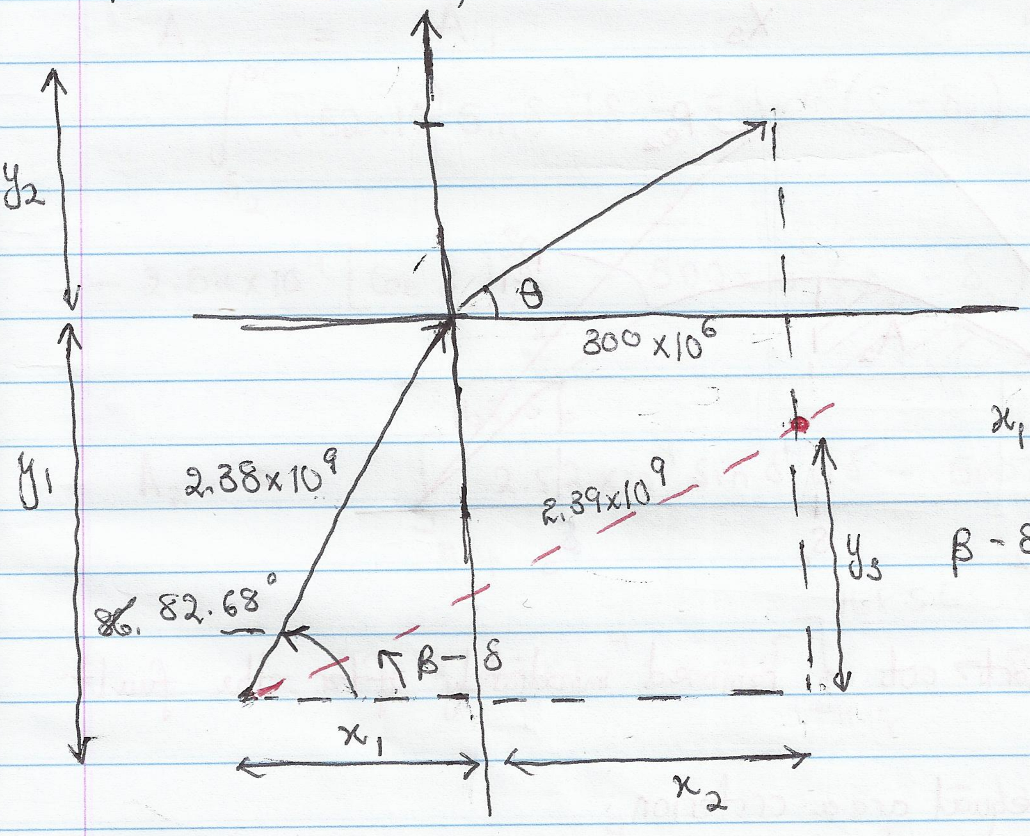
$$\frac{|A||V_R|^2}{|B|} = \frac{0.9975\times(275\times10^3)^2}{31.65}$$

$$= \cancel{2.38\ \text{MVA}}$$

$$= 2.38\ \text{GVA}$$

$$\frac{|V_S||V_R|}{|B|} = \frac{(275\times10^3)^2}{31.65} = 2.39\times10^9\ \text{VA}$$

$\beta = 82.7^\circ \qquad \alpha = 0.018^\circ$



$$x_1 = 2.38\times10^9 \cos 82.68$$
$$= 303.24\times10^6$$

$$x_2 = 300\times10^6$$

$$x_1 + x_2 = 603.24\times10^6$$

$$\beta - \delta = \cos^{-1}\left(\frac{603.24\times10^6}{2.39\times10^9}\right)$$

$$= 75.38^\circ$$

$$\therefore\ \delta = 82.7 - 75.38$$
$$= 7.32^\circ$$

$\Rightarrow$ Find y_1, y_2 and y_3 by resolving into the vertical.

Continued on page ~~10~~ 11

$$y_1 = 2.38\times10^9 \sin 82.68 = 2.36\times10^9 \text{ VAR}$$
$$y_2 = 300\times10^6 \tan 19.95 = 108.89\times10^6 \text{ VAR}$$
$$y_3 = 2.39\times10^9 \sin 75.38 = 2.31\times10^9 \text{ VAR}$$

$$\text{Required VAR} = y_1 + y_2 - y_3$$
$$= 158.89 \text{ MVAR}$$

$$P = \frac{V_R^2}{X_c} = \frac{V_R^2}{2\pi f C}$$

$$C = \frac{V^2}{2\pi f P}$$
$$= \frac{(275\times10^3)^2}{(2\pi\times50\times158.89\times10^6)}$$
$$= 1.515 \text{ F} \quad \text{(Shunt)}$$

SIL Defn: Refer to the book, pge 4

If $P_L > SIL \rightarrow V_R < V_S$

If $P_L < SIL \rightarrow V_R > V_S$

2010

$$P_L = \frac{V^2}{X_S}$$

NB

where $X_S = \cancel{\ } \left| j\left(\omega L - \frac{1}{\omega C}\right) \right| = \omega L - \frac{1}{\omega C}$

$P = 600 \text{MW}$

$$P_{New} = P + 0.2P = 1.2P = 720 \text{ MW}$$

$$X_s = \frac{V^2}{P}$$

$$= \frac{(400 \times 10^3)^2}{\frac{1}{3}(720 \times 10^6)}$$

$$\omega L - \frac{1}{\omega C} = \cancel{222.222}$$

$$2\pi \times 50 \times 475 \times 10^{-3} - \frac{1}{\omega C} = \cancel{222.222}$$

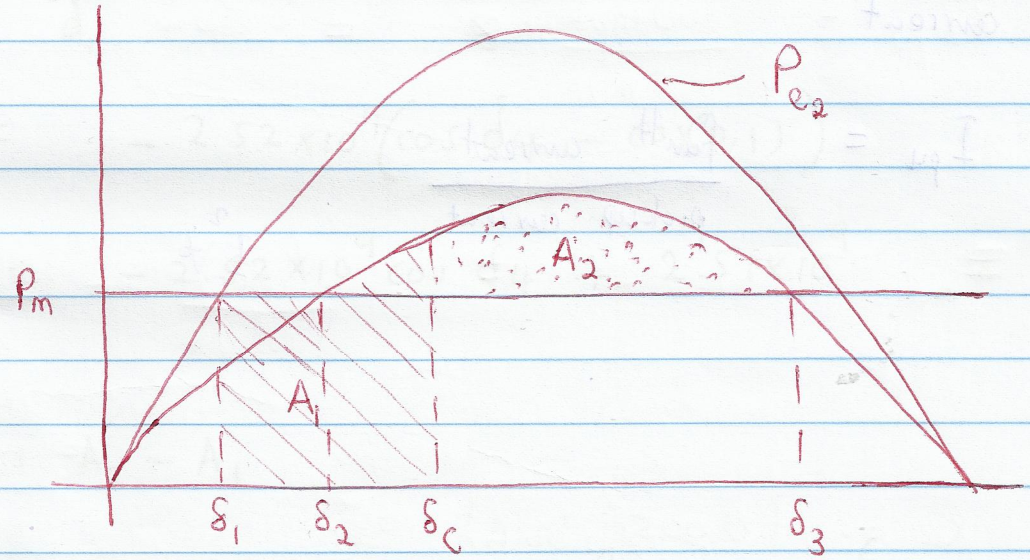
? ?

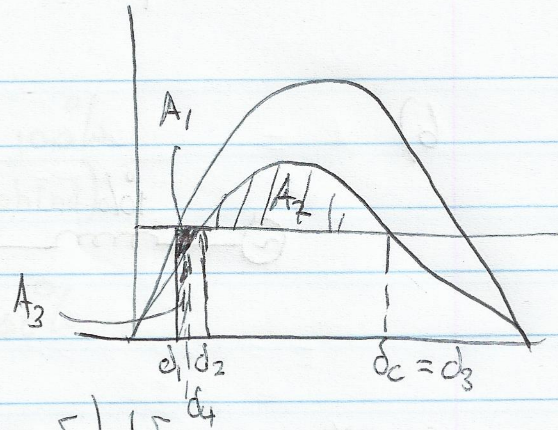
Stability

3 a Transient stability refers to the ability of a power system to regain equilibrium after a significant disturbance occurs in the power system.

bi Series Compensation
Shunt Compensation. } list adv and disadv

c) $P_m = 500\,MW$, $V_S = V_R = 275\,kV$, $X_S = 30\,\Omega$





$A_2 = 3.57 \times 10^9$

$$A_1 = \int_{\delta_1}^{\delta_2} (P_s - P_{e2max} \sin\delta)\, d\delta$$

$$= \int_{0.1}^{0.2} (500 \times 10^6 - 2.52 \times 10^9 \sin\delta)\, d\delta$$

$$= 500 \times 10^6 (0.2 - 0.1) + 2.52 \times 10^9 (\cos 0.2 - \cos 0.1)$$

$$= 12.6 \times 10^6$$

$$A_3 = \int_{\delta_1}^{\delta_4} P_{e2max} \sin\delta\, d\delta$$

$$= \int_{\delta_1}^{\delta_4} 2.52 \times 10^9 \sin\delta\, d\delta$$

$$= -2.52 \times 10^9 (\cos\delta_4 - \cos(0.1))$$

$$= -2.52 \times 10^9 \cos\delta_4 + 2.51 \times 10^9$$

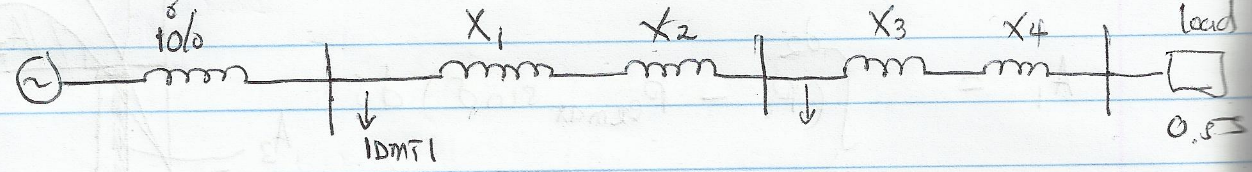
$$A_3 = A_2 - A_1$$

$$-2.52 \times 10^9 \cos\delta_4 = 3.57 \times 10^9 - 12.6 \times 10^6 - 2.5 \times 10^9$$

$$\cos\delta_4 = -\frac{1.047 \times 10^9}{2.52 \times 10^9}$$

$$\delta_4 = 1.14 \text{ rad}$$

6) Question 6 (2012)



$$X_{1_{pu}} = \frac{100\ MVA}{20\ MVA} \times 10\% = 50\%$$

$$Z_{base} = \frac{(V_{base})^2}{MVA_{base}} = \frac{(6.6 \times 10^3)^2}{100\ MVA}$$

$$= 0.4356$$

$$X_{2\ pu} = 1/0.4356$$

$$= 229.5\%$$

$$X_{3\ pu} = \frac{100\ MVA}{5\ MVA} \times 8\% = 160\%$$

$$Z_{base}\ \text{at bus 2} = \frac{(V_{base})^2}{MVA} = \frac{(400)^2}{100\ MVA}$$

$$= 0.0016$$

$$X_{4_{pu}} = (0.005/0.0016) \times 100\%$$

$$= 312.5\%$$

IDMT 1

$$\text{Fault level (MVA)} = \frac{MVA_{base}}{\text{Total impedence (behind)}} \times 100\%$$

$$= \frac{100\,MVA}{10\%} \times 100\%$$

$$= 1 \times 10^{9}\,V = 1000\,MVA$$

$$\text{Fault current} = \frac{\text{Fault level (MVA)}}{\sqrt{3}\,V_{bus}\text{ (connected to the fault point)}}$$

$$= \frac{1000\,MVA}{\sqrt{3}\,(132\,KV)}$$

$$= 4.37\,KA$$

$$\text{Rated current} = \frac{\text{rated MVA of transformer}}{\sqrt{3}\,V\text{ at the bus}}$$

$$= \cancel{87} \frac{20\,MVA}{\sqrt{3}\,(132\,KV)}$$

$$= 87.5\,A$$

current transformer ratio becomes 100 : 1 / 100 : 5

if primary current = 87.5 A, secondary current = ~~8~~ 0.875 A

$$\text{Current multiplier} = \frac{\text{rated current}}{1.25\,(\text{rated current})}$$

$$\text{current multiplier} = \frac{0.875\,A}{1.25 \times 0.875} = 0.8$$

$$t = \frac{0.14}{I_{pu}^{0.02} - 1} \times \text{time multiplier}$$

$$t = 0.5 + 0.5 + 0.5$$
$$= 1.5 s$$

$$\text{time multiplier} = \frac{t\left(I_{pu}^{0.02} - 1\right)}{0.14}$$

$$= \frac{1.5\left(49.94^{0.02} - 1\right)}{0.14}$$

$$= 0.872$$

$$I_{pu} = \frac{\text{Fault current}}{\text{rated current}} = \frac{4.37 \text{ KA}}{87.5 \text{ A}}$$

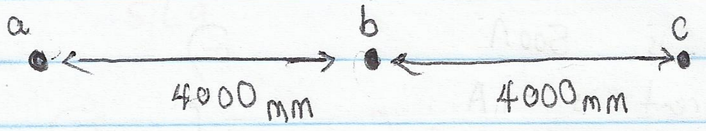
$$= 49.94$$

when there is a fuse

$$I^2 t = x$$

fault current

2010



$$G.M.D = \sqrt{ab \times ac}$$

$$= \sqrt{4 \times 8}$$

$$= 5.66\ m.$$

For Inductance:

$$G.M.R = r e^{-K_\delta \mu r/4}$$

$$m = \sqrt{\frac{2\pi \times 50 \times 4\pi \times 10^{-7}}{2.88 \times 10^{-8}}}$$

$$m = 118.11$$

$$mr = 118.11 \times 0.015 = 1.772$$

$$K_\delta = 0.975$$

$$G.M.R = 0.015\, e^{-0.975 \times 1/4}$$

$$= 0.0118 m.$$

$$L' = 2 \times 10^{-7} \ln\left(\frac{5.66}{0.0118}\right)$$

$$= 1.23\ \mu H/m.$$

For Capacitance:

$$GMR = 0.015\ m$$

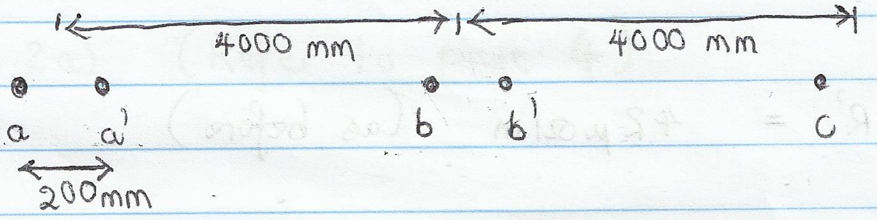
$$C' = \frac{2\pi \times 8.85 \times 10^{-12}}{\ln\left(\frac{5.66}{0.015}\right)}$$

$$= 9.37\ pF/m.$$

$$R' = K_s \frac{\rho}{A}$$

$$= 1.05 \times \frac{2.83 \times 10^{-8}}{\pi \times 0.015^2} = 42\ \mu\Omega/m.$$

b)



ab = 4 m , ab' = 4,200 m , ac = 8 m , ac' = 8,200 m
a'b = 3.8 m , a'b' = 4 m , a'c = 7.8 , a'c' = 8 m.

$$G.M.D = \sqrt[8]{ab \times ab' \times ac \times ac' \times a'b \times a'b' \times a'c \times a'c'}$$

$$= 4.36\ m.$$

Inductance :

$$m = \sqrt{\ldots\ldots} = 118.11$$

$$m_r = 1.772 \quad , \quad K_6 = 0.975$$

$$r' = 0.015\, e^{-0.975 \times 1/4} = 0.0118\ m.$$

$$GMR = \sqrt[4]{0.0118^2 \times 0.2^2} = 0.0486\ m.$$

$$L' = 2\times10^{-7} \ln\left(\frac{4.36}{0.0486}\right) = 899.32 \text{ nH/m}$$

Capacitance :

$$G.M.R = \sqrt[4]{0.015^2 \times 0.2^2}$$
$$= 0.0548 \text{ m.}$$

$$C' = \frac{2\pi \times 8.85\times10^{-12}}{\ln\left(\frac{4.36}{0.0548}\right)} = 12.7 \text{ nF/m.}$$

$$R' = 42\,\mu\Omega/\text{m} \quad \text{(as before)}$$

Power limit , $P_{lim} = \dfrac{V_S V_R}{\omega L}$

$$= \frac{182000^2}{\omega L' l}$$

(i) $L' = 1.23\,\mu$ $\quad P_{lim} = \dfrac{182000^2}{2\pi\times50\times1.23\times10^{-6}\times200\times10^{3}}$

$$= 225.5 \text{ MW}$$

(ii) $L' = 8.99.32 \text{ nH}$

$$P_{lim} = \frac{182000^2}{2\pi\times50\times\cancel{1.23\times10^{-6}}\,899.32\times10^{-9}\times200\times10^{3}}$$

$$= 308.4 \text{ MW}$$

$$L' = \frac{\mu_0}{2\pi} \ln\left(\frac{D_m}{D_s}\right)$$

No ~~dif~~ linear relationship.

Advantages
- Increasing power limit
- More real power compared to reactive
- Increase loadability of the line
- Check scanned paper (tuts)

2012 Qsn 2a) (Refer to page 4)

$$R_1 = 1.15 \times \frac{1.77 \times 10^{-8}}{\pi \times (20 \times 10^{-3})^2}$$
$$= 5.09 \times 10^{-5}\ \Omega/m.$$

$$R = R_1 + R_2 + R_3$$
$$= 1.58 \times 10^{-4}\ \Omega/m.$$

Question 2: Advantages of Bundles.

- Bundled conductors are primarily employed to reduce the corona loss. and radio interference.

1. Bundled conductors / phase reduces the voltage gradient in the vicinity of the line. Thus reduces the possibility of the corona.
2. Improvement in the transmission efficiency as loss due to corona effect is ~~on~~ countered.
3. Bundled conductor lines will have higher capacitance to neutral in comparison w single lines. Thus they will have higher charging currents wc helps in improving the power factor.
4. Bundled conductor lines have higher C and lower L than ordinary lines, they will have a higher SIL $[Z = (L/C)^{1/2}]$. Higher SIL will have higher maximum power transfer ability.
5. With increase in self GMD or GMR. inductance / phase will be reduced compared to single conductor line. This results in lesser reactance / phase compared to the ordinary single line. Hence lesser loss due to reactance drop.

3.

$$I \rightarrow J \rightarrow E \rightarrow V$$

$$J = \frac{I}{A} = \frac{I}{2\pi r \cancel{l}}$$

$$E = \frac{J}{\sigma} = \frac{I}{2\pi r \sigma \cancel{l}}$$