Supp for EIEN 4005

CN 3 13:30

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PTP Past papers 2013.

Example 8.8: pg 299

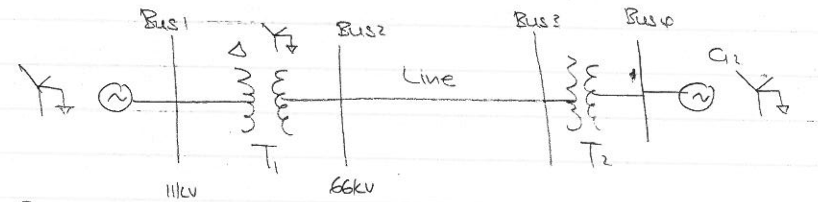
G_1 : 100 MVA, 11 kV, $X_1 = X_2 = 0.25$ pu, $X_0 = 0.05$ pu

G_2: 80 MVA, 11 kV, $X_1 = X_2 = 0.15$ pu, $X_0 = 0.07$ pu.

T_1: 100 MVA, 11/66 kV, $X_1 = X_2 = X_0 = 0.09$ pu

T_2: 80 MVA, 11/66 kV, $X_1 = X_2 = X_0 = 0.09$ pu.

Line: $X_1 = X_2 = 15\,\Omega$, $X_0 = 30\,\Omega$.



(i) $P_{base} = 100$ MVA.

new bases:

G_2: $X_1 = X_2 = 0.15\,\text{pu}\left(\frac{MVA(new)}{MVA(old)}\right)$ and $X_0 = 0.07\,\text{pu}\left(\frac{100}{80}\right)$

$= 0.15\,\text{pu}\left(\frac{100}{80}\right) = 0.1875$ pu. $= 0.0875$ pu.

T_2:

$X_1 = X_2 = X_0 = 0.09\,\text{pu}\left(\frac{\cancel{800}\,100}{80}\right)$

$= 0.1125$ pu.

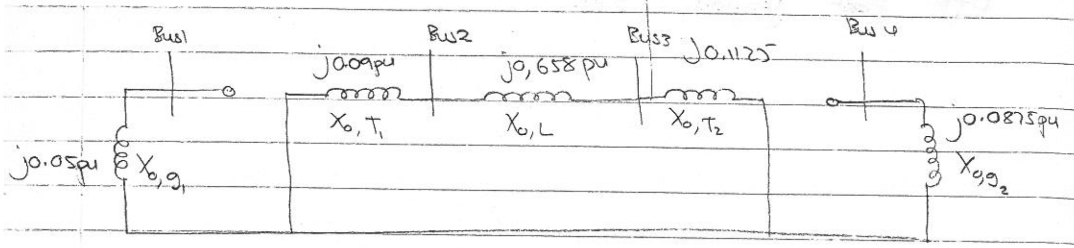
$Z_{base} = \frac{V_{base}^2}{VA_{base}} = \frac{(66 \times 10^3)^2}{100 \times 10^6}$

$= 43.56\,\Omega$.

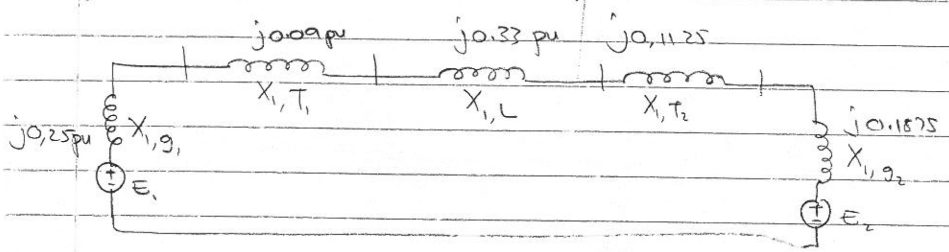
Line: $X_1 = X_2 = \frac{15}{45.56}$ pu $= 0.33$ pu

$X_0 = 0.658$ pu.

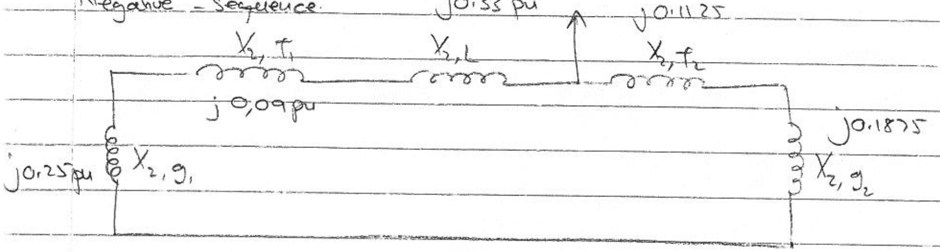
Zero - Sequence:



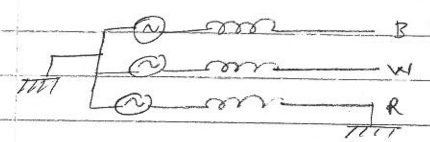
Positive - Sequence.

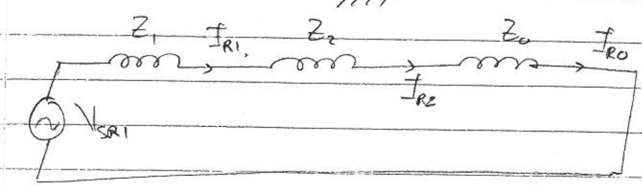


Negative - Sequence.



(ii) one-phase - to ground.





equivalent resistance:

The equivalent positive sequence and negative sequence

$$Z_1 = Z_2 = \frac{j(0.25 + 0.09 + 0.33)\,j(0.1125 + 0.1875)}{j(0.25 + 0.09 + 0.33 + 0.1125 + 0.1875)}$$

$$= j0.2072 \text{ pu}.$$

$$Z_0 = \frac{(j0.09 + j0.658)(j0.1125)}{(j0.09 + j0.658 + j0.1125)}$$

$$= j0.098 \text{ pu}.$$

$$I_{R1} = I_{R2} = I_{R0} = \frac{1\angle 0^\circ}{Z_1 + Z_2 + Z_0}$$

$$= \frac{1\angle 0^\circ}{j0.2072 + j0.2072 + j0.098}$$

$$= 1.95\angle -90^\circ$$

The fault current in phase R is: $I_R = 3I_{R1} = 5.85\angle$

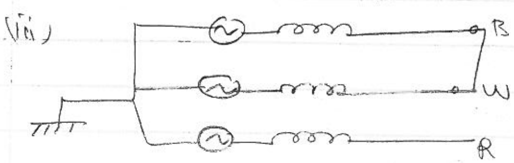
$$I_{base} = \frac{100\times 10^6}{\sqrt{3}\times 66\times 10^3}$$

$$= 874.773 \text{ A}.$$

The single line-to-ground fault current is:

$I_R = 5.82\times 874.77 \text{ A} = 5091.18 \text{ A}.$

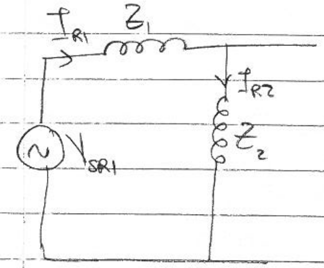
(iii)



$I_R = 0 \text{ A}$

$V_B = 0 \text{ V}$

$V_W = 0 \text{ V}$



$Z_0 = \infty$

$I_{R1} = I_{R2}$.

$$I_{R1} = \frac{E}{Z_1 + Z_2}$$

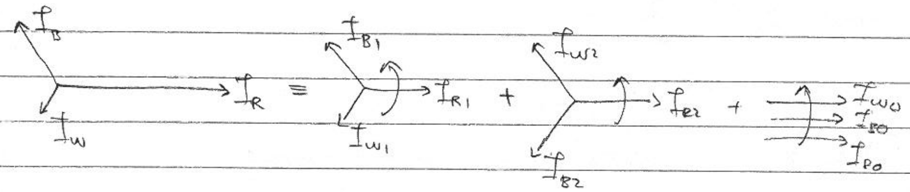
$$= \frac{1\angle 0^\circ}{j(0.2072)\times 2} = 2.41\angle -90^\circ$$

The zero sequence current:

$I_{R0} = 0\angle 0^\circ$ pu.

$I_{R1} = -I_{R2}$

$I_{R2} = 2.413\angle 90^\circ$



$I_R = I_{R1} + I_{R2} + I_{R0}$

$= 2.398\angle -90 + 2.398\angle 90 + 0\angle 0^\circ = 0\,A$

$I_W = I_{W1} + I_{W2} + I_{W0}$

$I_W = a^2 I_{R1} + a I_{R2} + 0\angle 0^\circ$

$I_W = 2.41\angle -90^\circ + 240^\circ + 2.41\angle 90 + 120$

$I_W = 2.41\angle 150^\circ + 2.41\angle 210^\circ$

$I_W = 4.174\angle 180^\circ$ pu

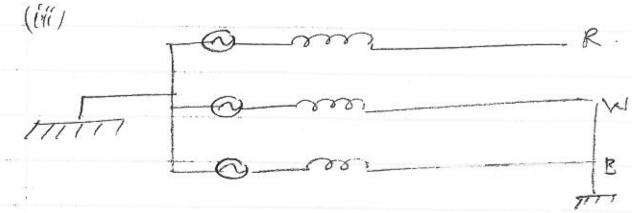
$I_W = -I_B$.

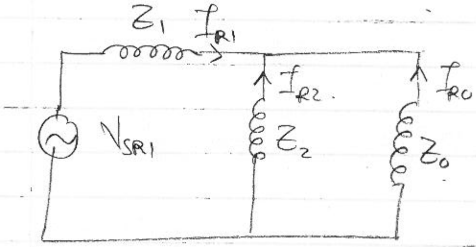
$I_B = -4.174\angle 180^\circ$ pu

$= 4.174$ pu.

The actual fault current ; $I_{f1} = 3651.29$ A.

(iii)





$\frac{V_f}{V_R}$

$\frac{V_R}{V} = \frac{R_R}{R_R + R}$

$I_{R1} = -(I_{R2} + I_{R0})$

$$Z_K = Z_1 + \frac{Z_0 Z_2}{Z_0 + Z_2}$$

$$= j0.2072 + \frac{j0.098(j0.2072)}{j0.098 + j0.2072}$$

$= 0.2737\angle 90^\circ$

$$I_{R1} = \frac{E}{Z_K} = \frac{1\angle 0^\circ}{0.2737\angle 90^\circ}$$

$I_{R1} = 3.65\angle -90^\circ$

$$I_{R2} = -I_{R1}\left(\frac{Z_0}{Z_0 + Z_2}\right) = -3.65\angle -90^\circ \left(\frac{j0.098}{j0.098 + j0.2072}\right)$$

$= 1.172\angle 90^\circ$ pu.

$$I_{R0} = -I_{R1}\left(\frac{Z_2}{Z_0 + Z_2}\right)$$

$$I_{R0} = -3.65\angle{-90^\circ}\left(\frac{j0.2072}{j0.098 + j0.2072}\right)$$

$$I_{R0} = 2.478\angle 90^\circ \text{ pu.}$$

$$I_R = I_{R1} + I_{R2} + I_{R0}$$

$$= 3.65\angle{-90} + 1.172\angle 90^\circ + 2.478\angle 90^\circ$$

$$= 0\angle 0^\circ \text{ pu.}$$

$$I_W = I_{W1} + I_{W2} + I_{W0}$$

$$I_W = a^2 I_{R1} + a I_{R2} + I_{R0}$$

$$I_W = 3.65\angle{-90^\circ + 240^\circ} + 1.172\angle{90^\circ + 120^\circ} + 2.478\angle 90^\circ$$

$$I_W = 5.59\angle 138.32^\circ \text{ pu.}$$

$$I_B = I_{B1} + I_{B2} + I_{B0}$$

$$I_B = a I_{R1} + a^2 I_{R2} + I_{R0}$$

$$I_B = 3.65\angle{-90^\circ + 120^\circ} + 1.172\angle{90^\circ + 240^\circ} + 2.478\angle 90^\circ$$

$$I_B = 5.591\angle 41.67^\circ \text{ pu.}$$

The actual fault current: 4889.96 A.

2010 EXAM:

Question 1

$r = 0.015$ m

$\rho = 2.83 \times 10^{-8}$ Ωm

$\mu_0 = 4\pi \times 10^{-7}$ H/m.

$\varepsilon_0 = \frac{10^{-9}}{36\pi}$ F/m.

$l = 200$ km.

$f = 50$ Hz

A ←— 4000 mm —→ B ←— 4000 m —→ C

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

$$m = \sqrt{\frac{\omega\mu}{\rho}} = \sqrt{\frac{2\times\pi\times 50 \times 4\pi\times 10^{-7}}{2.83\times 10^{-8}}}$$

$$= 118.11$$

$mr = 1.77$

$k_s = \frac{L}{L_0} = 0.97$

$$r' = r e^{-\frac{k_s}{4}}$$

$$= 0.015\, e^{-\frac{0.95}{4}}$$

$$= 0.012 \text{ m.}$$

$$GMD = \sqrt[3]{D_{AB} D_{BC} D_{AC}}$$

$$= \sqrt[3]{4\times 4\times 8} = 5.04 \text{ m.}$$

$$L' = 2\times 10^{-7} \ln\left(\frac{5.04}{0.012}\right) = 1.21\ \mu H/m.$$

$$L = 0.242 \text{ H.}$$

Capacitance.

$$C' = \frac{2\pi\varepsilon_0}{\ln\left(\frac{GMD}{GMR}\right)}$$

$$C' = \frac{2\pi \times \frac{10^{-9}}{36\pi}}{\ln\left(\frac{5.04}{0.01168}\right)}$$

$$C' = 9.156 \times 10^{-12} \ F/m$$

$C = 1.83 \ \mu F$

$$R = K_s \frac{\rho_{Al}}{A}$$

$A = \pi r^2 = \pi(0.015^2)$

$A = 7.069 \times 10^{-4} \ m^2.$

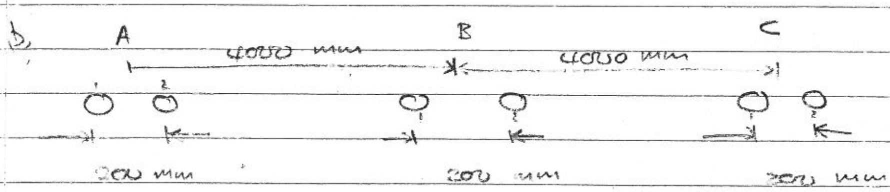
$$K_s = \frac{R}{R_0} = 1.05$$

$$R' = 1.05\left(\frac{2.83 \times 10^{-8}}{7.069 \times 10^{-4}}\right)$$

$R' = 4.204 \times 10^{-5} \ \Omega/m$

$R = 8.41 \ \Omega.$

b)



$GMD_{AB} = \sqrt[4]{D_{A1B1}}$

Question 2

2013

$l = 500 \ km.$

$f = 50Hz.$

$P = 600 \times 10^6 \ W$

$V_s = 400kV = V_R$

$R = 8\Omega$

$L = 475 \ mH$

$c = 5.5 \ \mu f$

$V_s = V_R \cosh(\gamma l) + Z_0 I_R \sinh(\gamma l)$

$A = \cosh(\gamma l)$

$B = Z_0 \sinh(\gamma l)$

$\gamma = \sqrt{(R' + j\omega L')(G' + j\omega C')}$

$R' = 1.6 \times 10^{-5} \ \Omega/m.$

$L' = 9.5 \times 10^{-7} \ H/m.$

$C' = 1.1 \times 10^{-11} \ f/m.$

$\omega L' = 2.985 \times 10^{-4}$

$\omega C' = 3.4558 \times 10^{-9}$

$\gamma = \sqrt{(1.6 \times 10^{-5} + j\,2.985 \times 10^{-4})(j\,3.4558 \times 10^{-9})}$

$= \sqrt{1.033 \times 10^{-12} \angle 176.93}$

$= \underline{1.0163661 \times 10^{-6} \angle 88.47^\circ}$

$\gamma l = 0.50818 \angle 88.47^\circ = 0.013569 + j0.5079988$

$e^{\gamma l} = e^{0.013569} \, e^{j0.5079988 \to 70^\circ}$

$= 1.0136 + j\,8.9873 \times 10^{-3}$

$= \underline{1.014 \angle 0.5^\circ}$

$e^{-\gamma l} = e^{-0.013569} \, e^{-j0.5079988}$

$= 0.9868 - j8.7466 \times 10^{-3} = 0.9868 \angle -0.5$

$$Z_0 = \sqrt{\frac{R' + j\omega l'}{G' + j\omega c'}} \quad ; \theta = 31.78°$$

$$= \sqrt{\frac{(1.6 \times 10^{-5} + j2.985 \times 10^{-4})}{j3.4538 \times 10^{-9}}}$$

$$= \sqrt{86500.52 \angle -3.068}$$

$$= 294.11 \angle -1.534°$$

$$\cosh(\gamma l) = \frac{e^{\gamma l} + e^{-\gamma l}}{2}$$

$$= \frac{1.014\angle 0.5° + 0.9868\angle -0.5°}{2}$$

$$A = \cosh(\gamma l) = 1 \angle 6.79 \times 10^{-3}$$

$$B = Z_0 \sinh(\gamma l)$$

$$= Z_0 \sinh(\gamma l) = 294.11\angle -1.534 \left(\frac{1.014\angle 0.5° - 0.9868\angle -0.5}{2} \right)$$

$$B = 4.75 \angle 31.163°$$

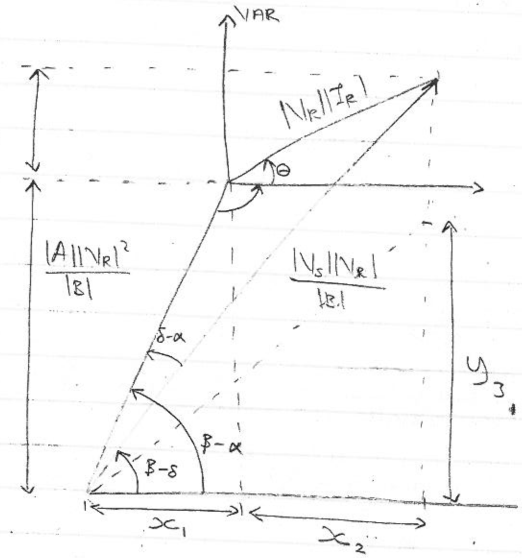
$$\sinh(\gamma l) = \frac{1.014\angle 0.5 - 0.9868\angle -0.5}{2}$$

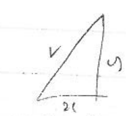
$$= 0.0161 \angle 32.69°$$

$$B = 4.75 \angle 31.16°$$

$$\frac{|A||V_R^2|}{|B|} = \frac{(1)(400 \times 10^{+3})^2}{(4.75)} = 3.3684 \times 10^{10}$$

$$\frac{|V_s||V_R|}{|B|} = 3.3684 \times 10^{10}$$





$r^2 =$

SOH CAH TO

$$\boxed{\text{Shunt compensation} = y_1 + y_2 - y_3}$$

$$x_2 = 600 \times 10^6 \times 1$$

$$\cos(\beta-\alpha) = \frac{x_1}{\frac{|A||V_R|^2}{|B|}}$$

$$x_1 = \frac{|A||V_R|^2}{|B|} \cos(\beta-\alpha)$$

$$x_1 = 2.8826 \times 10^{10}$$

$$\sin(\beta-\alpha) = \frac{y_1}{\frac{|A||V_R|^2}{|B|}}$$

$$y_1 = \frac{|A||V_R|^2}{|B|} \sin(\beta-\alpha)$$

$$y_1 = 1.742569 \times 10^{10}$$

$$\tan\theta = \frac{y_2}{600 \times 10^6}$$

$$y_2 = 600 \times 10^6 \times \tan(31.78)$$

$$= 0.37173 \times 10^9$$

Shunt-compensation $= y_1 + y_2 -$

$$(x_1 + x_2)^2 + y_3^2 = \frac{|V_s||V_R|}{|B|}$$

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

$$y_3 = \sqrt{(3.3684 \times 10^{10})^2 - (294}$$

$$y_3 = 1.63927 \times 10^{10}$$

Shunt - compensation $= y_1 + y_2 - y_3$

$= 1.742569 \times 10^{10} + 0.37173 \times 10^{9} - 1.63927 \times 10^{10}$

$= 1.40472 \times 10^{9}$ VAR.

$$1.40472 \times 10^{9} = \frac{V_R^2}{X_c}$$

$$X_c = \frac{V_R^2}{1.40472 \times 10^{9}}$$

$$\frac{1}{2\pi(50)C} = \frac{V_R^2}{1.40472 \times 10^{9}}$$

$$1.40447 \times 10^{9} = 2\pi(50) C V_R^2$$

$$C = \frac{1.40447 \times 10^{9}}{2\pi(50) V_R^2}$$

$C = 2.795 \times 10^{-5}$ f. (Shunt capacitors).

b) $$P_L = \frac{|V_s||V_R|}{|B|}$$

$$P_L = \frac{(400 \times 10^3)^2}{4.75} = 3.3684 \times 10^{10} \text{ W}$$

$$P_L = \frac{|V_s||V_R|}{WL}$$

$$P_{1L} = 1.2 P_L$$

$$P_{1L} = 1.2 \times 3.3684 \times 10^{10} \text{ W}$$

$$= 7.141 \times 10^{11} \text{ W} = \frac{|V_s||V_R|}{WL}$$

$$\cancel{P_L = \frac{|V_s||V_R|}{X_s}}$$

$$X_s = j(wL - \frac{1}{wC})$$

$$P_L = \frac{|V_s||V_R|}{WL}$$

$$7.141 \times 10^{11} = \frac{|V_s||V_R|}{|B| - \frac{1}{wC}}$$

$$(7.141 \times 10^{11})(|B| - \frac{1}{wC}) = |V_s||V_R|$$

$$|B| - \frac{1}{wC} = \frac{|V_s||V_R|}{7.141 \times 10^{11}}$$

$$\frac{-1}{wC} = \frac{|V_s||V_R|}{7.141 \times 10^{11}} - |B|$$

$$\frac{-1}{wC} = \frac{|V_s||V_R| - |B| 7.141 \times 10^{11}}{7.141 \times 10^{11}}$$

$$\frac{-1}{wC} = -4.526$$

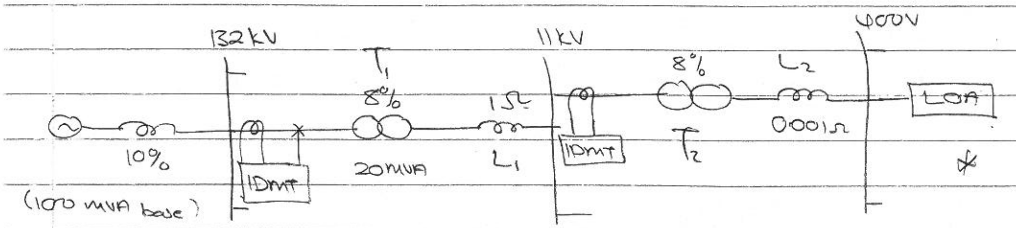
$$wC = \frac{1}{4.526}$$

$$C = \frac{1}{w 4.526}$$

$= 703.29 \mu F$.

c) Question 2 (c)

Question 6. 2013.



* Assume internal protection operates within 0.5s.

$MVA_{base} = 100\,MVA$

$X_1 = 0.1\,\Omega$.

@ L_1 : $Z_{base} = \frac{V_{base}^2}{VA_{base}}$

$= \frac{(11\times10^3)^2}{100\times10^6}$

$= 1.21\,\Omega$.

$Z_{L1(pu)} = \frac{1}{1.21} = 0.82644\,pu$

@ L_2 : $Z_{base} = \frac{V_{base}^2}{VA_{base}} = \frac{400^2}{100\times10^6}$

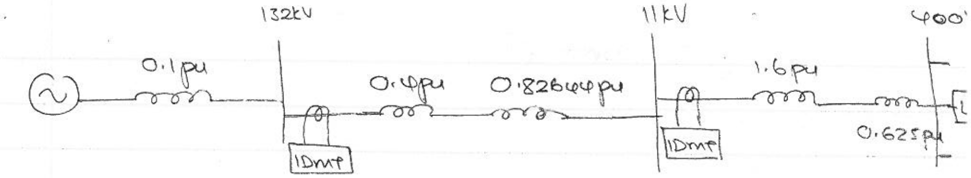
$= 1.6\times10^{-3}\,\Omega$.

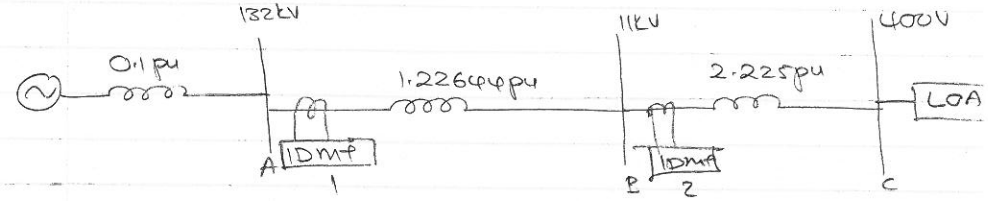
$Z_{L2(pu)} = \frac{0.001}{1.6\times10^{-3}}$

$= 0.625\,pu$.

@ T_2 : $0.08\,pu. \Rightarrow 0.08\left(\frac{100\,MVA}{5\,MVA}\right) = 1.6\,pu.$

T_1 : $0.08\,pu \Rightarrow 0.08\left(\frac{100\,MVA}{20\,MVA}\right) = 0.4\,pu$





$VA\,(\text{fault level}) = \frac{VA_{base}}{\text{Upstream impendance}}$

Network fault level $= \sqrt{3} \times$ nominal line voltage $\times$ actual fault current.

V_L ; I_f

$I_f = \frac{VA\,(\text{fault-level})}{\sqrt{3}\times V_L}$

IDMT 1:

$VA\,(\text{fault-level}) = \frac{100\times10^6}{0.1} = 1\,GA = 1\times$

$I_f = \frac{1\times10^9}{\sqrt{3}\times132\times10^3}$

$I_f = 4373.87\,A$.

IDMT 2 :

$VA\,(\text{fault-level}) = \frac{100\times10^6}{1.32644} = 75.389\times10^6\,V$

$I_f = \frac{75.389\times10^6}{\sqrt{3}\times11\times10^3} = 3956.89\,A$.

Rated current at IDMT (2)

$P = \sqrt{3} V_L I_L$

$I_L = \dfrac{P}{\sqrt{3} V_L}$

$= \dfrac{5 \times 10^6}{\sqrt{3} \times 11 \times 10^3}$

$I_L = 262.43$ A.

$I_{pu} = \dfrac{\text{fault current}}{1.25 \times \text{rated current}}$

$I_{pu} = \dfrac{3956.89}{1.25 \times 262.43}$

$I_{pu} = 12.06$

time: $t = (0.5 + 0.5)$ s $= 1$ s

$t = \dfrac{0.14}{I_{pu}^{0.02} - 1} \times$ Time multiplier.

$t(I_{pu}^{0.02} - 1) = 0.14(\text{Time multiplier})$

$\text{Time multiplier} = \dfrac{t}{0.14}(I_{pu}^{0.02} - 1)$

$= \dfrac{1}{0.14}((12.06)^{0.02} - 1)$

$= 0.365$

IDMT 1:

$I_L = \dfrac{P}{\sqrt{3} V_L}$

$I_L = \dfrac{20 \times 10^6}{\sqrt{3} \times 132 \times 10^3}$

$= 87.477$ A.

$I_{pu} = \dfrac{\text{fault current}}{1.25 \times 87.477} = \dfrac{4373.87}{1.25 \times 87.477}$

$= 40.$

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

$= \dfrac{1.5}{0.14}\left((40)^{0.02} - 1\right)$

$= 0.82$

~~CT~~

∴ CT ratios:

full load current at 132 kV:

$P = \sqrt{3} V_L I_L$

$I_L = \dfrac{P}{\sqrt{3} V_L} = \dfrac{20 \times 10^6}{\sqrt{3}(132 \times 10^3)} = 87.477$ A.

full load current at 11 kV:

$I_L = \dfrac{5 \times 10^6}{\sqrt{3}(11 \times 10^3)}$

$= 262.43$ A

Suitable CT ratios:

for 11 kV: 300/5

for 11 kV: 800/5

Assume a burden associated with the IDMT relay of 2 VA (

$P = VI$

$V = \frac{P}{I} = \frac{2}{5} = 0.4\ V$

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

$R = \frac{V^2}{P} = \frac{(0.4)^2}{2} = 0.08\ \Omega.$

$\therefore P = 10\ VA$ (burden

$I_f = \frac{1000 \times 10^6}{\sqrt{3} \times 22 \times 10^3}$

$= 26243.19\ A.$

$I_{pu} = \frac{26243.19}{1.25 \times 1314}$

$= 15.98.$

$VA_f = \frac{50 \times 10^6}{(0.13)} = 0.3846 \times 10^9$

$I_f = \frac{0.3846 \times 10^9}{\sqrt{3} \times 22 \times 10^3}$

$= 10093.53617\ A.$

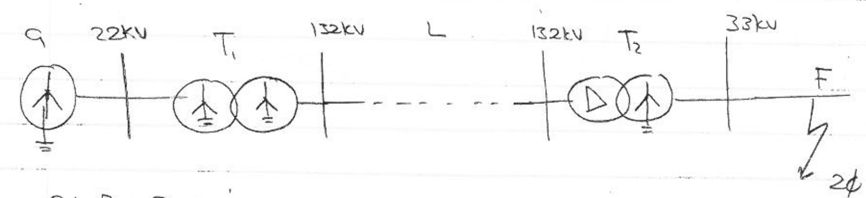
$1800 \rightarrow 5$

$10093.53 \rightarrow x$

$x = \frac{5 \times 10093.5}{1800}$

$I_{pu} = \frac{10093.53}{1.25 \times 1314} = 6.14$

2008 Question 3.



G: $Z_1 = Z_2 = j0.15$ pu

$Z_0 = j0.25$ pu

200 MVA

T1: $Z_1 = Z_2 = j0.10$ pu

$Z_0 = j0.10$ pu

100 MVA

Using 200 MVA as the base:

$Z_1 = j0.10\text{pu}\left(\frac{200\ \text{MVA}}{100\ \text{MVA}}\right) = j0.2\ \text{pu} = Z_2$

$Z_0 = j0.10\text{pu}\left(\frac{200}{100}\right) = j0.2$

Line:

$Z_{base} = \frac{V_{base}^2}{VA_{base}} = 87.12\ \Omega.$

$Z_1 = Z_2 = j15\Omega \quad \therefore Z_1 = Z_2 = \frac{j15\Omega}{87.12} = j0.17$ pu

$Z_0 = j20 \quad \therefore Z_0 = \frac{j20}{87.12} = j0.2295$ pu

T2:

100 MVA

$Z_1 = Z_2 = j0.12$ pu

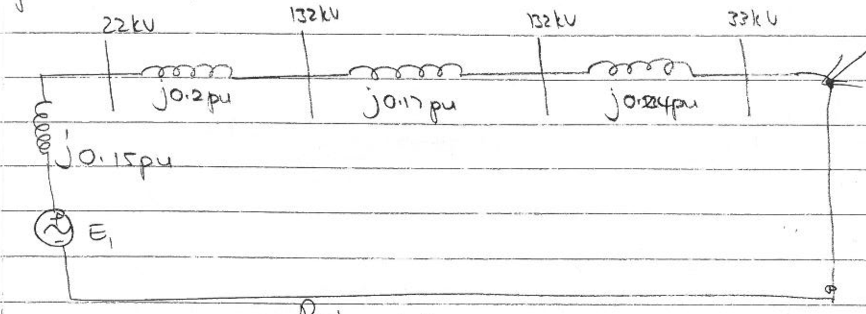
$Z_0 = j0.24$ pu

Using the 200 MVA base.

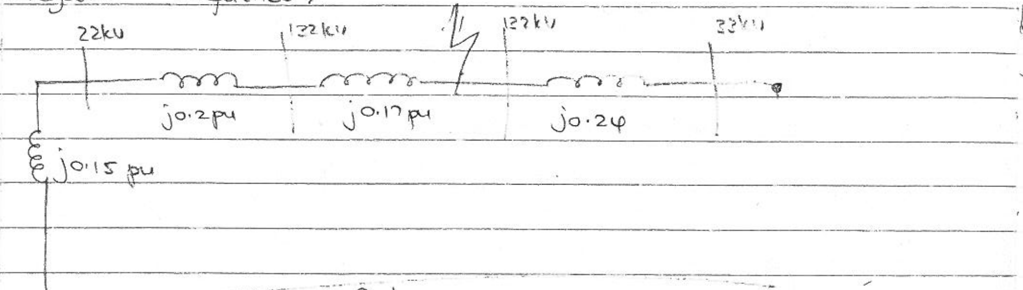
$Z_1 = Z_2 = j0.12\ \text{pu}\left(\frac{200}{100}\right) = j0.24$ pu.

$Z_0 = j0.24\ \text{pu}\left(\frac{200}{100}\right) = j0.48$ pu.

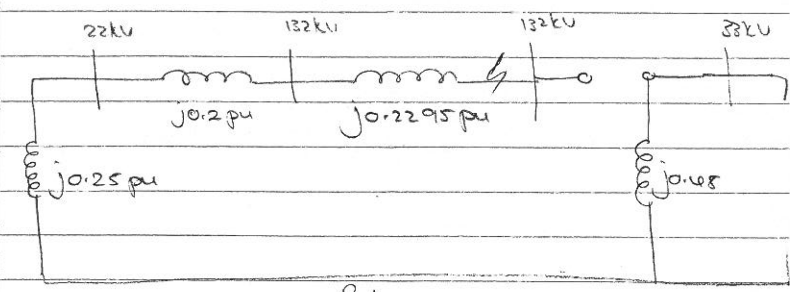
positive sequence:



Negative sequence:

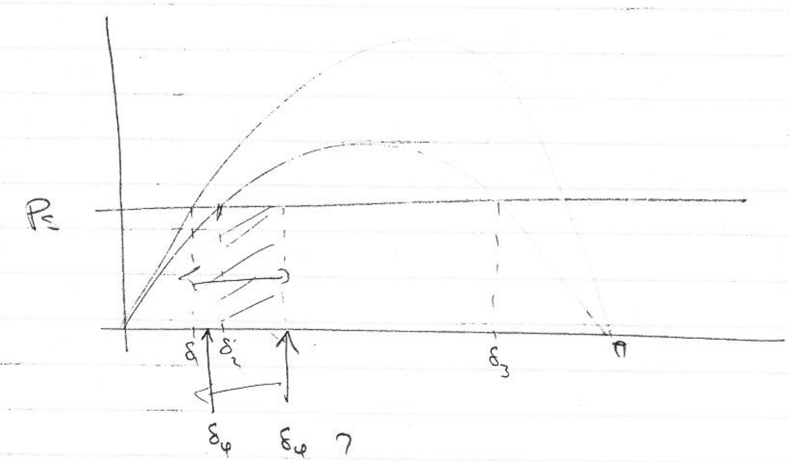


Zero sequence:



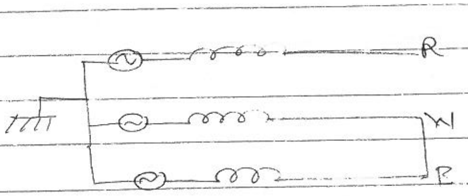
Vmline

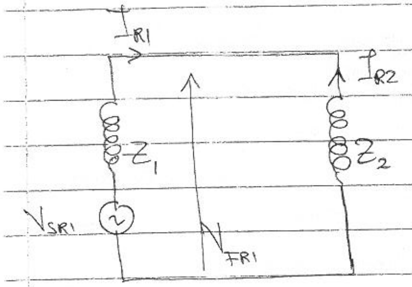
1. Question 3 2008 (do we close the sequences.
2. Question 5 2012
3. Question 2 2012 (do we divide the given voltage by $\sqrt{3}$ to get phase.
4. Question 6 2012 (do we only consider CTs for the sides where the IDMT are).
5. Question 5 2012
   - b (ii) is it after the line or before.
   - what do we do with Zn. (Generator)
6. Question 3 2012



$$t = \frac{\delta_4 - \delta_1}{Rate} \quad or \quad \frac{\delta_3 - \delta_1}{Rate}.$$

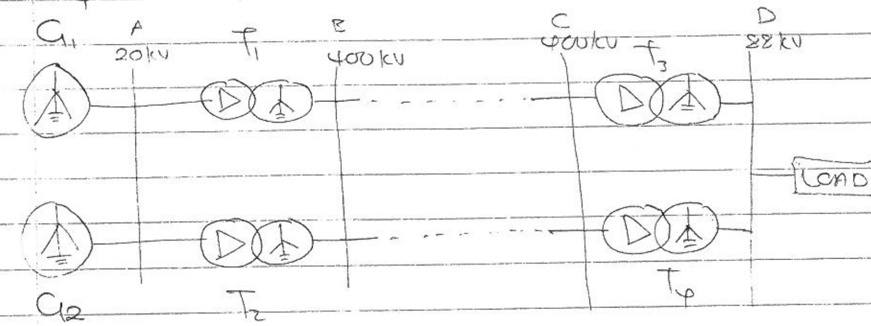
Continued Question 3



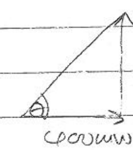


fault at 33 kV bars-bars:

Question 4 2013



G_1 & G_2: 400 MW @ 0.8 pf



$\theta = \cos^{-1}(0.8) = 36.87°$

SOH CAH TOA

$\cos\theta = \frac{400 \times 10^6}{MVA}$

$MVA = \frac{400 \times 10^6}{0.8} = 0.5 \times 10^9$ VA $= 500$ MVA

Using 500 MVA as base:

a)

G_1 & G_2: $Z_1 = Z_2 = j0.12$ pu. (500 MVA), $Z_0 = j0.1$ pu

T_1 & T_2: (500 MVA)

$Z_1 = Z_2 = j0.1$ pu, $Z_0 = j0.08$ pu.

T_3 & T_4: (300 MVA)

$Z_1 = Z_2 = j0.1$ pu, $Z_0 = j0.08$ pu.

Since the base is 500 MVA.

$Z_1 = Z_2 = j0.1\,pu\left(\frac{500}{300}\right) = j0.167$ pu.

$Z_0 = j0.08\,pu\left(\frac{500}{300}\right) = j0.133$ pu.

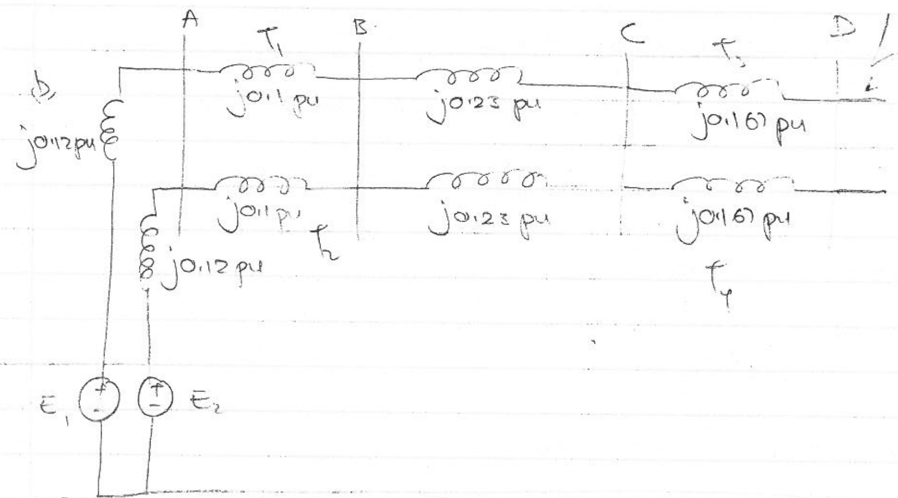
L_1 \$ L_2: $Z_1 = Z_2 = j75\,\Omega$

$Z_0 = j150$

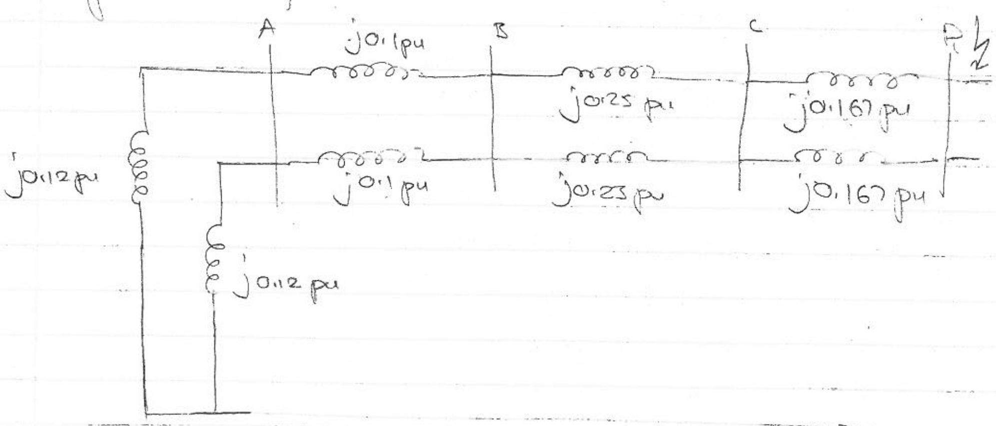
$$Z_{base} = \frac{V_{base}^2}{VA_{base}} = j320\,\Omega$$

$$Z_1 = Z_2 = \frac{75}{320} = j0.23\text{ pu}$$

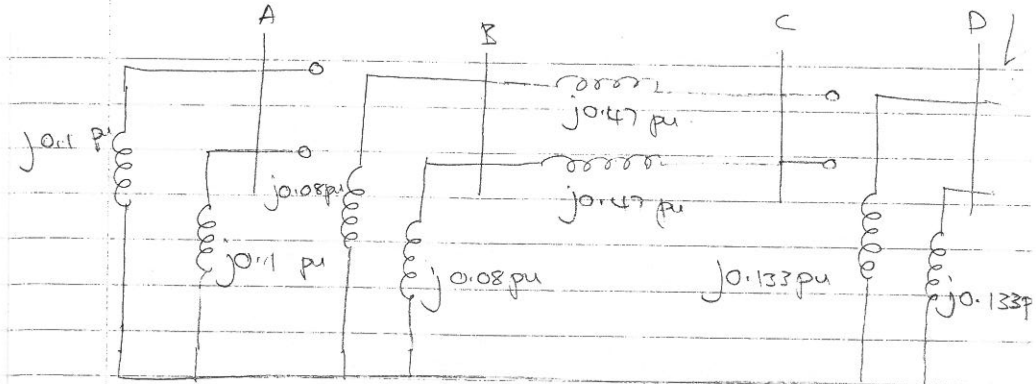
$$Z_0 = \frac{150}{320} = j0.47\text{ pu}$$



positive - Sequence.



Negative Sequence.



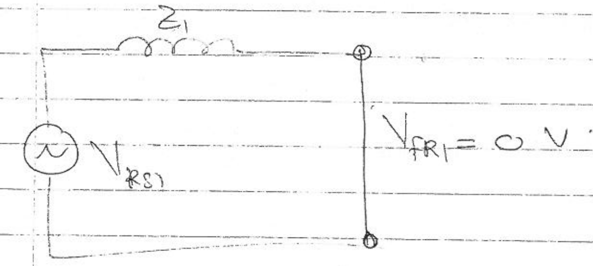
Zero sequence

$$Z_1 = \frac{\left(j(0.12\text{ pu} + 0.1\text{ pu} + 0.23\text{ pu} + 0.167\text{ pu})\right)^2}{2j(0.12\text{ pu} + 0.1\text{ pu} + 0.23\text{ pu} + 0.167\text{ pu})}$$

$Z_1 = Z_2 = 0.3085\angle 90^\circ$

$$Z_0 = \frac{(j0.133\text{ pu})^2}{2j(0.133\text{ pu})} = 0.0665\angle 90^\circ$$

Symmetrical 3ϕ fault.



The voltage is the same as the generators are connected in parallel.

$$I_{R1} = \frac{E}{Z_1} = \frac{1\angle 0^\circ}{0.3085\angle 90^\circ} = 3.241\angle -90^\circ$$

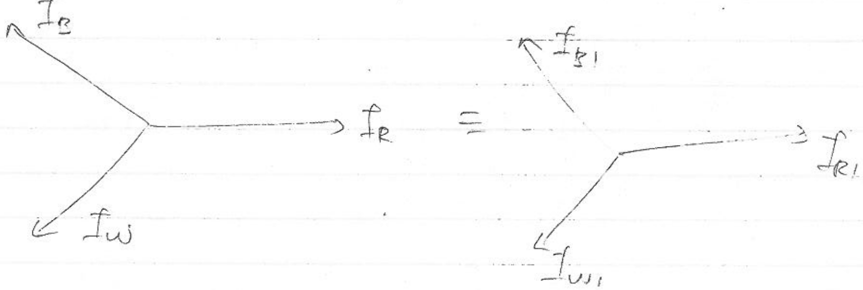
The actual current at bus bar D.

$$I = \frac{MVA_{base}}{\sqrt{3}\,V_{base}}$$

$$I = \frac{500 \times 10^6}{\sqrt{3} \times 88 \times 10^3} = 3280.399\ A.$$

$$\therefore I_R = I_{R1} = 3.24 \times 3280.399\ A$$

$$= 10628.493\angle 90^\circ A.$$

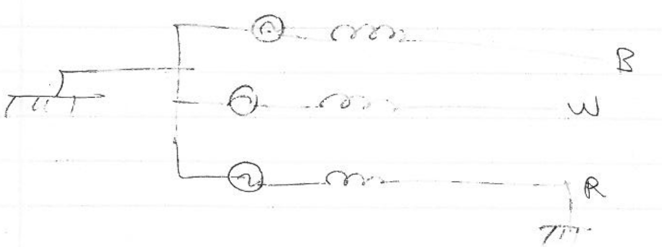


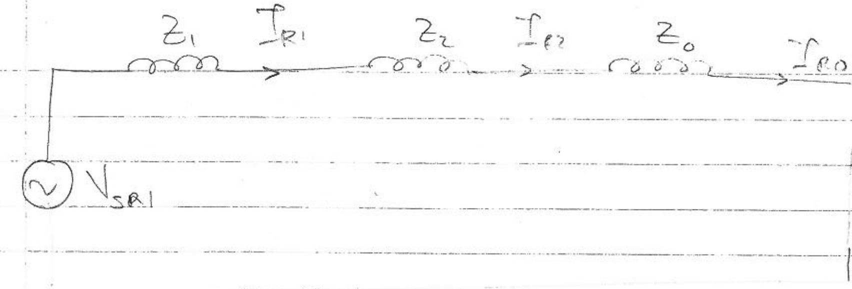
$$I_B = I_{B1} = aI_R$$

$$I_B = 10628.493\angle 120^\circ + 90^\circ\ A$$

$$I_W = I_{W1} = 10628.493\angle 240^\circ + 90^\circ$$

for the Single-phase-to-ground fault.





$$I_{R1} = I_{R2} = I_{R0}$$
$$I_B = 0\ A$$
$$I_W = 0\ A$$

$$I_{R1} = \frac{E}{Z_1 + Z_2 + Z_0}$$

$$= \frac{1\angle 0^\circ}{0.3085j + 0.3085j + 0.0665j}$$

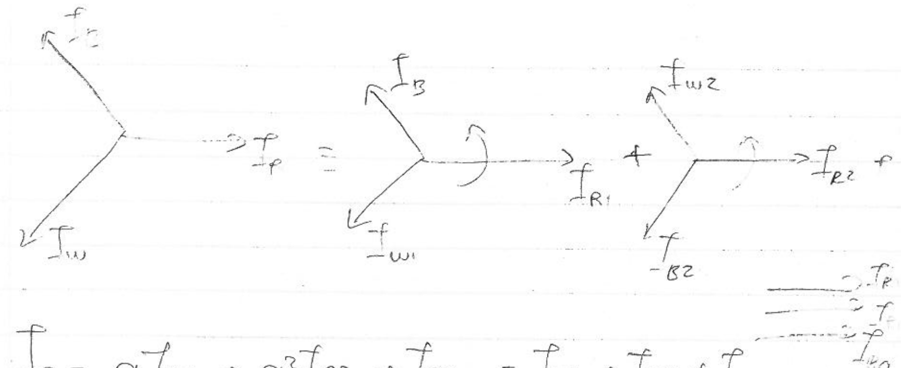
$$= 1.46\angle -90^\circ\ pu$$

The actual fault current; $I_f = 1.46 \times 3280.399$

$$I_f = 4789.38\ A\angle -90^\circ$$

$$I_R = 3I_{R1} = 3 \times 4789.38\ A$$

$$= 14368.14\ A$$



$I_R = aI_{R1} + a^2 I_{R2} + I_{R0} = I_{W1} + I_{W2} + I_{W0}$

$= 4789.38\angle 120^\circ + 4789.38\angle 240^\circ + 4789.38\angle 0^\circ$

$= 0\ A$

$I_W = 4789.38\angle 240^\circ + 4789.38\angle 120^\circ + 4789.38\angle 0^\circ$

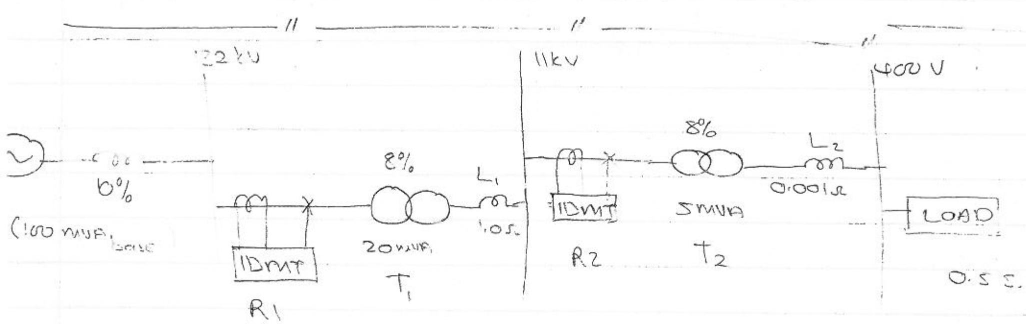
$= 0\ A$

$I_R\ 14\ 368.14\ A$

Therefore the each phase phase the currents.

$I_R = \frac{14368.14}{2} = 7184.07\ A$

$I_B = I_W = 0\ A$.



G: 100 MVA$_{base}$

$X = 10\% \Rightarrow j0.1\ pu$

T1: 20 MVA

$X = 8\% \Rightarrow j0.08\ pu \Rightarrow X = j0.08\,pu\left(\frac{100}{20}\right) = j$

L1: $Z_{base} = \frac{V_{base}^2}{VA_{base}} = \frac{(11\times10^3)^2}{100\times10^6}$

$Z_{base} = 1.21\ \Omega$.

$X = \frac{1}{1.21} = j0.826\ pu$.

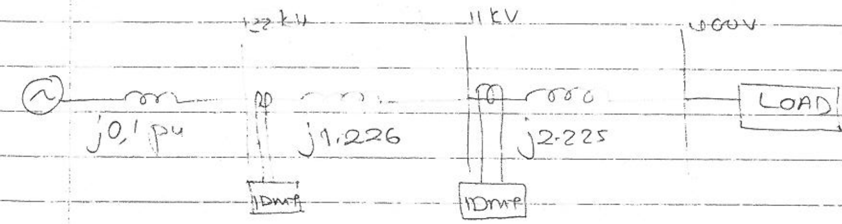
T2: 5 MVA

$X = 8\% \Rightarrow j0.08\ pu$

$X = j0.08\ pu\left(\frac{100}{5}\right) = j1.6\ pu$.

L2: $Z_{base} = \frac{V_{base}^2}{VA_{base}} = \frac{(400)^2}{100\times10^6} = 1.6\times10^{-3}\ \Omega$.

$X = \frac{0.001}{1.6\times10^{-3}} = j0.625\ pu$.



Current at 132 kV

$I_{base} = \frac{20\times10^6}{\sqrt{3}\times132\times10^3} = 87.48\ A$.

To ensure that the IDMT does not operate when rated current is flowing, the the rated current is multiplied by 1.25.

$\therefore 1.25\times87.48\ A = 109.35\ A$

The CT ratio is 200:5.

Current
when 109.35 A is flowing at the primary side

$200 \rightarrow 5$

$109.35 \rightarrow x$

$$x = \frac{5 \times 109.35}{200} = 2.73375 \text{ A}$$

The current multiplier: $\frac{2.73375}{5} = 0.54$, when

assuming that the input current to the IDMT relay is 5A.

$$VA_{fault\text{-}level} = \frac{VA_{base}}{\text{upstream impedance (pu)}}$$ plg 67

$$= \frac{100 \times 10^6}{0.1} = 1000 \text{ MVA}$$

$$I_f = \frac{VA_{fault\text{-}level}}{\sqrt{3}(132 \times 10^3)} = 4373.87 \text{ A}$$

$$I_{pu} = \frac{4373.87}{109.35} = 39.998 \approx 40.$$

$t = 1.5\text{ s}$ $(0.5 + 0.5 + 0.5$

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

Time multiplier $= 0.82$

Summary for first IDMT
IDMT 1:

Current multiplier $= 0.54$
Time multiplier $= 0.82$
response time $= 1.5$ s
CT ratio: 200:5

The second IDMT:

$$\text{Current at } \frac{5 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = I_{base}$$

$I_{base} = 262.43$ A.

$1.25 \times 262.43 = 328.04$ A

choose 400:5 for the CT ratio.

$400 — 5$
$328.04 — x$
$x = 4.1$ A

current multiplier: $\frac{4.1}{5} = 0.82$

$$VA_{fault\text{-}level} = \frac{VA_{base}}{\text{upstream impedance (pu)}}$$

$$= \frac{100 \times 10^6}{1.326} = 75.415 \times 10^6 \text{ VA}$$

$$I_f = \frac{75.415 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = \frac{VA_{fault\text{-}level}}{\sqrt{3}\, V_{base}}$$

$I_f = 3958.26$ A.

$$I_{pu} = \frac{3958.26}{328.04} = 12.066$$

$t = 1s.$

$$\text{Time multiplier} = \frac{1}{0.14}\left(12.060^{0.02} - 1\right)$$

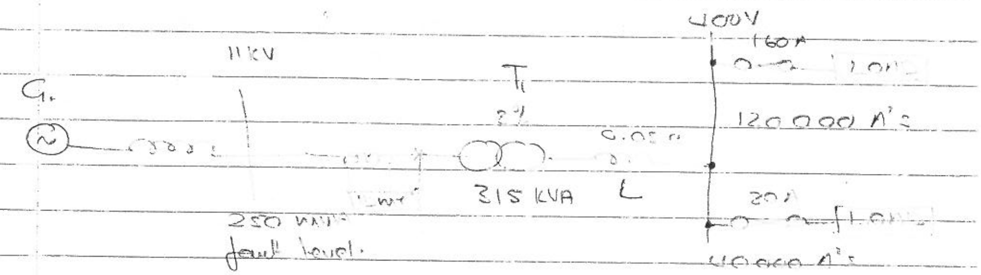
$$= 0.365$$

Summary:

Time multiplier = 0.365
Current multiplier = 0.82
Operate time = 1s.
CT ratio = 400 : 5

Question 6

2010



$$VA(\text{fault level}) = \frac{VA_{base}}{\text{upstream impedance pu}}$$

$$9\% = \frac{VA_{base}}{VA\ \text{fault level}}$$

choose base of 100 MVA

$$G_{pu} = \frac{100 \times 10^6}{250 \times 10^6} = 0.4\ pu.$$

Generator:

$X = 0.4\ pu$

T1:

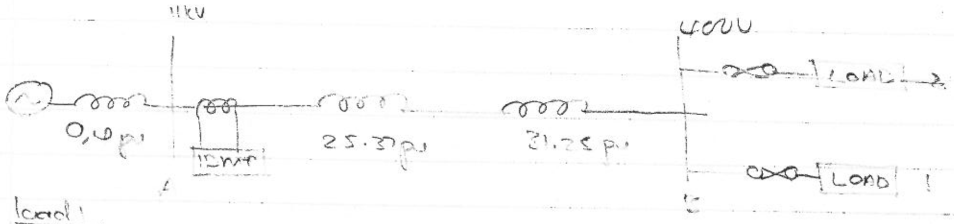
$X = 0.08\ pu.$

$$X = 0.08\ pu\left(\frac{100 \times 10^6}{315 \times 10^3}\right) = 25.37\ pu.$$

Line:

$$Z_{base} = \frac{V_{base}^2}{VA_{base}} = \frac{(400)^2}{100 \times 10^6} = 1.6 \times 10^{-3}$$

$$X = \frac{0.05}{1.6 \times 10^{-3}} = 31.25\ pu$$



load 1

$I_1^2 t_1 = 40000\ A^2 s$

$t_1 = \dfrac{40\,000}{I_1^2}$

load 2

$I_1^2 t_2 = 120\,000$

$t_2 = \dfrac{120\,000}{I_1^2}$

fault level @ 400V.

$VA_{(\text{fault level})} = \dfrac{VA\ \text{base}}{\text{upstream impedance}}$

$= \dfrac{100 \times 10^6}{(0.60pu + 25.37pu + 31.25pu)}$

$= 1.7250 \times 10^6\ VA$

$I_{f_2} = \dfrac{1.7250 \times 10^6}{\sqrt{3} \times 400}$

$= 2501.20\ A = 2.5\ kA.$

Assume that

rated current:

$I_{base} = \dfrac{315 \times 10^3}{\sqrt{3} \times 11 \times 10^3}$

$= 16.53\ A.$

To allow the IDMT not to trip when rated current is

$1.25 \times 16.53 = 20.67\ A.$

CT ratio: 100 : 5

$100 \rightarrow 5$

$20.67 \rightarrow x$

$x(100) = 5 \times 20.65$

$x = \dfrac{5 \times 20.65}{100}$

$x = 1.033\ A.$

assume that the relay has a 5A.

Current multiplier $= \dfrac{1.033}{5} = 0.2066.$

Questions

1. Question 4 2013 (Load at the end of the line)
2. Question 6 2010 (fuses)
3. Stability pg 56

So left or right.

$I^2t = 40\ 000$

$$P = \frac{|V_S||V_R|}{X_S} \sin\delta$$

$$P_{max} = \frac{|V_S||V_R|}{X_S}$$

$$SIL = \frac{|V_L|^2}{Z_0}$$

if $P_L > SIL \rightarrow V_R < V_S$

if $P_L < SIL \rightarrow V_R > V_S$

$$L_{int} = \frac{\mu_r \mu_0}{8\pi}$$

$$L_{ext} = \frac{\mu_0}{2\pi} \ln\left(\frac{D}{r}\right)$$

$$L' = 2\times10^{-7} \ln\left(\frac{D}{r'}\right) \quad H/m.$$

$$r' = r e^{-\frac{\mu_r}{4}}$$

$$L_x = 2\times10^{-7} \ln\left(\frac{GMD}{GMR_x}\right)$$

$$GMD = \sqrt[mn]{(D_{11'} D_{12'} \cdots D_{1m})(D_{21'} D_{22'} \cdots D_{2m}) \cdots (D_{n1'} D_{n2'} \cdots D_{nm'})}$$

$$GMR_x = \sqrt[n^2]{(D_{11} D_{12} \cdots D_{1n})(D_{21} D_{22} \cdots D_{2n}) \cdots (D_{n1} D_{n2} \cdots D_{nn})}$$

$$GMR = \sqrt[n]{n(e^{-\frac{\mu_r}{4}} r)R^{n-1}} = \sqrt[n]{n(re^{-k_s \frac{\mu_r}{4}})R^{n-1}}$$

$$L' = 2\times10^{-7} \ln\left(\frac{\sqrt[3]{D_{AB} D_{BC} D_{CA}}}{r'}\right)$$

$$GMD = \sqrt[3]{D_{AB} D_{BC} D_{CA}}$$

$$\cancel{C' = \frac{2\pi\varepsilon_0}{\ln\left(D_m\right.}}$$

$$C' = \frac{2\pi\varepsilon_0}{\ln\left(\frac{GMD}{GMR}\right)}$$

$R' = k_s \frac{f}{A}$

$V_s = AV_R + BI_R$

→ Short-lines ($< 50km$).

$R = R'l$

$X_L = \omega L' l$

→ Medium lines (50km – 200 km)

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

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

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

$Y_T = (G' + j\omega C')l$

$V_s = (1 + Z_T Y_T)V_R + Z_T(2 + Y_T Z_T)I_R$

$V_s = V_R(1 + Y_\pi Z_\pi) + I_R Z_\pi$

$I_s = I_R(1 + Z_T Y_T) + V_R Y_T$

long lines: ($> 200km$)

~~$V_R =$~~

$V_s = V_R \cosh(\gamma l) + I_R Z_0 \sinh(\gamma l)$

$\gamma = \sqrt{(R' + j\omega L')(G' + j\omega C')}$

$Z_0 = \sqrt{\frac{R' + j\omega L'}{G' + j\omega C'}}$

$I_s = I_R \cosh(\gamma l) + \frac{V_R}{Z_0} \sin(\gamma l)$

$Z_\pi = Z_0 \sinh(\gamma l)$

$Y_\pi = \frac{\cosh(\gamma l) - 1}{Z_\pi}$

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

$Y_T = \frac{\sinh(\gamma l)}{Z_0}$

$Z_T = \left(\frac{\cosh(\gamma l) - 1}{\sinh(\gamma l)}\right) Z_0$

$\frac{|V_s||V_R|}{|B|} \angle(\beta - \delta) = \frac{|A||V_R|^2}{|B|} \angle(\beta - \alpha) + |V_R||I_R| \angle\theta$

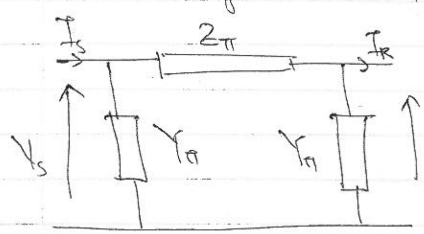
Load real power $= |V_R||I_R| \cos\theta = \frac{|V_s||V_R|}{|B|} \cos(\beta - \delta)$

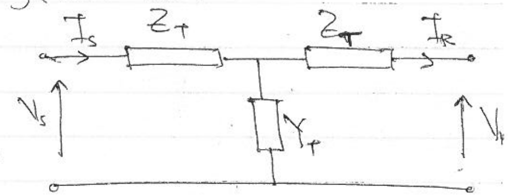
$- \frac{|A||V_R|^2}{|B|} \cos(\beta - \alpha)$ ...

Load real power $= \frac{|V_s||V_R|}{|B|} \cos(\beta - \delta) = \frac{|V_s||V_R|}{|B|} \sin\delta$

Power limit (P_L) $= \frac{|V_s||V_R|}{|B|} = \frac{|V_s||V_R|}{X_s} = \frac{|V_s||V_R|}{\omega L}$

series compensation : $X_s = j(\omega L - \frac{1}{\omega C})$





$P_{e1} = 2 \frac{V_s V_R}{X_s} \sin\delta$

$P_{e2} = \frac{V_s V_R}{X_s} \sin\delta$

Network fault level $= \sqrt{3}$ x nominal line voltage x actual fault current

Network fault level $= \sqrt{3} \times V_L \times I_{fault}$.

Rupturing capacity of circuit breaker $= \sqrt{3} \cdot V_L \cdot$ fault current rating

flux excursion $= \frac{1}{N_{sec}} \left(\frac{\frac{X}{R} + 1}{\omega} \right)$

$VA_{base} = \sqrt{3} V_{base} I_{base}$

$Z_{base} = \frac{V_{base}}{\sqrt{3} I_{base}} = \frac{V_{base}^2}{VA_{base}} =$ ~~(kV_{base})~~

$Z_{pu} = \frac{Z_{\Omega(actual)}}{Z_{base}}$

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

$Z_{pu} = Z_{pu(MVA_{new})} = Z_{pu(MVA_{old})} \left(\frac{MVA_{base(new)}}{MVA_{base(old)}}\right)$

$$Z_{\%(MVA_{base})} = Z_{\%(MVA_{rated}(\text{transformer}))}\left(\frac{MVA_{base}}{MVA_{rated}(\text{transformer})}\right)$$

$$\begin{pmatrix} I_R \\ I_W \\ I_B \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{pmatrix}\begin{pmatrix} I_{R1} \\ I_{R2} \\ I_{R0} \end{pmatrix} \qquad \begin{pmatrix} I_{R1} \\ I_{R2} \\ I_{R0} \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{pmatrix}\begin{pmatrix} I_R \\ I_W \\ I_B \end{pmatrix}$$

Balanced three phase faults:

$$I_R = I_{R1} = \frac{E(pu)}{Z_1}$$

$$I_W = I_{W1} = a^2 I_{R1}$$

$$I_B = I_{B1} = a I_{R1}$$

Single phase to ground fault.

$$I_{R1} = \frac{E(pu)}{Z_1 + Z_2 + Z_0}$$

$$I_R = 3 I_{R1}$$

Two-phase short circuit to ground

$$B_K = \frac{Z_0 Z_2}{Z_0 + Z_2}$$

$$I_{R1} = \frac{E(pu)}{Z_1 + B_K} = \frac{E(pu)}{Z_1 + B_K}$$

$$I_{R2} = -I_{R1}\left(\frac{Z_0}{Z_2 + Z_0}\right)$$

$$I_{R0} = -I_{R1}\left(\frac{Z_2}{Z_2 + Z_0}\right)$$

Two-phase short circuit without earth fault.

$$I_{R1} = -I_{R2}$$

$$I_{R1} = \frac{E(pu)}{Z_1 + Z_2}$$

Current multiplier = $\frac{1.25 \times \text{rated current}}{\text{relay input}}$

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

$$I_{pu} = \frac{\text{fault current}}{1.25 \times \text{rated current}}$$

~~long time delay (LTD) : $t = \frac{120}{I_{pu} - 1} \times$ Time multiplier.~~

~~Standard inverse (SI) : $t = \frac{13.5}{I_{pu} - 1} \times$ Time multiplier.~~

~~very inverse (VI) : $t =$~~

long time delay (LTD) : $t = \frac{120}{I_{pu} - 1} \times$ Time multiplier

Standard inverse (SI) : $t = \frac{0.14}{I_{pu}^{0.02} - 1} \times$ Time multi

very inverse (VI) : $t = \frac{13.5}{I_{pu} - 1} \times$ Time multiplier.

extreme inverse (EI) : ($I^2 t \approx$ constant)

$$t = \frac{80}{I_{pu}^2 - 1} \times \text{Time multiplier}$$

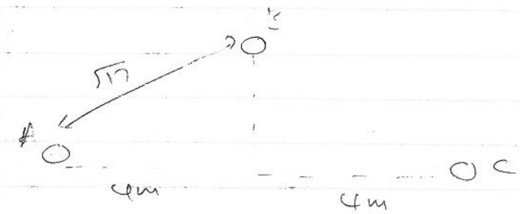
$$MVA(\text{fault-level}) = \frac{MVA\,base}{\text{upstream impedance}}$$

$$I_{fault} = \frac{MVA(\text{fault-level})}{\sqrt{3} \times V_L}$$

Bundle advantages:

- Reduces line reactance that improves the line performance.
- Reduces voltage gradient.
- reduces corona loss.
- Reduces surge impedance.
-

Question 1 2013



$m = \sqrt{\frac{\omega\mu}{\rho}} = \sqrt{\frac{2\pi 50 \times 4\pi \times 10^{-7}}{2.83 \times 10^{-8}}} = 118.11$; $mr = 1.772$

$k_s = \frac{L}{L_o} = 0.975$, $k_s = \frac{R}{R_o} = 1.06$

$r = 0.015m$

Inductance: $L' = 2\times10^{-7} \ln\left(\frac{D_m}{D_s}\right)$

$D_m = \sqrt[3]{AB \cdot BC \cdot AC}$

$D_m = \sqrt[3]{\sqrt{17} \cdot \sqrt{17} \cdot 8} = 5.14m.$

$D_s = re^{-k_s\frac{1}{4}} = 0.01176$ m

$L' = 1.215 \times 10^{-6}$ H/m

$L = 0.121$ H.

Capacitance: $C' = \frac{2\pi\varepsilon_0}{\ln\left(\frac{GMD}{GMR}\right)}$

$GMR = re^{-\frac{1}{4}} = 0.01168$ m.

$C' = 9.13 \times 10^{-12}$ F/m.

$C = 9.13 \times 10^{-7}$ F.

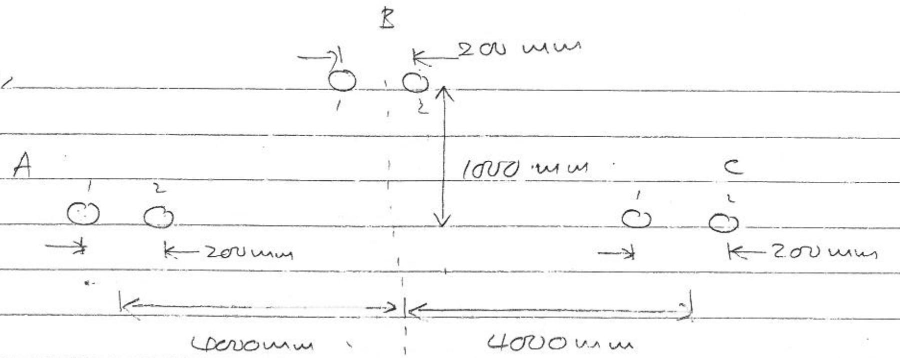
Resistance:

$R' = k_s \frac{\rho}{A} = 4.24 \times 10^{-5}$ Ω/m

$A = \pi r^2 = \pi(0.015)^2 = 7.069 \times 10^{-4}$ m^2

$R = R'l = 4.24$ Ω.

(b)



$GMR_A = GMR_B = GMR_C = \sqrt[n^2]{D_{A1A1} D_{A1A2} D_{A2A2} D_{A2A1}}$

$= \sqrt[n^2]{\left(re^{-\frac{k_s}{4}}\right)^2 (200\times10^{-3})^2}$

$= \sqrt[4]{(0.01176)^2 (200\times10^{-3})^2} = 0.0484$

$GMD_{AB} = \sqrt[mn]{(D_{A1B1} D_{A1B2} D_{A2B1} D_{A2B2})} = GMD_{BC}$

$D_{A1B1} = 4.12$ m.
$D_{A1B2} = 4.2176$ m.
$D_{A2B1} = 3.9294$ m.
$D_{A2B2} = 4.12$.

$GMD_{AB} = GMD_{BC} = 4.11957 4084$ m.

$GMD_{AC} = \sqrt[4]{(D_{A1C1} D_{A1C2})(D_{A2C1} D_{A2C2})}$

$D_{A1C1} = 8$ m.
$D_{A1C2} = 8.2$ m.
$D_{A2A1} = 7.8$ m.
$D_{A2A2} = 8$ m.
$GMD_{AC} = 7.99875$ m.

$GMD = \sqrt[3]{GMD_{AB}\, GMD_{BC}\, GMD_{AC}}$
$= 5.139297$ m.

Inductance:

$L' = 2\times10^{-7} \ln\left(\frac{GMD}{GMR}\right)$

$= 2\times10^{-7} \ln\left(\frac{5.139297}{0.0484}\right)$

$= 9.33\times10^{-7}$ H/m

$L = 0.0933$ H.

Capacitance:

$C' = \frac{2\pi\varepsilon_0}{\ln\left(\frac{GMD}{GMR}\right)}$

for capacitance: $GMR_A = GMR_B = GMR_C = \sqrt[n^2]{\left(re^{-\frac{1}{4}}\right)^2 (200\times1$

$R = \frac{4.2}{2} = 2.1\ \Omega$.

(b) $P_{lim} = \frac{|V_R||V_S|}{\omega L} = \frac{(132\times10^3)^2}{2\pi 50(0.121)}$

$= 458.37$ MW.

bundle:

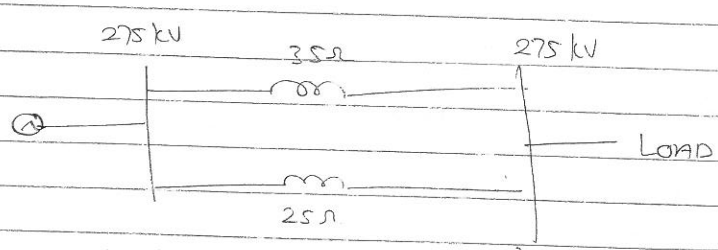
$P_{lim} = \frac{|V_R||V_S|}{\omega L} = \frac{(132\times10^3)^2}{2\pi 50(0.0933)}$

$= 594.45$ MW.

There is no linear relation between the number of conductors per bundle and inductance.

Question 3.

(a)



$P_{e2} = \frac{|V_s||V_R|}{X_s} \sin\delta = \frac{(275\,kV)^2}{35} \sin\delta = 2.16 \times 10^9 \sin\delta$

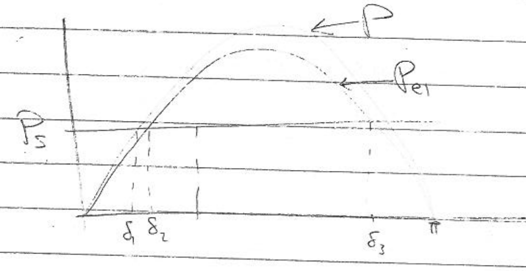
$X_s = 35\,\Omega$

$P_{e1} = 3.0299 \times 1 \sin\delta \qquad X_s = 25\,\Omega$

$P = P_{e1} + P_{e2}$

$P = 5.1859\,GW \sin\delta$

$P_s = 1500\,MW$



@ δ_1

$P_s = P$

$1500 \times 10^6 = 5.1859 \sin\delta_1$

$\delta_1 = \sin^{-1}\left(\frac{1500 \times 10^6}{5.1859}\right) = 16.8°$

@ δ_1

$P_s = P_{e1}$

$\delta_2 = \sin^{-1}\left(\frac{1500 \times 10^6}{3.029 \times 10^9}\right) = 29.68°$

$\delta_3 = 180° - \delta_2 = 150.3°$

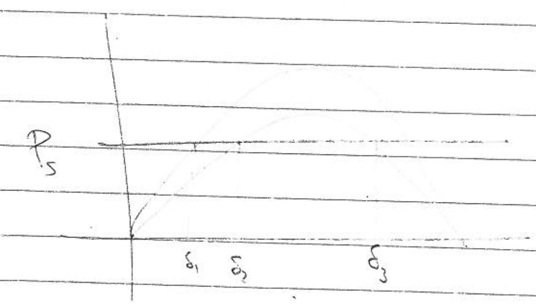
$\delta_1 = 0.293$ rad

$\delta_2 = 0.5?$ rad

$\delta_3 = 2.622$ rad

rate $= 0.5°/ms$

we want $A_1 = A_2$



$P_s(\delta_4 - \delta_1) = \int_{\delta_4}^{\delta_3} 3.0299 \sin\delta\, d\delta - P_s(\delta_3 - \delta_4)$

$P_s(\delta_4 - \delta_1) = -3.0299\left[\cos(\delta_3) - \cos\delta_4\right] - P_s(\delta_3 - \delta_4)$

$\cancel{P_s\delta_4} - P_s\delta_1 + P_s\delta_3 - \cancel{P_s\delta_4} + 3.0299\cos\delta_3) = 3.0299\cos\delta_4$

$\cos\delta_4 = \frac{1}{3.0299}\left(P_s(\delta_3 - \delta_1) + 3.0299\cos(\delta_3)\right)$

$\delta_4 = 1.281$ rad.

$\delta_4 = 1.28$ rad.

$t = \frac{\delta_4 - \delta_1}{\text{rate}} = \frac{73.40° - 16.8°}{0.5} = 113\,ms.$

$e^{\gamma l} = 1.03 + j\, 2.338 \times 10^{-3}$

$\gamma l = 0.0456 + j0.0750$

$e^{\gamma l} = 1.04661 + j\, 8.677 \times 10^{-3}$

$e^{-\gamma l} = e^{-0.0456 - j0.0750}$

$= 0.955 - j\, 7.92 \times 10^{-3}$

$\cosh(\gamma l) = \dfrac{e^{\gamma l} + e^{-\gamma l}}{2}$

$=$

$\gamma l = 0.03 + j0.13$

$e^{0.03} e^{j0.13} = e^{0.03} (\cos(7.74) + j \sin(7.74))$

$= 1.02 + j0.1387795$

$= 1.029 \angle 7.7^\circ$

$e^{0.03} e^{j0.13} = e$

$e^{-\gamma l} = 0.961 - j\, 0.13069$

$= 0.96 \angle -7.7^\circ$

$\sinh(\gamma l) = 0.364491 \angle 88.64^\circ$

$B =$

$e^{\gamma l} = e^{0.00931} e^{j0.3730}$

$e^{\gamma l} = e^{0.00931} (\cos(21.37) + j \sin(21.37))$

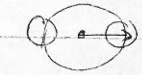
$e^{\gamma l} = 0.9399 + j0.3678 = 1.0093 \angle 21.37^\circ$

$e^{-\gamma l} = e^{-0.0093} (\cos(21.37) - j \sin(21.37))$

$= 0.9226 - j0.3610 = 0.99071 \angle -21.37^\circ$

$\cosh(\gamma l) = \dfrac{1.0093 \angle 21.37^\circ + 0.99071 \angle -21.37}{2}$

$= 0.93 \angle 0.208^\circ$



$(N-1)$