Power System

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Exercise 1.5

Maximum demand on system = 40 MW
Load unit-1 = 28 MW
Load unit-2 = 20 MW
Energy produced annually by unit 1
= 2×10^8 units

Avg. load (unit-1) = $\dfrac{2 \times 10^8 \text{ kWhr}}{8760 \text{ hr}}$

a) Load factor of unit 1 = $\dfrac{\text{Avg load}}{\text{Peak load}} = \dfrac{2 \times 10^8}{8760 \times 28 \text{ MW}} = 0.815$

Avg. load of unit 2 = $\dfrac{15 \times 10^6}{8760 \times 0.4}$ $\dfrac{\text{kWh}}{\text{h}}$.

Peak load in unit 2 = 40 MW − 28 MW
= 12 MW

Load factor of unit-2 = $\dfrac{\text{Avg. load}}{\text{Peak load}} = \dfrac{15 \times 10^6}{8760 \times 12 \times 0.4}$
= 0.356

b) for unit-1

$PCF = \dfrac{2 \times 10^8}{28 \times 10^6 \times 8760} = 0.815$

for unit-2

$PCF = \dfrac{15 \times 10^6}{20 \times 10^6 \times 8760} = 0.0856$.

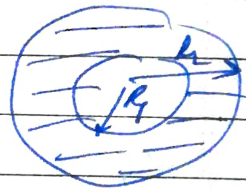
(c) For unit 1, $PUF = \dfrac{2\times10^8}{28\times10^6\times8760} = 0.815$

For unit 2, $PUF = \dfrac{15\times10^6}{20\times10^6\times0.4\times8760} = 0.214$

(d) Load factor of entire plant $= \dfrac{\dfrac{2\times10^8 + 15\times10^6}{8760}}{40\times10^6} = 0.613$

Example 2.4

From the solved example, we know that the inductance of a single hollow conductor is given by,



$$L = L_{int} + L_{ext}$$

$$= 0.2\left[\frac{r_1^2+r_2^2}{4(r_2^2-r_1^2)} + \frac{r_1^4 \ln\frac{r_2}{r_1}}{(r_2^2-r_1^2)^2} - \frac{r_1^2}{(r_2^2-r_1^2)} + \ln\frac{D}{r_2}\right] mH/km$$

Let r' be the effective radius

$$L = 0.2\ln\left(\frac{D}{r'}\right) mH/km$$

$$0.2\ln\frac{D}{r'} = 0.2\left[\frac{r_1^2+r_2^2}{4(r_2^2-r_1^2)} - \frac{r_1^2}{(r_2^2-r_1^2)} + \frac{r^4}{(r_2^2-r_1^2)^2}\ln\frac{r_2}{r_1} + \ln\frac{D}{r_2}\right]$$

$$\Rightarrow \ln\frac{r_2}{r'} = \frac{r_1^2+r_2^2}{4(r_2^2-r_1^2)} - \frac{r_1^2}{(r_2^2-r_1^2)} + \frac{r^4}{(r_2^2-r_1^2)^2}\ln\frac{r_2}{r_1}$$

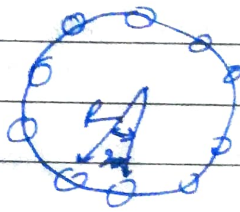
$$= f(r_2, r_1) \text{ (say)}$$

$$\Rightarrow \frac{r_2}{r_1'} = e^{f(r_2, r_2)}$$

$$\Rightarrow r' = r_2 e^{-f(r_1, r_2)}$$

Effective Radius $= r' = r_2 \exp\left[-\left(\frac{r_2^2+r_1^2}{4(r_2^2-r_1^2)} - \frac{r_1^2}{(r_2^2-r_1^2)} + \frac{r_1^4}{(r_2^2-r_1^2)^2} \ln\frac{r_2}{r_2}\right)\right]$

Exercise 2.2

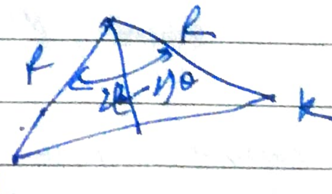


Let D_{si} represent the geometric mean of all possible mutual distance from i subconductors to the n subconductors where $D_{ii} = r'$

From symmetry,

$$D_{s1} = D_{s2} = \cdots D_{sn} = D \text{ (say)}$$

$$D_{s1} = \left[D_{11} D_{12} D_{13} \cdots D_{1n}\right]^{1/n}.$$



$$D_{1k} = 2R \sin(k-1)\theta$$

$$D_{11} = r'$$

$$D_{s1} = \left[D_{11} D_{12} D_{13} \cdots D_{1n}\right]^{1/n}.$$

$$= \left[r' \prod_{k=2}^{n} 2R \sin(k-1)\theta\right]^{1/n}.$$

$$= \left[r'(2R)^{n-1} \prod_{k=1}^{n-1} \sin k\theta\right]^{1/n} = D.$$

$$D_s = \left[D_{s1} D_{s2} \cdots D_{sn}\right]^{1/n} = \left[D^n\right]^{1/n} = D = \left[r'(2R)^{n-1} \prod_{k=1}^{n-1} \sin(k\theta)\right]^{1/n}$$

Exercise 3.4

Given Inductance $L = 1.2\ mH/km$, $r = 0.02m$

$$L = 0.4605 \log \frac{D}{r'}\ mH/km \quad \text{where } r' = re^{-1/4}$$

$$\Rightarrow 0.4605 \log \frac{D}{re^{-1/4}} = 1.2.$$

$$\Rightarrow D = re^{-1/4}\ 10^{\frac{1.2}{0.4605}} = 6.284m.$$

Capacitance of phase to neutral

$$C_{an} = \frac{0.0242}{\log\left(\frac{D}{r}\right)} = \frac{0.0242}{\log\left(\frac{6.884}{0.02}\right)}$$

$$\simeq 9.69 \times 10^{-3}\ \mu F/km.$$

Ex-5.3

Consider base MVA $(MVA)_B$ = 100 MVA

base MVA $\left(\frac{\cancel{MVA}}{kV}\right)_B$ = 20 kV.

When moving across transformer, the voltage base is changed is proportional to the transformer voltage ratings

$$V_{B2} = \frac{200}{20} \times 20 = 200kV$$

$$V_{B3} = \frac{20}{200} \times 200 = 20kV$$

$$Z_{B2} = \frac{V_{B2}^2}{(MVA)_B} = \frac{(200)^2}{100} = 400\ \Omega$$

$$X_{g1,new} = 0.09 \times \frac{100}{90}\left(\frac{20}{20}\right)^2 = 0.1\ pu.$$

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$X_{g2,new} = 0.09 \times \frac{100}{90} \times \left(\frac{18}{20}\right)^2 = 0.081\ pu$

$X_{g3,new} = 0.16 \times \frac{100}{80} \times 1^2 = 0.2\ pu.$

$X_{T2,new} = 0.2 \times \frac{100}{80} = 0.25\ pu.$

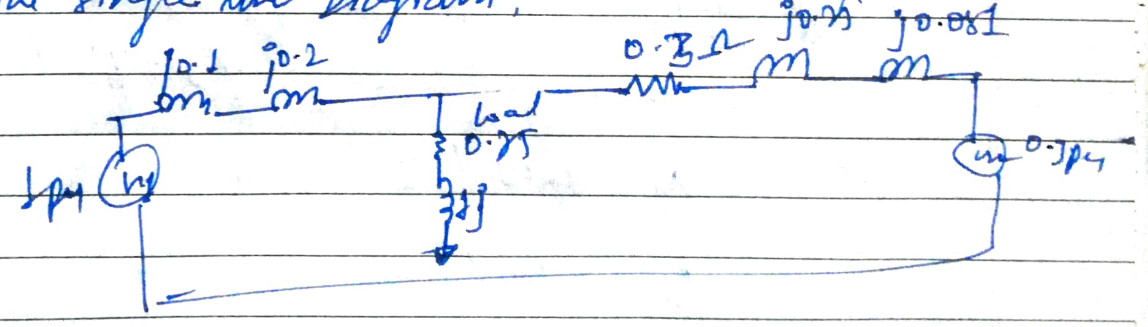
$X_{line} = \frac{120}{400} = 0.3\ pu.$

Considering load as a series combination of resistance & reactance.

$$Z^*_{load}\ (\Omega) = \frac{200^2}{48+64j} = \frac{100}{640}(48-64j)$$

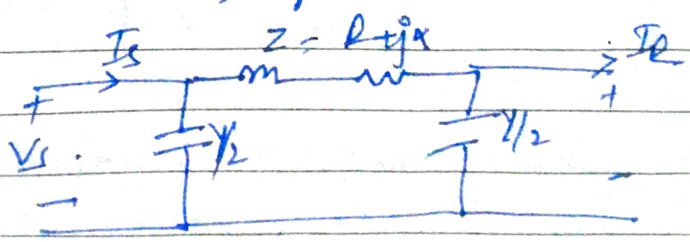
$$Z^*_{load}\ (pu) = \frac{48}{64} + \frac{64}{64}j = (0.75+1j)$$

The single line Diagram,



Ex - 6.13

Initial circuit Diagram,



$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad -(1)$$

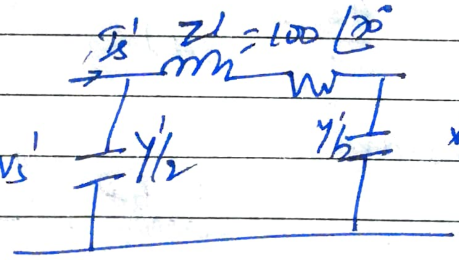
$A = 0.92\angle 5.3^\circ = D.$

$B = 65.3\angle 81^\circ$

Also, $AD - BC = 1$

$$C = \frac{AD-1}{B} = 3.508\angle 56.98 \text{ m mho}$$

Consider transformers is added at sender's end,
The circuit would be.



$A_1 = D_1 = 1 + \frac{Z'Y'}{2}$

$B_1 = Z'$

$C_1 = Y'\left(1 + \frac{Z'Y'}{4}\right)$

Here, $A_1 = 1.01\angle -0.05^\circ = D_1$.

$B_1 = 100\angle 70^\circ\ \Omega$

$C_1 = 2\times10^{-4}\angle -75^\circ$ mho.

$$\begin{bmatrix} V_S' \\ I_S' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V_S \\ I_S \end{bmatrix} \quad -(2)$$

Similarly when transformer is added at receiver end, A_1, B_1, C_1, D_1 remains same as Z', Y' parameters are same.

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$$\begin{bmatrix} V_R^E \\ I_R^E \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V_R' \\ I_R' \end{bmatrix} \quad -(3)$$

let the new ABCD parameters be A_0, B_0, C_0 & D_0.

$$\begin{bmatrix} V_S' \\ I_S' \end{bmatrix} = \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \begin{bmatrix} V_R' \\ I_R' \end{bmatrix} \quad -(4)$$

$$\begin{bmatrix} V_S' \\ I_S' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$= \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V_R' \\ I_R' \end{bmatrix}$$

On comparing with eq(4).

$$A_0 = A_1AA_1 = B_1CA_1 + A_1BC_1 + B_1DC_1$$
$$B_0 = A_1BD_1 + B_1DD_1 + A_1AB_1 + B_1CB_1$$
$$C_0 = C_1AA_1 + D_1CA_1 + C_1BA_1 + D_1DC_1$$
$$D_0 = C_1AB_1 + D_1CA_1 + C_1BD_1 + D_1DB_1$$

On solving

$A_0 = 0.8438 \angle 26.20°$ $\quad D_0 = 0.8438 \angle 26.20° = A_0$

$B_0 = 236.94 \angle 84.41\ \Omega$ $\quad C_0 = 33.73 \angle 90.98°$ m mho.

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Exercise 7.5

$$y_{12} = \frac{1}{z_{12}} = \frac{1}{0.028 + j0.096} = 10 \angle -73.74^\circ$$

$$Y_{11} = Y_{12} = y_{22} = 10 \angle -73.74^\circ.$$

$$Y_{12} = Y_{21} = -y_{12} = 10 \angle 106.26^\circ$$

Given $V_1 = 1\angle 0^\circ \Rightarrow |V_1| = 1, \ \delta_1 = 0^\circ$

Assume initialization,

$$V_2^{(0)} = 1\angle 0^\circ \Rightarrow |V_2|^{(0)} = 1, \ \delta_2^{(0)} = 0$$

$$Y\text{-bus matrix} = Y = \begin{bmatrix} 10\angle -73.74^\circ & 10\angle 106.26^\circ \\ 10\angle 106.26^\circ & 10\angle -73.74^\circ \end{bmatrix}$$

$$P_2^{scheduled} = P_{g2} - P_{load_2}$$

$$= 0 - \frac{145}{100} = -1.45 \text{ pu.}$$

$$Q_2^{scheduled} = Q_{g2} - Q_{load_2} = -0.55 \text{ pu.}$$

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2 |Y_{22}| \cos\theta_{22}$$

$$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1)$$
$$-|V_2|^2 |Y_{22}| \sin\theta_{22}$$

Also $\frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1)$

$\frac{\partial P_2}{\partial |V_2|} = |V_1||Y_{21}| \cos(\theta_{21} - \delta_2 + \delta_1) + 2|V_2||Y_{22}| \cos\theta_{22}$

$\frac{\partial Q_2}{\partial \delta_2} = |V_2||V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1)$

$\frac{\partial Q_2}{\partial |V_2|} = -|V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1) - 2|V_2||Y_{22}| \sin\theta_{22}$

Assuming matrix $J = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial |V_2|} \end{bmatrix}$

here, $\frac{\partial P_2}{\partial \delta_2} = 10 \sin(106.26^\circ) = 9.6$

$\frac{\partial P_2}{\partial |V_2|} = 10 \cos(106.26^\circ) + 20 \cos(-73.24^\circ) = 2.78$

$\frac{\partial Q_2}{\partial \delta_2} = 10 \cos(106.26^\circ) = \cancel{9.6}\ -2.78$

$\frac{\partial Q_2}{\partial |V_2|} = 10 \sin(106.26^\circ) = 9.6$

$P_2^{(0)} = 10 \cos(106.26^\circ) + 10 \cos(-73.74^\circ) = 0$

$Q_{12}^{(0)} = -10 \sin 106.26^\circ + 10 \sin(-73.24^\circ) = 0$

$J = \begin{bmatrix} 9.6 & 2.78 \\ -2.78 & 9.6 \end{bmatrix}, \quad J^{-1} = \begin{bmatrix} 0.096 & -0.028 \\ 0.028 & 0.096 \end{bmatrix}$

$\Delta P_2^{(0)} = P_2^{scheduled} - P_2^{(0)} = -1.45 \text{ pu}$

$\Delta Q_2^{(0)} = Q_2^{scheduled} - Q_2^{(0)} = -0.55 \text{ pu}$

We know

$\begin{bmatrix} \Delta P_2^{(0)} \\ \Delta Q_2^{(0)} \end{bmatrix} = J \begin{bmatrix} \Delta \delta_2^{(0)} \\ \Delta |V_2|^{(0)} \end{bmatrix}$

$\begin{bmatrix} \Delta \delta_2^{(0)} \\ \Delta |V_2|^{(0)} \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P_2^{(0)} \\ \Delta Q_2^{(0)} \end{bmatrix} = \begin{bmatrix} -7.09^\circ \\ -0.0934 \end{bmatrix}$

$\delta_2^{(1)} = \delta_2^{(0)} + \Delta\delta_2^{(0)} = -7.09^\circ$

$|V_2|^{(1)} = |V_2|^{(0)} + \Delta|V_2|^{(0)} = 0.9066$

After 1st iteration, $V_2^{(1)} = 0.9066 \angle -7.09^\circ$

$P_2^{(1)} = 0.9066 \times 1 \times 10 \cos(106.26^\circ + 7.09^\circ) + 0.9066^2 \times 10 \cos(-73.74^\circ)$

$= -1.29$

$Q_2^{(1)} = -0.43$

$\Delta P_2^{(1)} = P_2^{scheduled} - P_2^{(1)} = -0.16$

$\Delta Q_2^{(1)} = Q_2^{scheduled} - Q_2^{(1)} = -0.12$

$$\begin{bmatrix} \Delta\delta_2^{(1)} \\ \Delta|V_2|^{(1)} \end{bmatrix} = \begin{bmatrix} -0.012 \text{ rad} \\ -0.0160 \end{bmatrix} = \begin{bmatrix} -0.687^\circ \\ -0.016 \end{bmatrix}$$

$\delta_2^{(2)} = \delta_2^{(1)} + \Delta\delta_2^{(1)} = -7.777^\circ$

$|V_2|^{(2)} = |V_2|^{(1)} + \Delta|V_2|^{(1)} = 0.8906$

After second iteration,

$P_2^{(2)} = -1.408$, $Q_2^{(2)} = -0.52$

$\Delta P_2^{(2)} = P_2^{scheduled} - P_2^{(2)} = -0.042$

$\Delta Q_2^{(2)} = Q_2^{scheduled} - Q_2^{(2)} = -0.03$

$$\begin{bmatrix} \Delta\delta_2^{(2)} \\ \Delta|V_2|^{(2)} \end{bmatrix} = \begin{bmatrix} -0.813^\circ \\ -0.0041 \end{bmatrix}$$

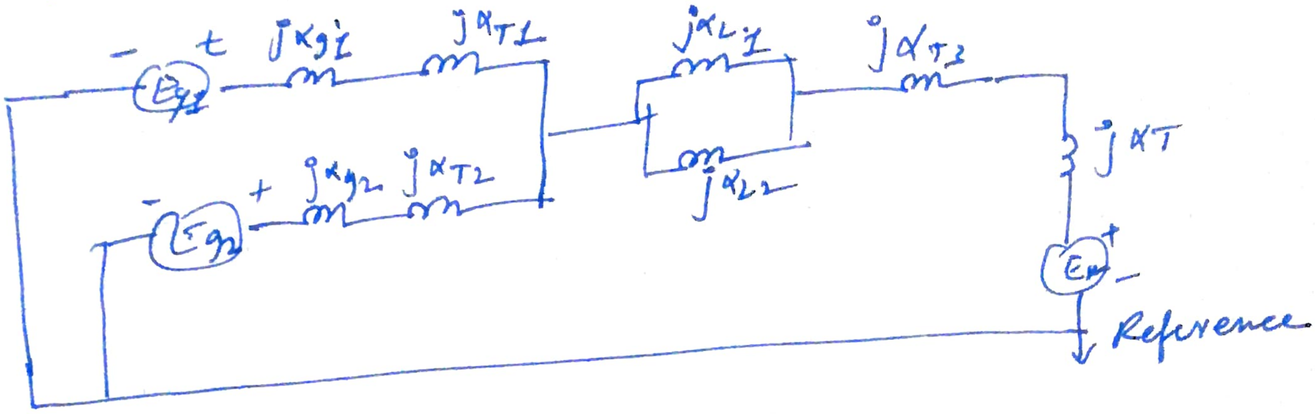
$\delta_2^{(3)} = \delta_2^{(2)} + \Delta\delta_2^{(2)} = -7.953^\circ$

$|V_2|^{(3)} = |V_2|^{(2)} + \Delta|V_2|^{(2)} = 0.8865$

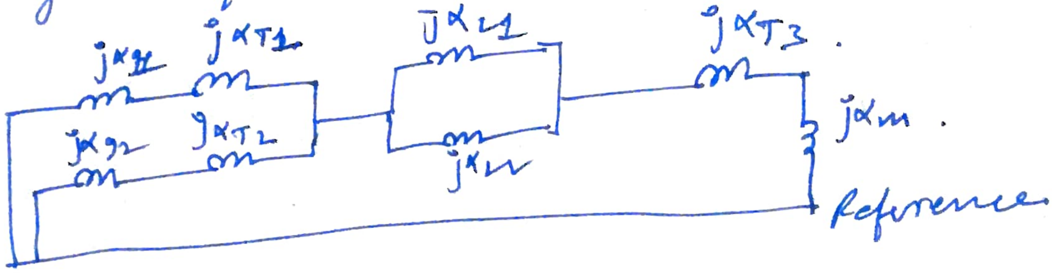
After third iteration = $V_2^{(3)} = 0.8865 \angle -7.953^\circ$.

Exercise-9.4

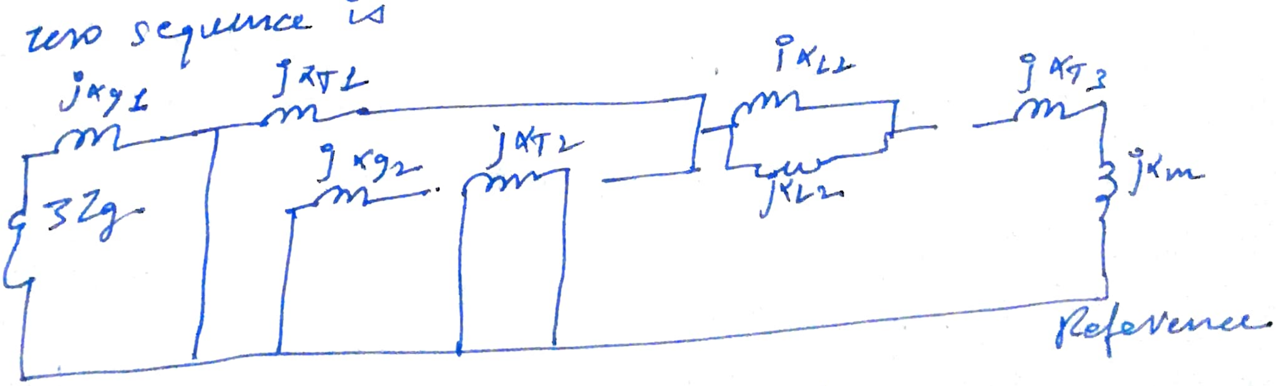
The positive sequence is



The negative sequence is

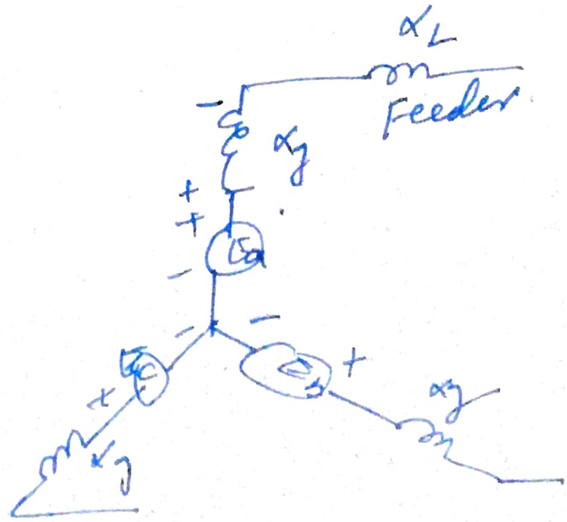


The zero sequence is



Exercise-10.10

75MVA
0.8 pf (Lagging)
11.8kV Y-Connected



Given $x_{g1} = 1.20$ pu $\quad x_{L1} = 0.10$ pu

$x_{g2} = 0.18$ pu $\quad x_{L2} = 0.10$ pu

$x_{g0} = 0.12$ pu $\quad x_{L0} = 0.30$ pu

$$I_g \text{ rated} = \frac{75 \times 10^3}{11.8 \times \sqrt{3}} = 3669.59 \, A$$

Total sequence Impedance:

$$Z_1 = j(1.70 + j0.10) = j1.80 \text{ pu}$$

$$Z_2 = j0.28 \text{ pu}$$

$$Z_0 = j0.42 \text{ pu} \qquad Z_1 + Z_0 + Z_2 = j2.5 \text{ pu}$$

For line-ground fault

$$I_f = I_a = 3I_{a1} = \frac{3E_a}{Z_1 + Z_2 + Z_0 + 3Z_f} \text{ pu}$$

($Z_f = 0$) as star is grounded.

$E_a = 1$ pu

$$I_f = \frac{3}{j2.5} = 1.2 \angle -90^\circ \text{ pu} \qquad |I_f| = \frac{1.2 \times 75 \times 10^3}{11.8 \times \sqrt{3}} A \simeq 4.4 \, kA$$

$$|I_{a1}| = \frac{|I_a|}{3} = 1.4678 \, kA$$

for line to neutral voltage at generator terminals

$$V_b = \frac{[(\beta^2 - \beta) Z_2 + (\beta^2 - 1) Z_0] E_a}{Z_1 + Z_2 + Z_0} = 0.422 \angle -126.58 \text{ pu.}$$

$$V_b = 0.422 \angle 126.58 \times \frac{75 \times 10^6}{\sqrt{3} \times 11.8 \times 10^3} = 1.55 \angle -126.58^\circ \, kV.$$

As we know that

$$|V_c| = \frac{0.6415 \angle -79.10^\circ}{2.5 \angle 90} = 0.2566 \angle -169.1^\circ \text{ pu}$$

$$V_c = 0.9416 \angle -169.1^\circ \, kV$$

$$|V_c| = 0.9416 \, kV.$$