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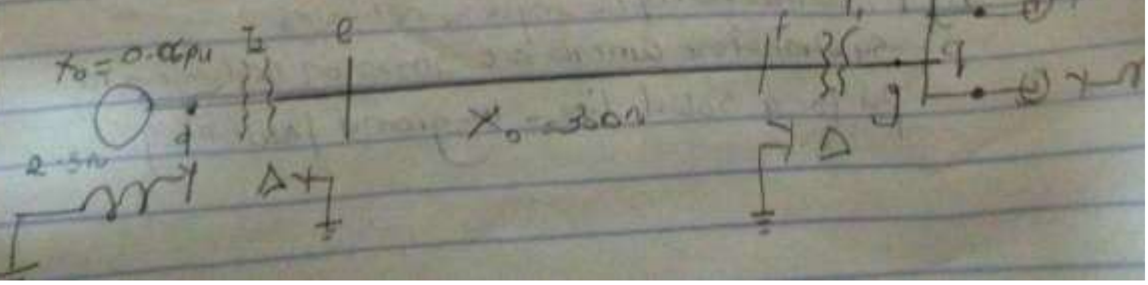
Assignment

A 25MVA, 11KV three phase generator has a subtransient reactance of 20%. The generator supplies two motors over a transmission line with transformers at both ends as shown in one - line diagram. The motors have rated inputs of 15 and 7.5 MVA, both 10KV with 25% subtransient reactance. The three-phase transformers are both rated 30MVA, 10.5/11kV connection Δ-Y with leakage of 10% each. The series reactance of the line is 100ohms.

(a) Draw the positive, negative and the zero sequence networks of the system with reactances marked in per unit.

(b) If the motors are loaded to draw 15 and 7.5MW at 10kV 0.8 leading power factor before the occurrence of a solid LG at bus g and the prefault current is neglected, calculate the fault current and subtransient current in all parts of the system.

(c) Assume that the negative sequence reactance of each machine is equal to the subtransient reactance. Omit resistances, select generator rating as base in the generator circuit.



Solution

A base of 25MVA, 11kV in the generator circuit requires a 25MVA base in all other circuits and the following voltage bases.

Transmission line voltage base $= 11 \times \frac{121}{10.8} = 123.24kV$

Motor voltage base $= 123.2 \times \frac{10.8}{121}$ = [illegible] $= 10.996kV = 11kV$

The reactances for transformers, transmission line and motors converted to pu values with their bases respectively

Transformer reactance $= 0.1 \times \frac{25}{30} \times \left(\frac{10.8}{11}\right)^2 = j0.0805pu$

Transmission line reactance $= \frac{100 \times 05}{(123.2)^2} = j0.164pu$

Reactance of motor 1 $= 0.25 \times \frac{25}{15} \times \left(\frac{10}{11}\right)^2 = j0.343pu$

Reactance of motor 2 $= 0.25 \times \frac{25}{7.5} \times \left(\frac{10}{11}\right)^2 = j0.69pu$

The positive sequence network is shown below

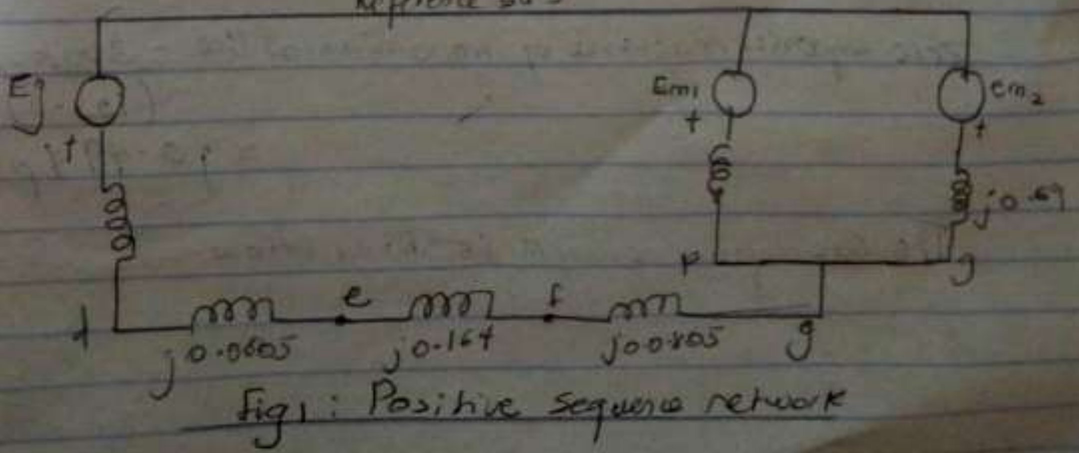


Fig1: Positive sequence network

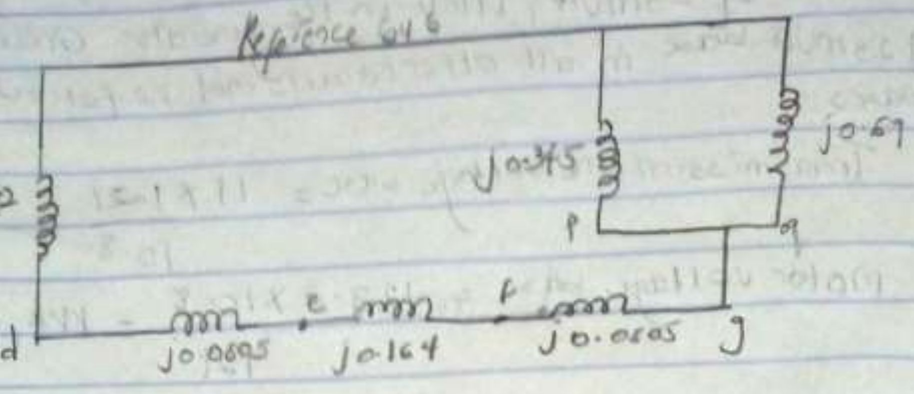


Figure 2: Negative Sequence network

[Since all the negative sequence reactances of the system are equal to the positive sequence reactances, the negative sequence network is identical to the positive sequence network.]

Zero sequence reactance of motor 2 $= 0.06 \times \frac{25}{7.5} \times \left(\frac{10}{11}\right)^2$

$= j0.164\,pu$

Reactance of current limiting reactors $= \frac{2.5 \times 25}{(11)^2} = j0.516\,pu$

Reactance of current limiting reactor included in zero sequence network $= 3 \times 0.516 = j1.548\,pu$

Zero sequence reactance of transmission line $= \frac{300 \times 25}{(123.2)^2}$

$= j0.494\,pu$

The zero sequence network is shown below

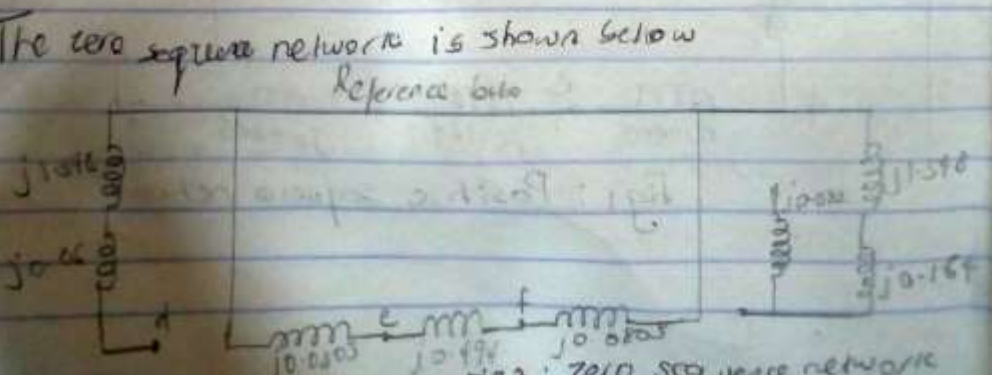


Fig 3: Zero sequence network

Solution – The sequence networks are connected below to give a solid LG fault at bus g.

If prefault currents are neglected

$$E_g'' = E_{m_1}'' = E_{m_2}'' = V_f^{\circ} \text{ (prefault voltage at } g)$$

$$\frac{10}{11} = 0.909 pu$$

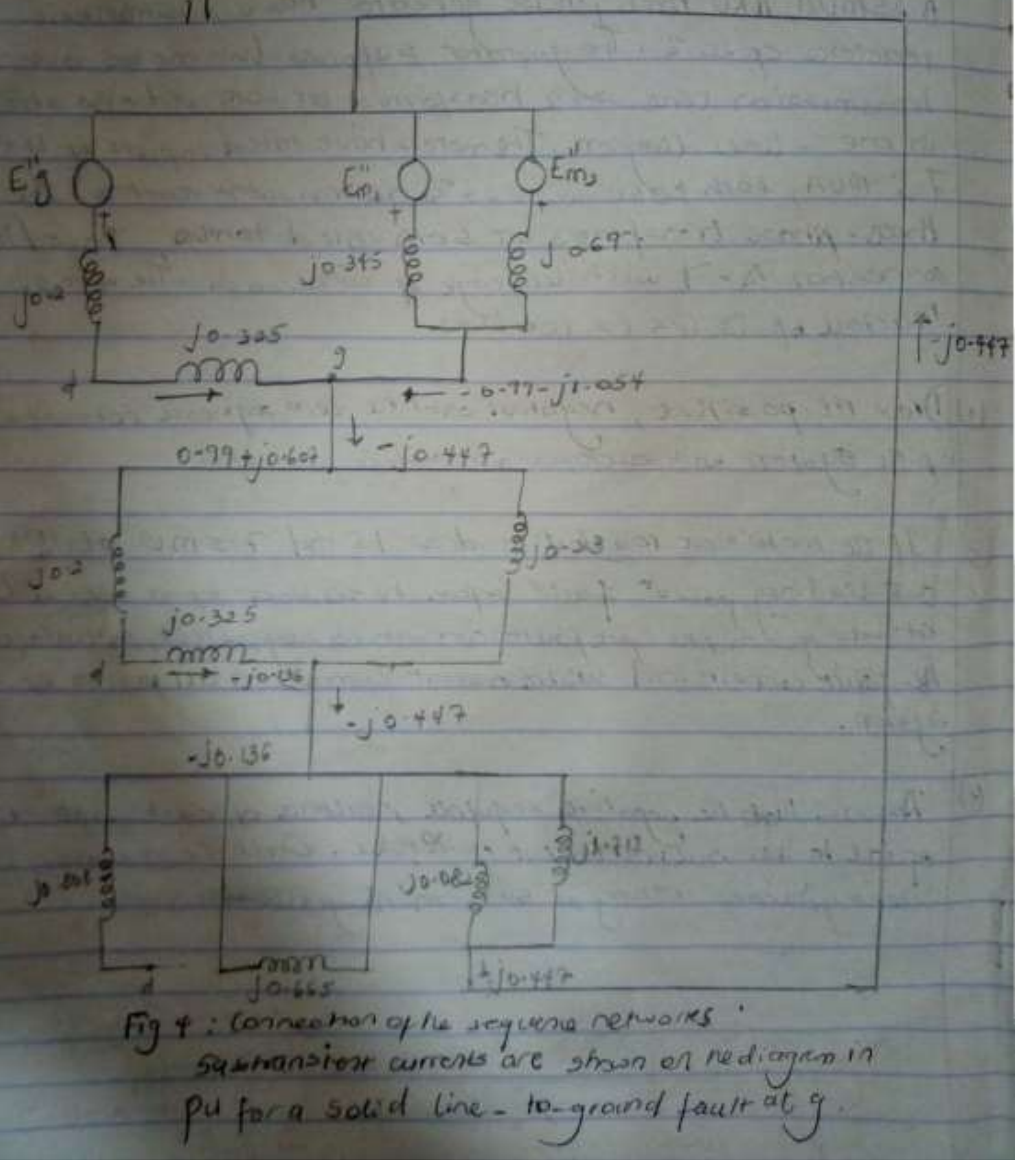


Fig 4 : Connection of the sequence networks subtransient currents are shown on the diagram in pu for a solid line - to-ground fault at g.

The positive sequence network can be easily replaced by its Thevenin equivalent shown in fig 5

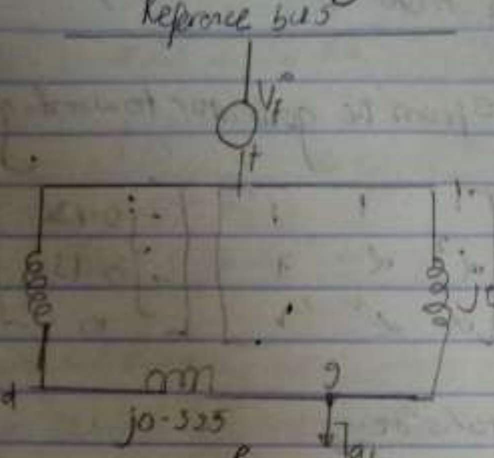


fig 5

Now calculating Z_1

$$Z_1 = \frac{j0.525 \times j0.23}{j0.755} = j0.16pu$$

$$Z_2 = Z_1 = j0.16pu$$

From the sequence network connection

$$I_{a1} = \frac{V_f^\circ}{Z_1 + Z_2 + Z_0}$$

$$= \frac{0.909}{j2.032} = -j0.447pu$$

$$I_{a2} = I_{a0} = I_{a1} = -j0.447pu$$

$$\text{Fault current} = 3I_{a0} = 3 \times (-j0.447) = -j1.341pu$$

The component of I_{a1} flowing towards g from the generator side

$$-j0.447 \times \frac{j0.23}{j0.755} = -j0.136pu$$

and its component flowing towards g from the motor side is

$$-j0.447 \times \frac{j0.525}{j0.755} = -j0.311pu$$

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Similarly the component I_{a2} from the generator side is $-j0.136$ pu and its component from the motor side is $-j0.311$. All of I_{a0} flows towards g from motor 2

Fault currents from the generator towards g are:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \begin{bmatrix} -j0.136 \\ -j0.136 \\ 0 \end{bmatrix} = \begin{bmatrix} -j0.272 \\ j0.136 \\ j0.136 \end{bmatrix} pu$$

and to g from motors are:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \begin{bmatrix} -j0.311 \\ -j0.311 \\ -j0.447 \end{bmatrix} = \begin{bmatrix} -j1.069 \\ -j0.136 \\ -j0.136 \end{bmatrix} pu$$

The positive and negative sequence components of the transmission line currents are shifted $-90°$ and $+90°$ respectively, from the corresponding components on the generator side of T_2, i.e.

Positive sequence current $= -j(-j0.136) = -0.136$ pu

Negative sequence current $= j(-j0.136) = 0.136$ pu

Zero sequence current $= 0$

∴ There are no zero sequence currents on the Transmission line from figure 3

Line a current on the transmission line

$I_a = -0.136 + 0.136 + 0 = 0$

I_b and I_c are similarly calculated

Calculating the voltages behind subtransient reactances to load of the load currents are accounted for:-

The per unit motor currents are;

Motor 1: $\frac{15}{25 \times 0.909 \times 0.8} \angle 36.86^\circ$

$= 0.825 \angle 36.86^\circ = \underline{0.66 + j0.495 \, pu}$

Motor 2: $\frac{7.5}{25 \times 0.909 \times 0.8} \angle 36.86^\circ$

$= 0.4125 \angle 36.86^\circ = \underline{0.33 + j0.248 \, pu}$

Total current drawn by both motors $= 0.99 + j0.743 \, pu$

The voltages behind subtransient reactances are calculated;

Motor 1: $E''_{m_1} = 0.909 - j0.345 \times 0.825 \angle 36.86^\circ$

$= 1.08 - j0.228 = 1.104 \angle 11.92^\circ \, pu$

$= \underline{1.104 \angle -11.92^\circ \, pu}$

Motor 2: $E''_{m_2} = 0.909 - j0.69 \times 0.4125 \angle 36.86^\circ$

$= 1.08 - j0.228$

$= \underline{1.104 \angle -11.92^\circ \, pu}$

Generator: $E''_g = 0.909 + j0.525 \times 1.2375 \angle 36.86^\circ$

$= 0.52 + j0.52 = \underline{0.735 \angle 45^\circ \, pu}$

It may be noted with the voltages behind subtransient reactances, the Thevenin circuit will still be the same as that of Fig 5.

∴ In calculating fault currents taking into account prefault loading condition, there's no need to calculate E''_{m_1}, E''_{m_2} and E''_g. Using Thevenin equivalent approach, there's a need to calculate currents caused by fault to which the load can be added.

Thus, the actual value of positive sequence current from the generator towards fault is:

$0.99 + j0.743 - j0.136$

$= \underline{0.99 + j0.607}$

and the actual value of positive sequence current from the motors to the fault is

$$-0.99 - j0.743 - j0.311 = -0.99 - j1.054$$

Since the zero sequence reactance is large, load current is comparable with the fault current. In a real situation, reverse will be the case, so that it is normal practice to neglect load current without causing an appreciable error.