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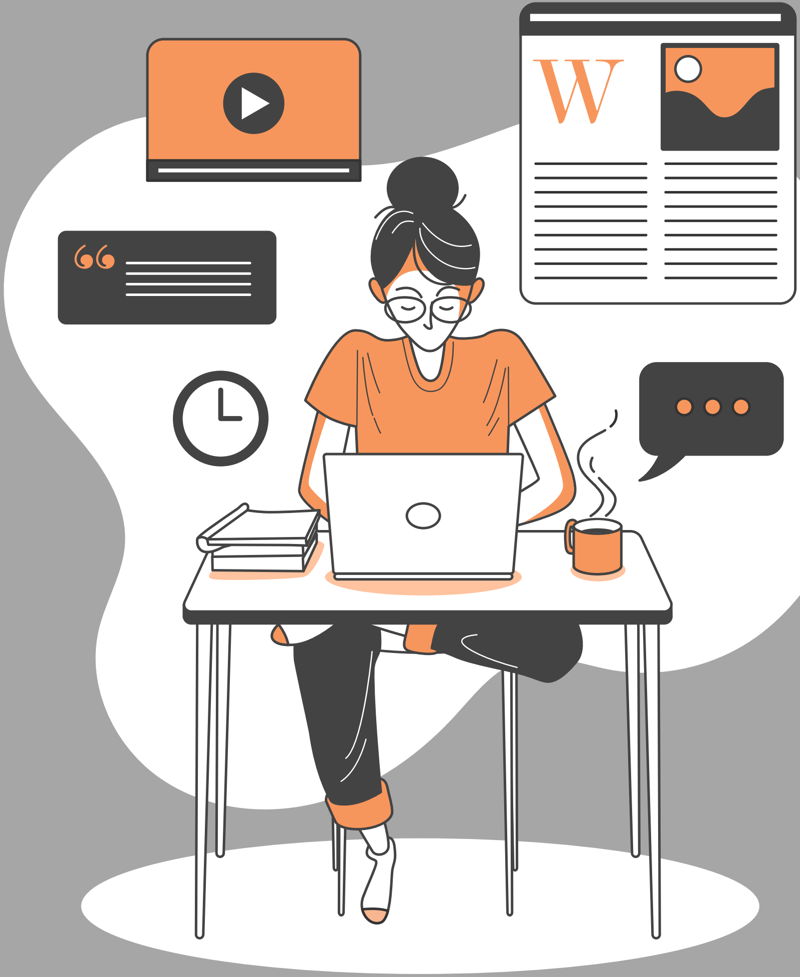

ELECTRICAL AND ELCTRONICS ENGINEERING

III rd YEAR / V th SEMESTER

EE8501 – Power System Analysis

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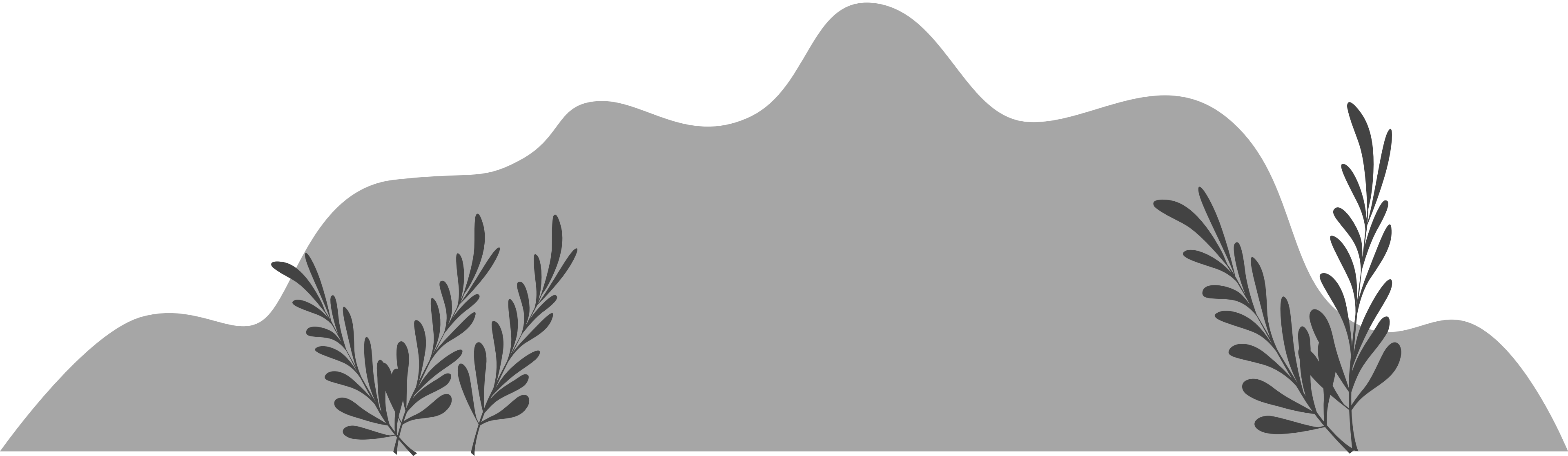
UNIT 03 – Symmetrical Fault Analysis



Your positive action combined with positive thinking results in success.

-Shiv Khera

UNIT-3

- Assumption in short circuit analysis
- Symmetrical short circuit analysis using Thevenin’s theorem
- Bus Impedance matrix building algorithm
- Symmetrical fault analysis through bus impedance matrix
- Post fault bus voltages
- Current limiting reactors.

Introduction:

- A fault in a circuit is any failure which interferes with the normal flow of current. The faults are associated with abnormal change in current, voltage and frequency of the power system.

- The faults occur in a power system due to

(i)Insulation failure of equipment

(ii)Flashover of lines initiated by a lighting stroke

(iii)Due to permanent damage to conductors and towers or due to accidental faulty operations.

Various types of faults

(i) Series fault or open circuit fault
One open conductor fault
Two open conductor fault

(ii) Shunt fault or short circuit fault.
Symmetrical fault or balanced fault
Three phase fault

Unsymmetrical fault or unbalanced fault

- Line to ground (L-G) fault
- Line to Line (L-L) fault
- Double line to ground (L-L-G) fault

Basic Assumptions in Fault Analysis of Power Systems

- Representing each machine by a constant voltage source behind proper reactance which may be X”, X’, or X

- Pre-fault load current are neglected

- Transformer taps are assumed to be nominal

- Shunt elements in the transformers model that account for magnetizing current and core loss are neglected

- A symmetric three phase power system is conducted
- Shunt capacitance and series resistance in transmission are neglected.
- The negative sequence impedances of alternators are assumed to be the same as their positive sequence impedance $Z+ = Z-$

Need for short circuit studies or fault analysis

- Short circuit studies are essential in order to design or develop the protective schemes for various parts of the system .To estimate the magnitude of fault current for the proper choice of circuit breaker and protective relays.

Reason for transients during short circuits

- The faults or short circuits are associated with sudden change in currents. Most of the components of the power system have inductive property which opposes any sudden change in currents, so the faults are associated with transients.

Doubling effect

- If a symmetrical fault occurs when the voltage wave is going through zero then the maximum momentary short circuit current will be double the value of maximum symmetrical short circuit current. This effect is called doubling effect.

Bolted fault or solid fault

- A Fault represents a structural network change equivalent with that caused by the addition of impedance at the place of a fault. If the fault impedance is zero, the fault is referred as bolted fault or solid fault.

DC off set current

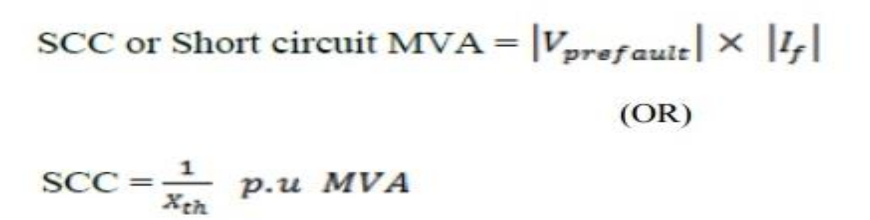
- The unidirectional transient component of short circuit current is called DC off set current.

Symmetrical Fault

- In symmetrical faults all the three phases are short circuited to each other and to earth also. Such faults are balanced and symmetrical in the sense that the voltage and current of the system remains balanced even after the fault and it is enough if we consider any one phase.

Short circuit capacity of power system or fault level.

Short circuit capacity (SCC) or Short circuit MVA or fault level at a bus is defined as the product of the magnitude of the pre fault bus voltage and the post fault current



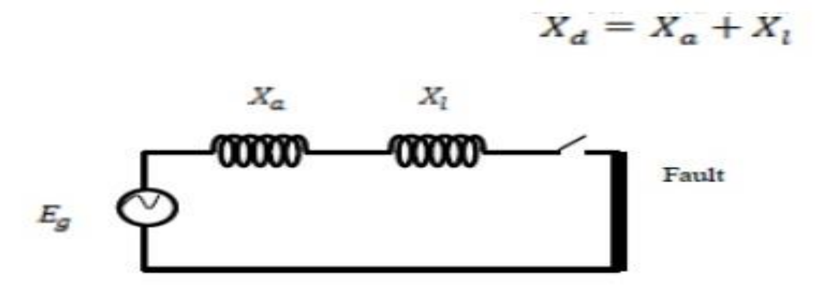
$$\text{SCC or Short circuit MVA} = |V_{prefault}| \times |I_f|$$

(OR)

$$\text{SCC} = \frac{1}{X_{th}} \quad p.u \; MVA$$

Synchronous reactance or steady state condition reactance

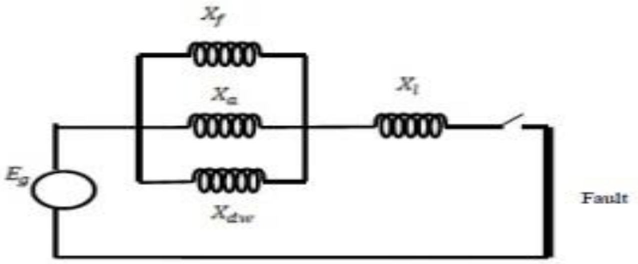
- The synchronous reactance is the ratio of induced emf and the steady state rms current. It is the sum of leakage reactance (*Xl*) and the armature reactance (*Xa*).



$$X_d = X_a + X_l$$

Sub transient reactance

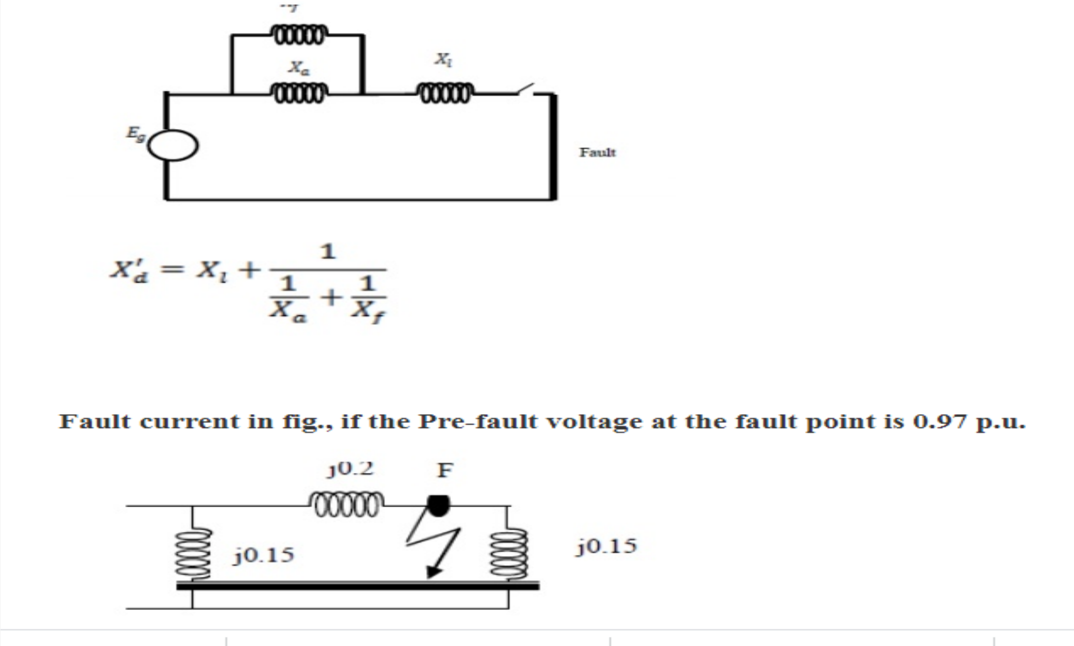
The synchronous reactance is the ratio of induced emf on no load and the sub transient symmetrical rms current.



$$X_d'' = X_l + \frac{1}{\frac{1}{X_a} + \frac{1}{X_f} + \frac{1}{X_{dw}}}$$

Transient reactance

The synchronous reactance is the ratio of induced emf on no load and the transient symmetrical rms current.



$$X'_d = X_l + \cfrac{1}{\cfrac{1}{X_a} + \cfrac{1}{X_f}}$$

Fault current in fig., if the Pre-fault voltage at the fault point is 0.97 p.u.

Thevenin’s Theorem

- Fault current = $Eth / (Zth+Zf)$

- Determine current contributed by the two generators

$IG1 = If * (Z2/(Z1+Z2))$
$IG2 = If * (Z1 / (Z1+Z2))$

- Determine Post fault voltage $Vif = Vi° + \Delta V = V° + (-Zi2*IGi)$

- Determine post fault voltage line flows $Iij = (Vi - Vj) / Zij$ series

- Short circuit capacity $If = |Eth| 2 / Xth$

Z_{BUS} Building Algorithm

- It is a step-by-step programmable technique which proceeds branch by branch. It has the advantage that any modification of the network does not require complete rebuilding of Z_{BUS} Formulation.

$$Z_{BUS}\ (\text{old}) \xrightarrow{Z_b = \text{branch impedance}} Z_{BUS}\ (\text{new})$$

Notation and addition of branch and link

- Notation: i,j old buses;
  reference bus;
  k-new bus
- Addition of branch: For connecting a new bus to an already existing old bus.
- Addition of link: For connecting two buses which already exist in partial network.

Type I Modification

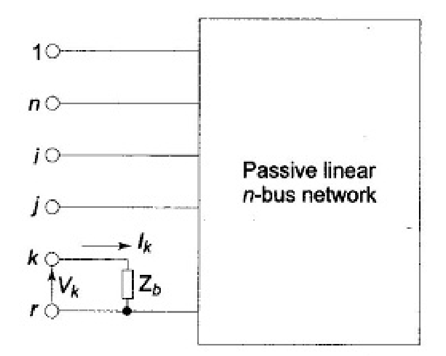
passive (linear) n-bus network in which branch with impedance Z_b is added to the new bus k and the reference bus r.

$$V_k = Z_b I_k$$

$$Z_{ki} = Z_{ik} = 0;\ i = 1, 2, \ldots, n$$

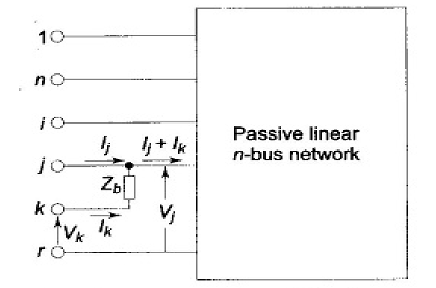
$$Z_{kk} = Z_b$$

$$Z_{BUS}\,(\text{new}) = \left[\begin{array}{c|c} Z_{Bus}(\text{old}) & \begin{array}{c} 0 \\ \vdots \\ 0 \end{array} \\ \hline 0 \quad \ldots 0 & Z_b \end{array}\right]$$



Type II Modification:

Z_b is added from new bus k to the old bus j ,



$$Z_{\mathrm{BUS}}\ (\text{new}) = \left[\begin{array}{c|c} & Z_{1j} \\ & Z_2 j \\ Z_{\mathrm{BUS}}(\text{old}) & \vdots \\ & Z_{nj} \\ \hline Z_{ji} Z_{j2} \ldots Z_{jn} & Z_{jj} + Z_b \end{array}\right]$$

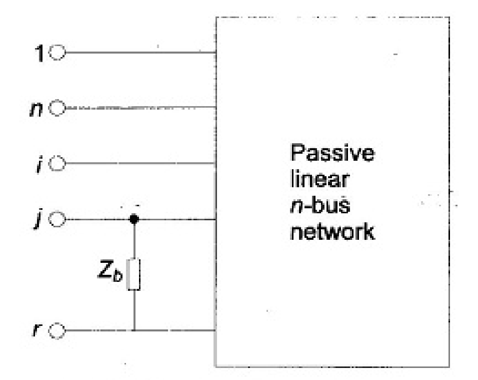
$$\begin{aligned} V_k &= Z_b I_k + V_j \\ &= Z_b I_k + Z_{j1} I_1 + Z_{j2} I_2 + \ldots + Z_{jj}\,(I_j + I_k) + \ldots + Z_{jn} I_n \end{aligned}$$

Rearranging,

$$V_k = Z_{j1} I_1 + Z_{j2} I_2 + \ldots + Z_{jj} I_j + \,.\,.\, + Z_{jn} I_n + (Z_{jj} + Z_b) I_k$$

Type III Modification:

Z_b connects an old bus (j) to the reference bus (r). Vk=0

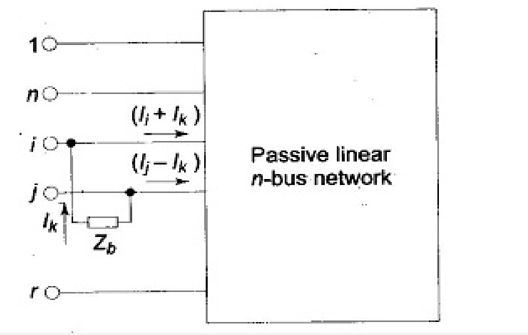


$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ 0 \end{bmatrix} = \left[\begin{array}{c|c} & Z_{1j} \\ & Z_2 j \\ Z_{\text{BUS}}(\text{old}) & \vdots \\ & Z_{nj} \\ \hline Z_{j1} Z_{j2} \ldots Z_{jn} & Z_{jj} + Z_b \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ I_k \end{bmatrix}$$

$$Z_{\text{BUS}}\ (\text{new}) = Z_{\text{BUS}}\ (\text{old} - \frac{1}{Z_{jj} + Z_b} \begin{bmatrix} Z_{1j} \\ \vdots \\ Z_{nj} \end{bmatrix} [Z_{j1} \ldots Z_{jn}]$$

Type IV Modification

Z_b connects two old buses

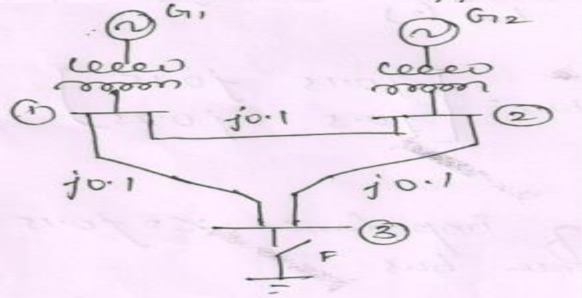


$$\left[\begin{array}{c} V_1\\ V_2\\ \vdots\\ V_n\\ -\\ 0\end{array}\right] = \left[\begin{array}{c|c} Z_{\mathrm{BUS}} & \begin{matrix}(Z_{1i}-Z_{1j})\\ |\\ (Z_{ni}-Z_{nj})\end{matrix}\\ \hline (Z_{i1}-Z_{j1})\ldots(Z_{in}-Z_{jn}) & Z_b+Z_{ii}+Z_{jj}-2Z_{ij}\end{array}\right]\left[\begin{array}{c} I_1\\ I_2\\ \vdots\\ I_n\\ \hline I_j\end{array}\right]$$

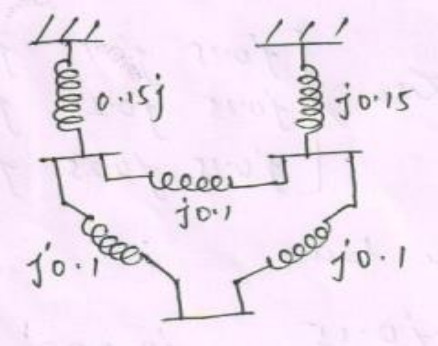
$$Z_{\mathrm{BUS}}\ (\text{new}) = Z_{\mathrm{BUS}}\ (\text{old}) - \frac{1}{Z_b + Z_{ii} + Z_{jj} - 2Z_{ij}}\begin{bmatrix} Z_{1i} & - & Z_{1j}\\ & \vdots & \\ Z_{ni} & - & Z_{nj}\end{bmatrix}$$

Problem#1

Consider a 3bus System as shown in fig. below the generators are rated at 100MVA with transient reactance of 10% each. Both the T/f are rated at 100MVA with a leakage reactance of 5%. The reactance of each line to a base of 100MVA, 110kVA is 10%. obtain the short circuit solution for a 3ϕ solid short-ckt occuring at bus 3

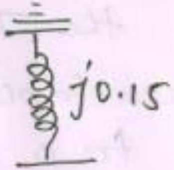


Solution:



Step 1:

Finding a branch of impedance $Z = 0.15j$ b/w the reference bus and new bus.



, $Z_{bus} = [j0.15]$

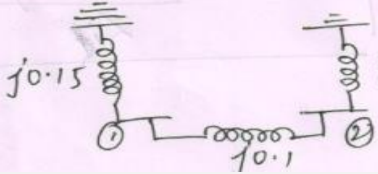
Step 2 :-

Adding a branch of impedance $z = j0.1$ b/w old bus (1) and new bus (2)

, $Z_{bus} = \begin{bmatrix} j0.15 & j0.15 \\ j0.5 & j0.25 \end{bmatrix}$

Step 3 :-

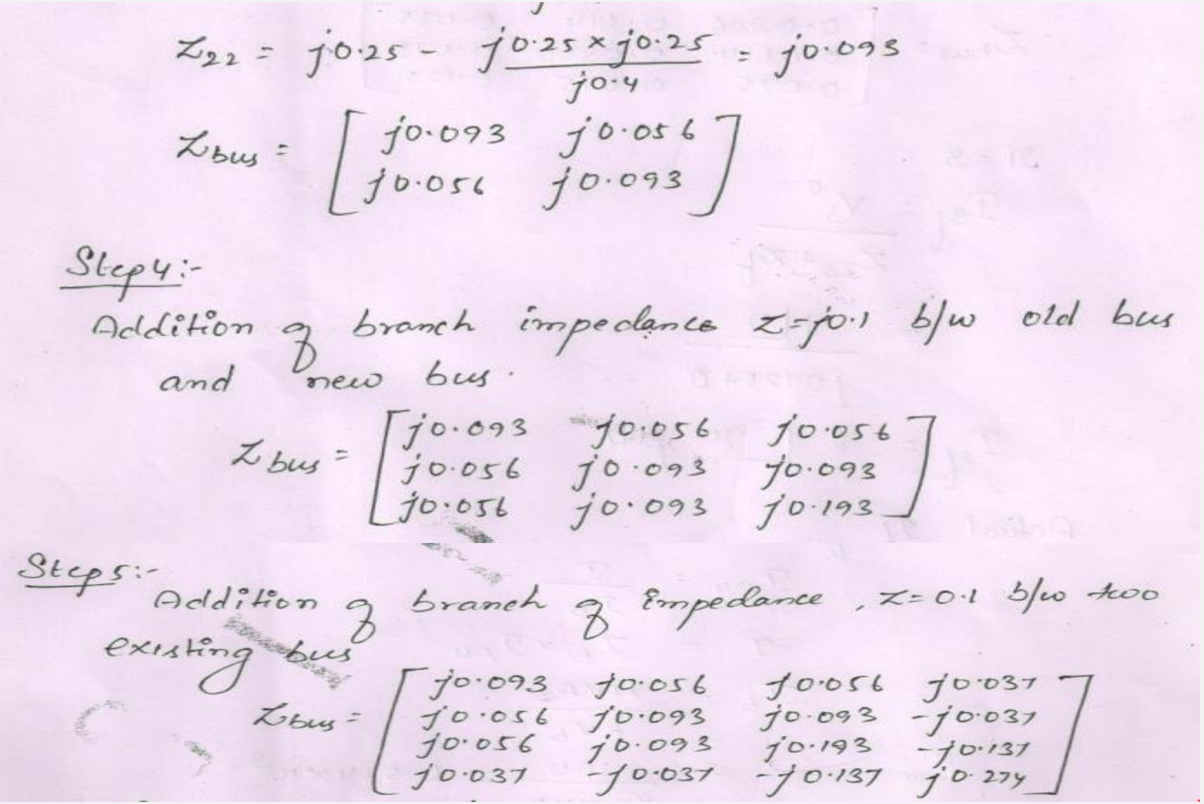
Addition a branch of impedance, $z = j0.15$ b/w old bus and reference bus



, $Z_{bus} = \begin{bmatrix} j0.15 & j0.15 & j0.15 \\ j0.15 & j0.25 & j0.15 \\ j0.15 & j0.25 & j0.4 \end{bmatrix}$

Eliminating the reference bus,

$$Z_{11} = j0.15 - \frac{j0.15 \times j0.15}{j0.4} = j0.093$$



$$Z_{22} = j0.25 - \frac{j0.25 \times j0.25}{j0.4} = j0.093$$

$$Z_{bus} = \begin{bmatrix} j0.093 & j0.056 \\ j0.056 & j0.093 \end{bmatrix}$$

Step 4:-

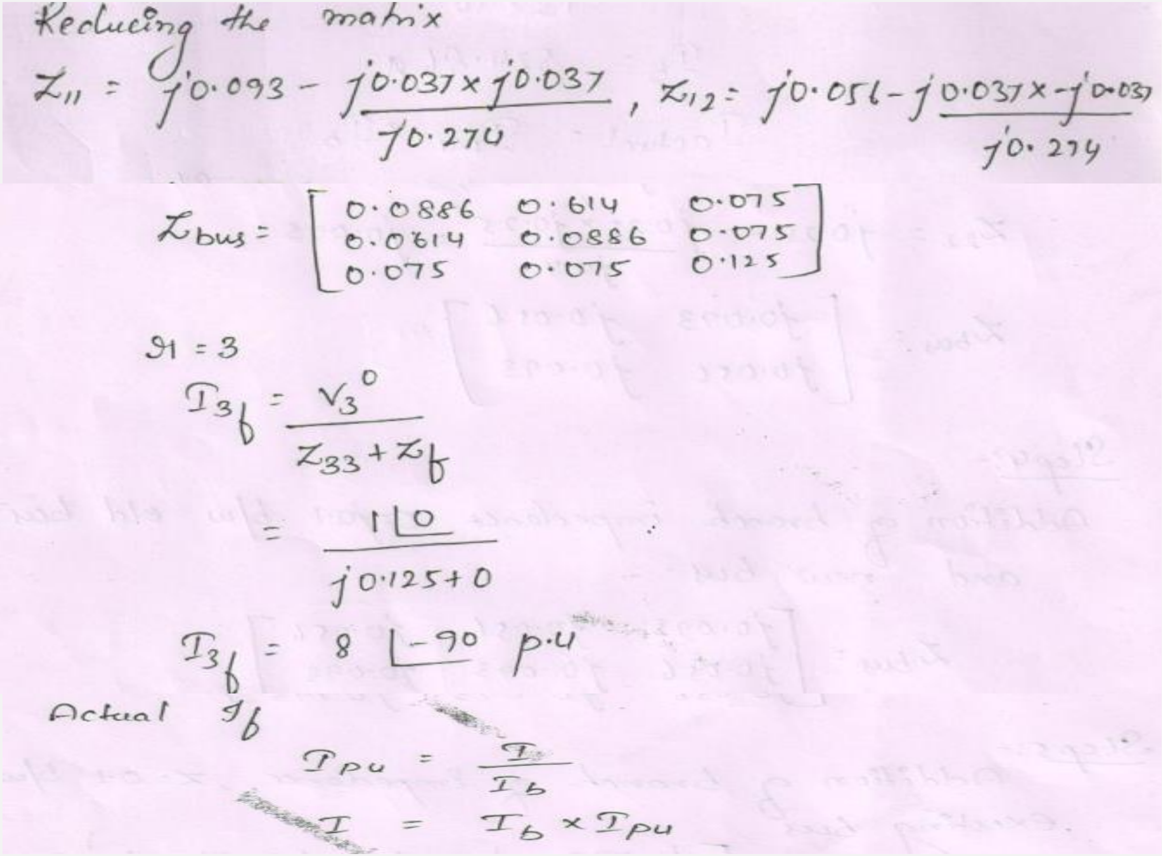
Addition of branch impedance z = j0.1 b/w old bus and new bus.

$$Z_{bus} = \begin{bmatrix} j0.093 & j0.056 & j0.056 \\ j0.056 & j0.093 & j0.093 \\ j0.056 & j0.093 & j0.193 \end{bmatrix}$$

Step 5:-

Addition of branch of impedance, z = 0.1 b/w two existing bus

$$Z_{bus} = \begin{bmatrix} j0.093 & j0.056 & j0.056 & j0.037 \\ j0.056 & j0.093 & j0.093 & -j0.037 \\ j0.056 & j0.093 & j0.193 & -j0.137 \\ j0.037 & -j0.037 & -j0.137 & j0.274 \end{bmatrix}$$



Reducing the matrix

$$Z_{11} = j0.093 - \frac{j0.037 \times j0.037}{j0.274}, \quad Z_{12} = j0.056 - j\frac{0.037 \times -j0.037}{j0.274}$$

$$Z_{bus} = \begin{bmatrix} 0.0886 & 0.614 & 0.075 \\ 0.0614 & 0.0886 & 0.075 \\ 0.075 & 0.075 & 0.125 \end{bmatrix}$$

$q = 3$

$$I_{3f} = \frac{V_3^0}{Z_{33} + Z_f}$$

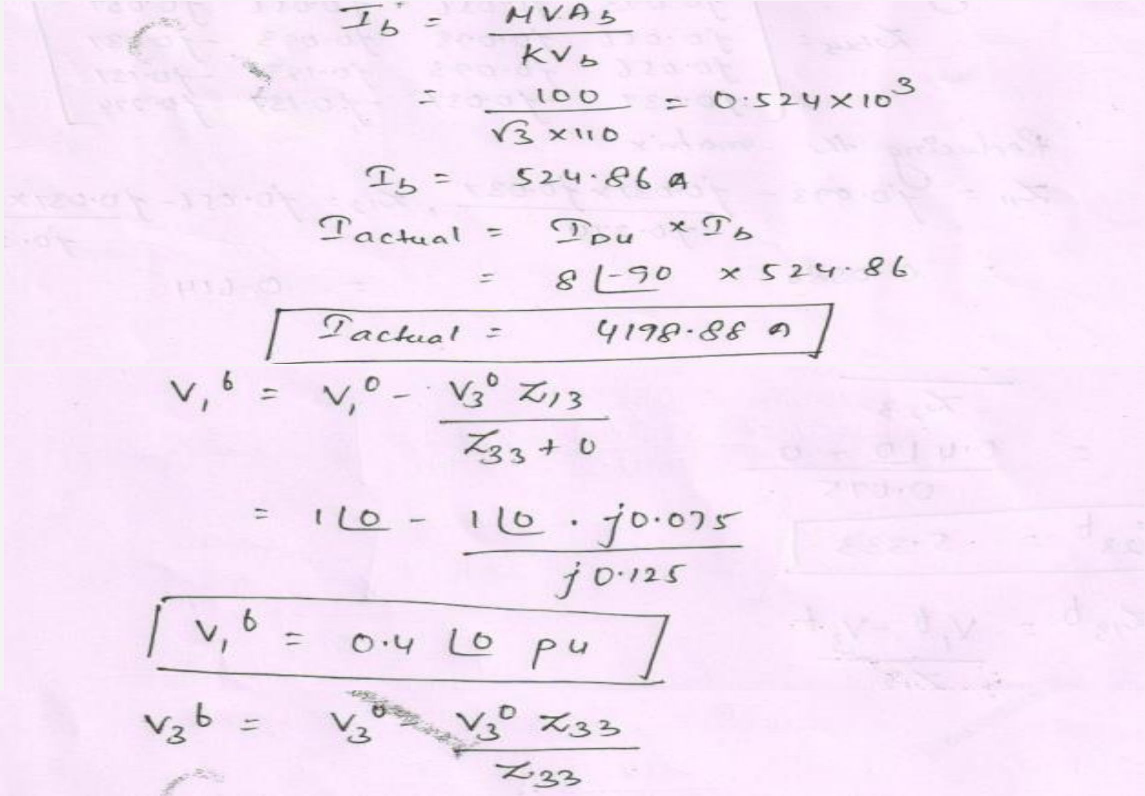
$$= \frac{1\angle 0}{j0.125 + 0}$$

$$I_{3f} = 8\angle -90 \text{ p.u}$$

Actual I_f

$$I_{pu} = \frac{I}{I_b}$$

$$I = I_b \times I_{pu}$$



$$I_b = \frac{MVA_b}{kV_b}$$

$$= \frac{100}{\sqrt{3} \times 110} = 0.524 \times 10^3$$

$$I_b = 524.86\ A$$

$$I_{actual} = I_{pu} \times I_b$$

$$= 8\angle{-90} \times 524.86$$

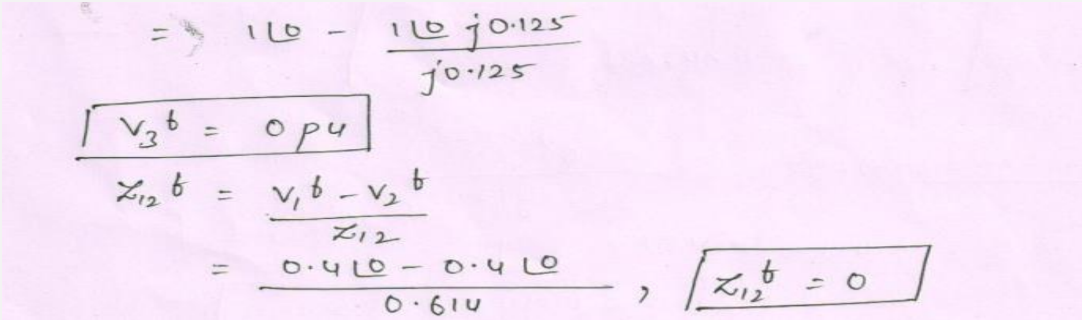
$$\boxed{I_{actual} = 4198.88\ A}$$

$$V_1^b = V_1^0 - \frac{V_3^0 Z_{13}}{Z_{33} + 0}$$

$$= 1\angle 0 - \frac{1\angle 0 \cdot j0.075}{j0.125}$$

$$\boxed{V_1^b = 0.4\angle 0\ pu}$$

$$V_3^b = V_3^0 - \frac{V_3^0 Z_{33}}{Z_{33}}$$

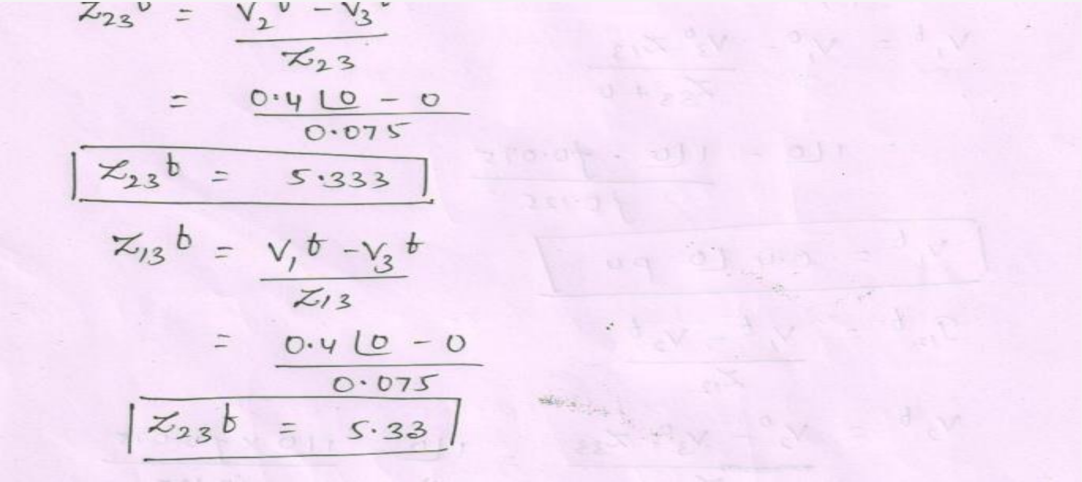


$$= 1\angle 0 - \frac{1\angle 0\; j0.125}{j0.125}$$

$$\boxed{V_3^b = 0\,pu}$$

$$Z_{12}^b = \frac{V_1^b - V_2^b}{Z_{12}}$$

$$= \frac{0.4\angle 0 - 0.4\angle 0}{0.614} \;,\quad \boxed{Z_{12}^b = 0}$$



$$Z_{23}^b = \frac{V_2^b - V_3^b}{Z_{23}}$$

$$= \frac{0.4\angle 0 - 0}{0.075}$$

$$\boxed{Z_{23}^b = 5.333}$$

$$Z_{13}^b = \frac{V_1^b - V_3^b}{Z_{13}}$$

$$= \frac{0.4\angle 0 - 0}{0.075}$$

$$\boxed{Z_{23}^b = 5.33}$$

Current Limiting Reactor

- The current limiting reactor is an inductive coil having a large inductive reactances in comparison to their resistance and is used for limiting short circuit currents during fault conditions.

- Current-voltage reactors also reduced the voltage disturbances on the rest of the system.

- It is installed in feeders and ties, in generators leads, and between bus sections, for reducing the magnitude of short circuit currents and the effect of the respective voltage disturbance.

Functions of Current Limiting Reactor

- Current limiting reactor reduces the flow of short circuit current so as to protect the appliances from mechanical stress and overheating.

- Current reactor reduced the magnitude of voltage disturbances which is caused by short circuits.

- It limits the fault current to flow into the healthy feeders or parts of the system, thereby avoiding the fault from spreading. This increase the chances of continuity of supply.

Drawbacks of current limiting reactor

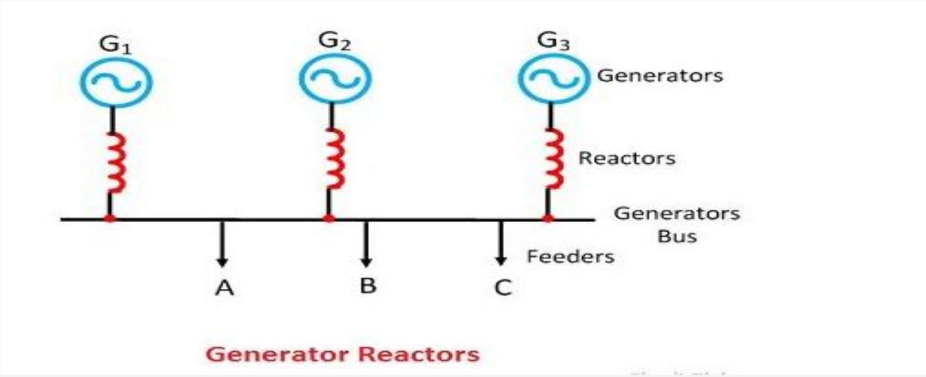
The main drawbacks of the current limiting reactors are as follows

- When the reactor is installed on the network, the total percentage reactance of the circuit increases.
- It decreases the power factor and thus the regulation becomes poorer.

<u>Location</u>:

Generators Reactors

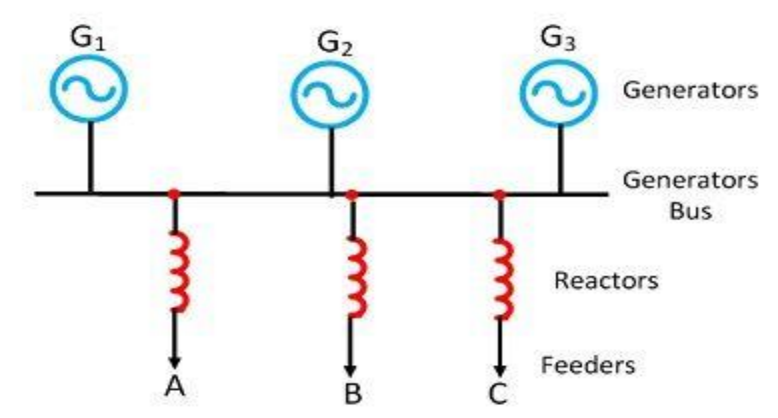
- Generator reactors are inserted between the generator and the generator bus. Such reactors protect the machines individually.
- The magnitude of reactors is approximately about 0.05 per unit.



Generator Reactors

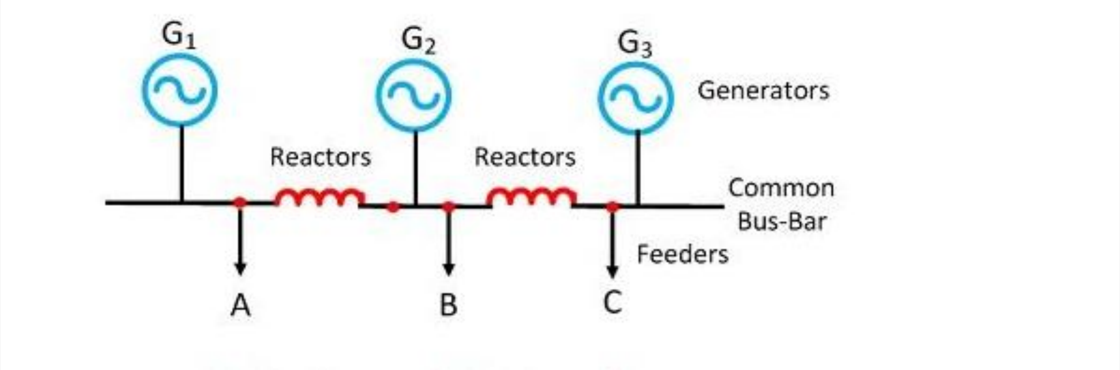
Feeders Reactors

- Reactors, which is connected in series with the feeder is called feeders reactor. When the fault occurs on any one feeder, then the voltage drops occur only in its reactors and the bus bar is not affected much.



Bus-Bar Reactors (Ring System)

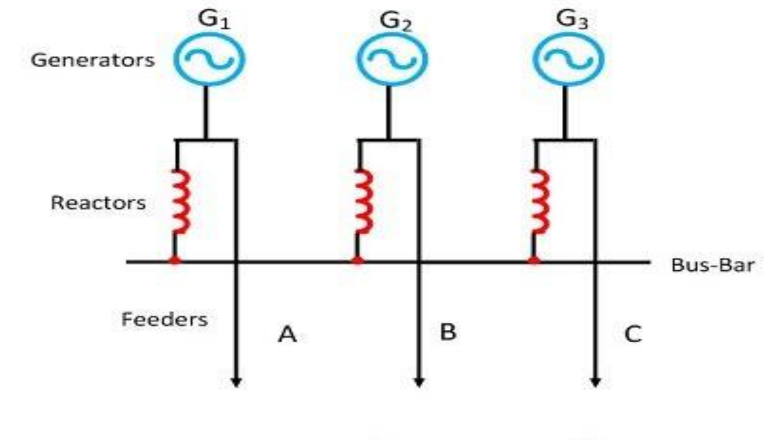
- Bus-bar reactors are used to tie together the separate bus sections.
- In this system sections are made of generators and feeders and these sections are connected to each other to a common bus bar.



Bus-Bar Reactors (Ring System)

Bus-bar Reactors (Tie-Bus System)

- This is the modification of the above system. In tie-bus system, the generator is connected to the common bus-bar through the reactors, and the feeder is fed from generator side.



Bus-Bar Reactors (Tie-Bar System)

Thank you