SYMMETRICAL FAULTS IN POWER SYSTEMS

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INTRODUCTION

- A power system ideally operates under balanced condition.
- Abnormal conditions such as faults, makes the system unbalanced.
- Faults (short circuits) are conditions which said to occur when the insulation of system fails at any point or two or more conductor come in contact with each other.
- A fault may occur due to number of reasons which includes
  - **Natural disturbance** like lighting, high speed wind, earthquake, snow, etc.
  - **Insulation breakdown** in the protective equipment for generator, transformers, etc.
  - **Accidents** due to falling of trees, vehicles collision, animal shorting lines, etc.

INTRODUCTION

- Faults may occur at any point of the transmission line and are mainly of two types
  - **Symmetrical faults**
    - Under these faults condition the system remains in balanced conditions and generally occurs when all the three phases are shorted to each other and often with the ground also.
    - These faults are most severe types and occurs rarely in the system.
  - **Unsymmetrical faults**
    - These faults occurs when either one or two phases comes in contract with each other or along with ground.
    - As these faults give rise to unbalanced voltage and current; these faults are known as unsymmetrical faults.

INTRODUCTION

- Unsymmetrical faults based on there occurrence are further classified as
  - **Single line to ground (LG) faults**
    - These faults occurs when a conductor falls on ground or comes in contact with the neutral conductor.
  - **Line to line (LL) faults**
    - A line to line fault occurs when two conductor are shorted with each other.
  - **Line to line to ground (LLG) faults**
    - A double line to ground fault occurs when two conductor comes in contact with each other along with ground.

INTRODUCTION

- Faults can damage or disrupt power system in several ways –
  - Faults give rise to abnormal operating conditions (excessive voltage and current) which result in overheating of the equipment and may result in reduced life,
  - Interrupt the flow of electric power,
  - System instability, Voltage collapse, etc.
- Owing to these concerns, fault analysis also known as short circuit study or short circuit analysis is done.
- Fault analysis helps
  - To determine the value of voltage and current at different points of the system during fault.
  - To determine the rating of circuit breaker.
  - In the selection of appropriate scheme of protective relays.

ASSUMPTIONS FOR FAULT ANALYSIS

- Accurate fault calculation involves much labor and time. Therefore, some assumptions are made so that the calculation becomes simplified.
  - Synchronous machine model is represented by a constant voltage source behind a proper reactance.
  - In transformer, shunt element for magnetizing current and core losses are neglected.
  - Transformer are considered to be at their normal taps.
  - In transmission line, the shunt capacitance are neglected.
  - All series resistance in generator, transmission line, transformer are neglected.
  - Load impedance are neglected and therefore, the pre-fault is unloaded or open circuited. With the system, network open all the pre-fault bus voltage will have the same magnitude of 1.0 pu and phase angle of 0. This condition where the voltage magnitude at any point along our transmission line is the same is commonly known as **flat profile**.

SHORT CIRCUIT CAPACITY (SCC)

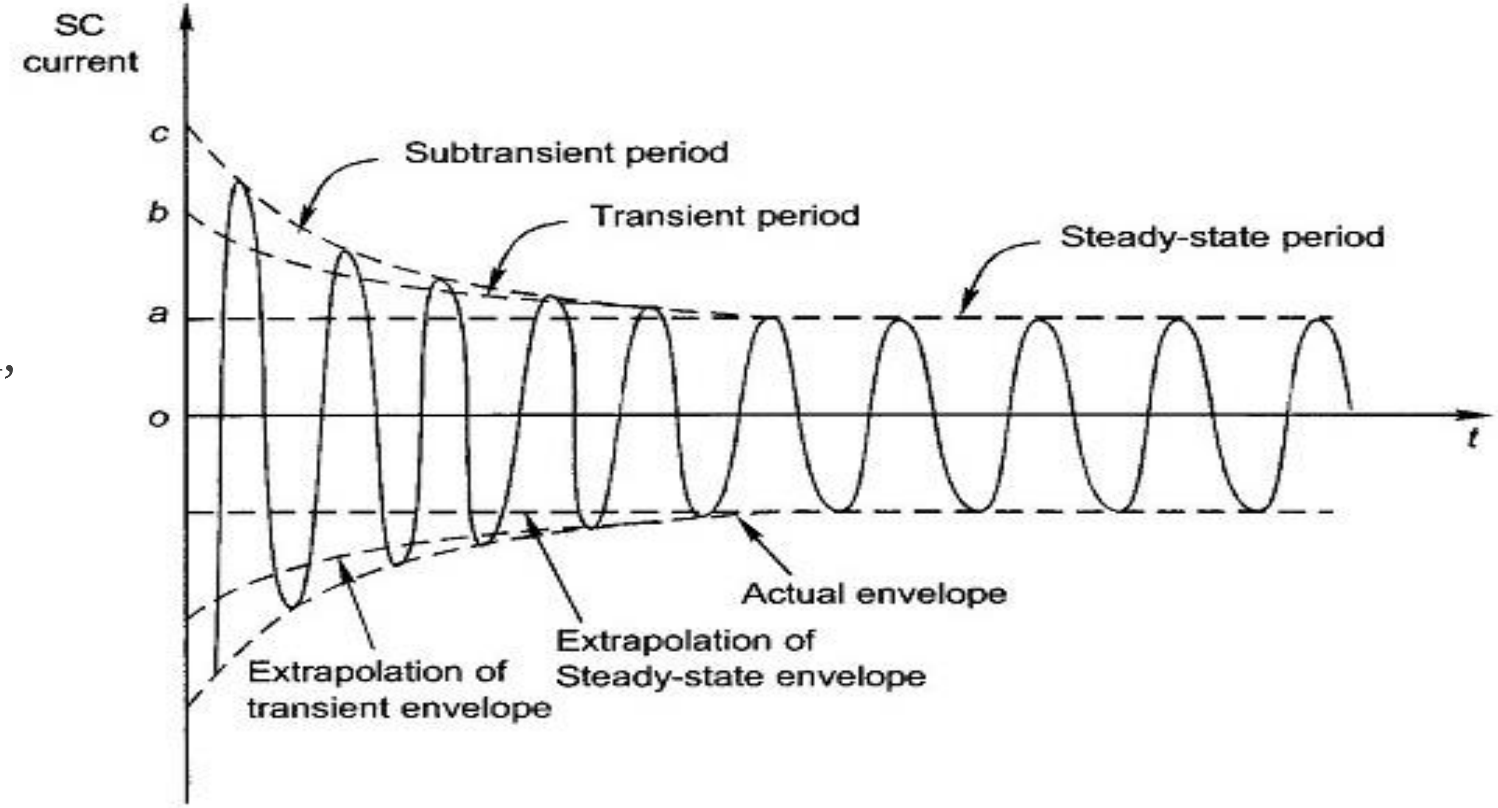
- The short circuit capacity (SCC) or fault level of a bus in a network is defined as the product of the magnitude of the pre fault voltage and post fault current.
- Mathematically SCC is given as follows

$$SSC = V_0 . I_F = \frac{S_b}{Z_{pu}}$$

- Calculation for the SSC is done using the following procedure
  - Draw a single line diagram
  - Compute all impedance in per unit value on same base.
  - Draw the reactance diagram
  - Calculate the total impedance from source to the fault point and determine the fault MVA and current using the above formula.

SUDDEN SHORT CIRCUIT AT ARMATURE TERMINAL OF GENERATOR

- The current flowing in the armature of a three phase synchronous generator when its terminal are short circuited is similar to the current flowing in a series R-L circuit when a sudden sinusoidal voltage is suddenly applied.
- The short circuit current in each phase will consists of ac and dc component.
- If the dc component is subtracted, the armature current as a wave shape as shown in the figure.



SUDDEN SHORT CIRCUIT AT ARMATURE TERMINAL OF GENERATOR

- The wave is divided into three distinct time period
  - **Sub transient period –**
    - During this period the current decays rapidly and it last for about 2 cycles.
    - RMS value of initial current is called sub transient current and the reactance corresponding to this period is called direct axis sub transient reactance.
    - The reactance is essentially due to the presence if the damper winding.
  - **Transient period –**
    - During this period the current decreases some what slower than sub transient period and it last for about 30 cycles.
    - The rms value of current represented by the intersection of OB is called transient current and the corresponding reactance is called direct axis transient reactance.
    - This reactance is essentially because of the field winding.

SUDDEN SHORT CIRCUIT AT ARMATURE TERMINAL OF GENERATOR

- **Steady state –**
  - The current reaches its steady state value.
  - The intersection of OC is called steady state short circuit current and
  - the corresponding reactance is called synchronous reactance.

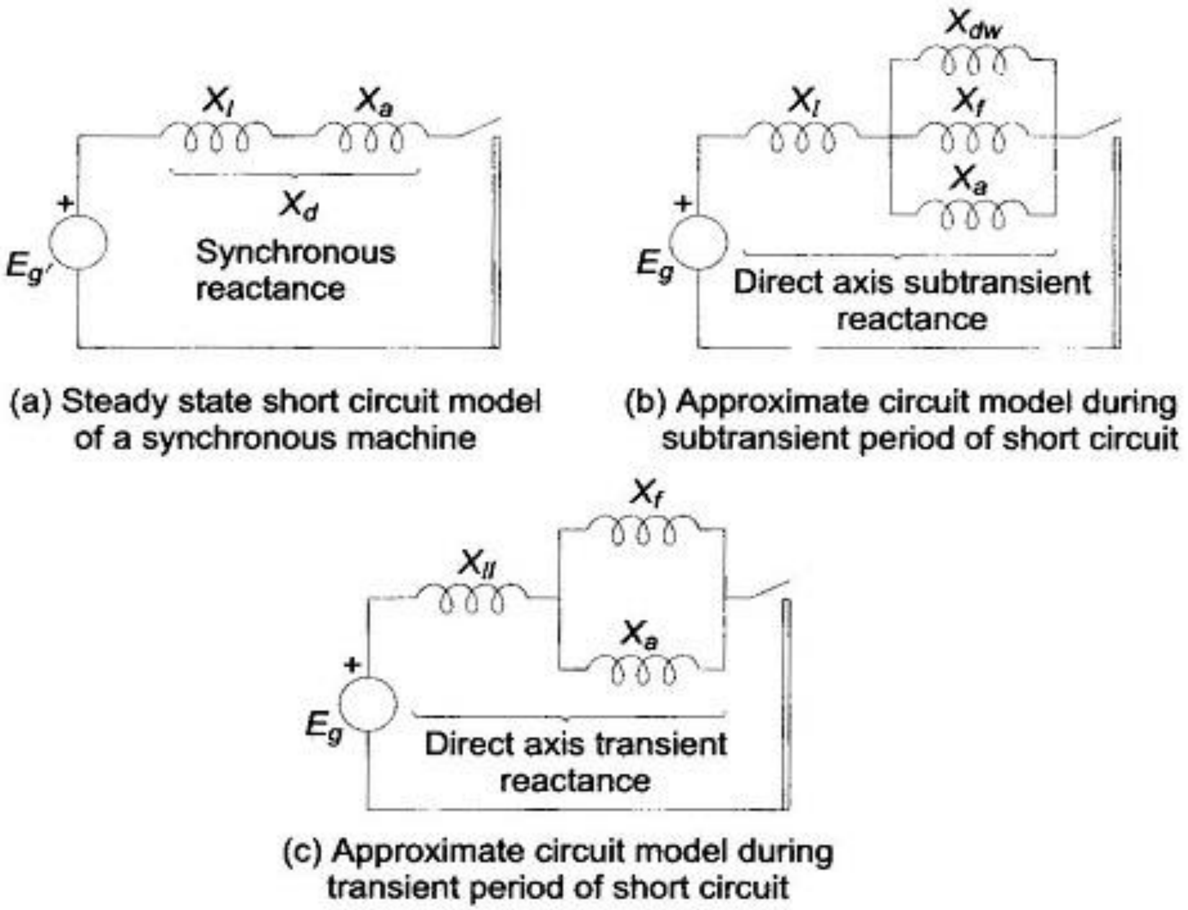
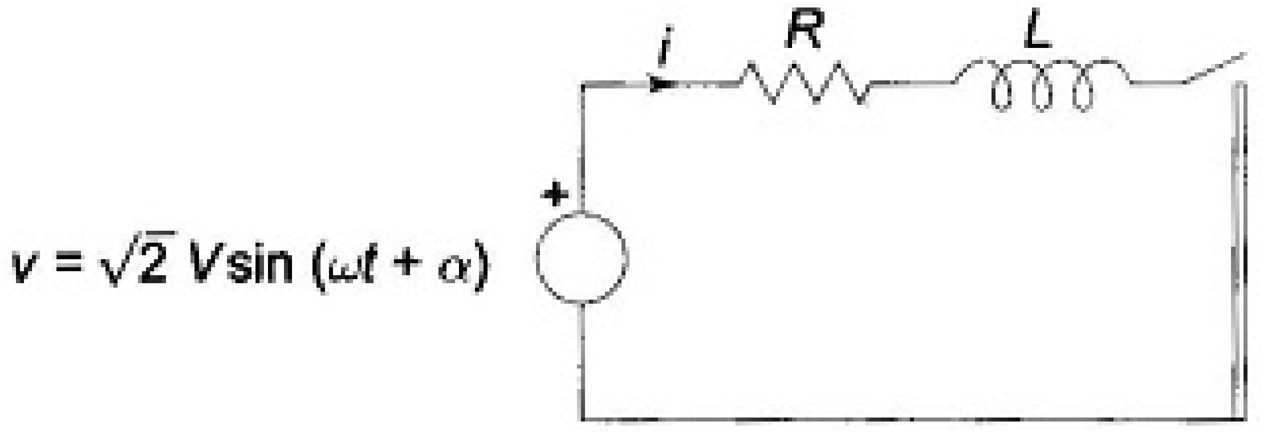


Fig. 9.3

TRANSIENT ON TRANSMISSION LINES

- Consider a short circuit on one end of a unload transmission line which is supplied by a constant voltage source with the line capacitance neglected and series impedance lumped (as shown in the figure below).



- Under this condition, the current flowing through the line will include steady state current (i_s) and transient current (i_t).
- Mathematically, the current, i is given as

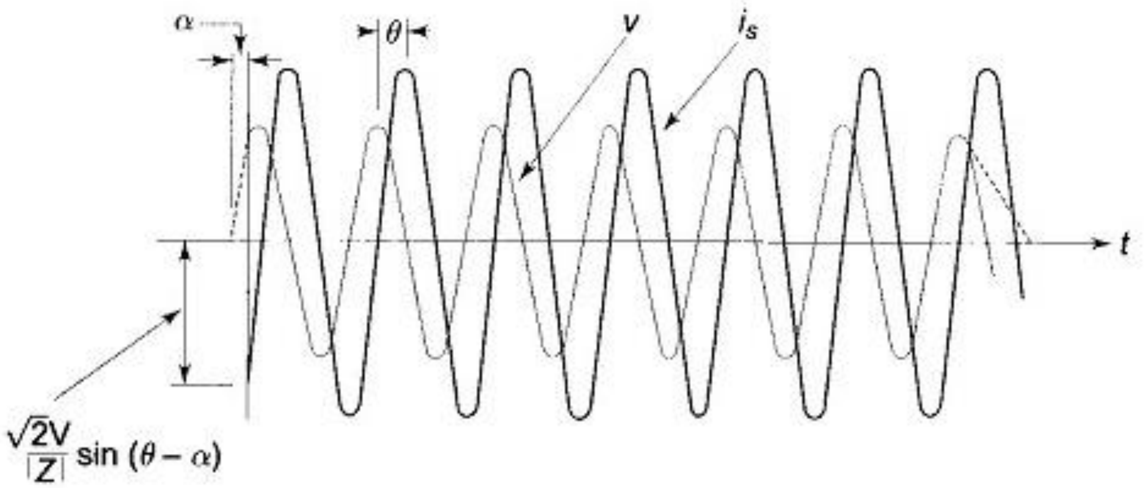
$$i = i_s + i_t$$

TRANSIENT ON TRANSMISSION LINES

- Mathematically, the steady state current is given by

$$i_s = \frac{\sqrt{2}.V}{|Z|} sin(\omega t + \alpha - \theta)$$

- Graphically, the steady state current is represented as follows

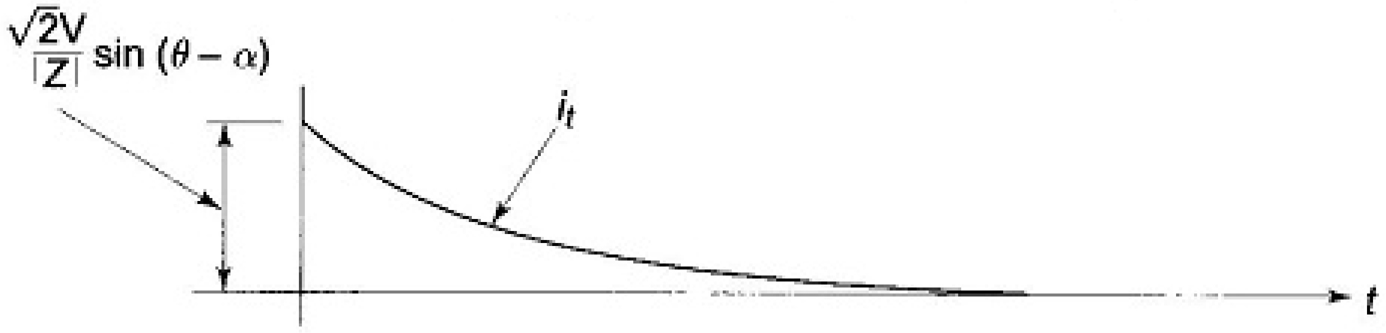


TRANSIENT ON TRANSMISSION LINES

- Mathematically, the transient current is given by

$$i_t = i_s(0).e^{-\frac{R}{L}.t} = \frac{\sqrt{2}.V}{|Z|}sin(\alpha - \theta).e^{-\frac{R}{L}.t}$$

- Graphically, the transient current is represented as follows

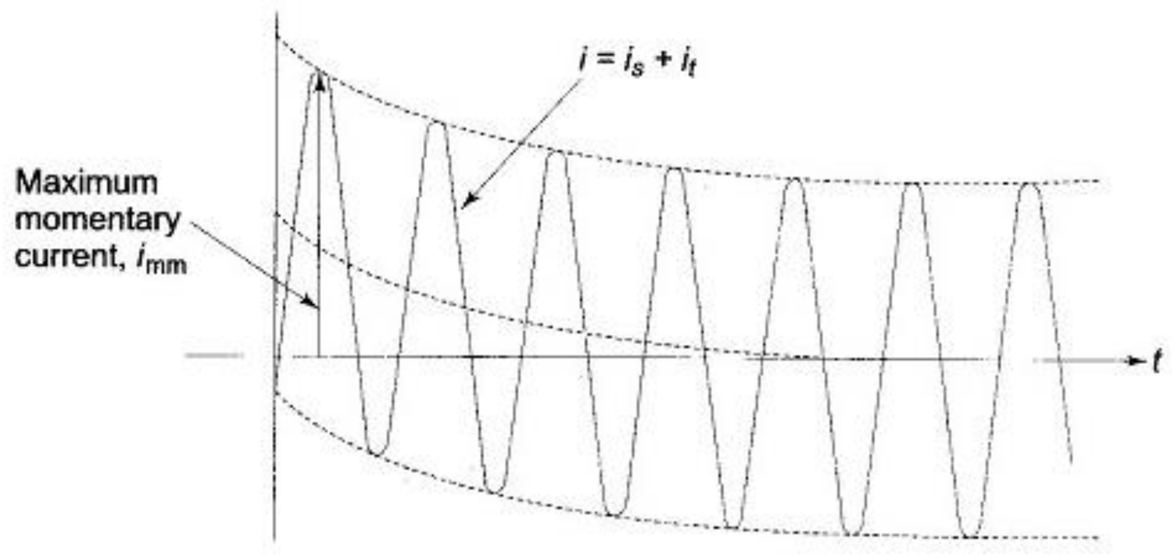


TRANSIENT ON TRANSMISSION LINES

- Mathematically, the total current flowing in the system is does given as

$$i_s = \frac{\sqrt{2}.V}{|Z|} sin(\omega t + \alpha - \theta) + \frac{\sqrt{2}.V}{|Z|} sin(\alpha - \theta).e^{-\frac{R}{L}.t}$$

- Graphically, the transient current is represented as follows



CURRENT LIMITING REACTORS

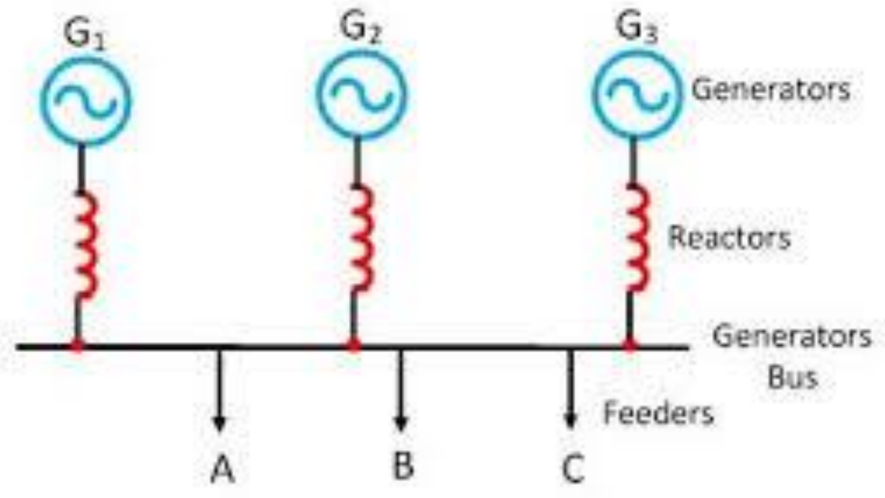
- Fault current are large enough to cause damage to the transmission lines and other equipment.
- To handle this, the interrupting capacity of circuit breaker must be high.
- Fault current can be limited by system reactance which includes impedance of the generator, transformers, transmission line and other equipment.
- Therefore, to have fault current within the safety limits, system reactance is increased by connecting reactor at strategic points called **current limiting reactors**.
- These reactors are coils used to limit current during fault conditions and have large value of inductive reactance & low ohmic resistance.
- For these reactors, it is important that magnetic saturation at high current does not reduce the coil reactance and therefore air cored type reactors are used which do not have magnetic saturation, their reactance are independent of current.

CONSTRUCTION OF CURRENT LIMITING REACTORS

- Air core reactors are of two types
  - **Dry type air cored reactors**
    - The winding od a dry type reactor are embedded on supports made of non ferro magnetic material generally concrete and are insulated from ground using porcelain structure.
    - They are generally cooled by natural ventilation and sometimes by forced air circulation.
    - They occupy relatively large space & used up to 33 KV.
  - **Oil immersed air cored reactors**
    - Used for voltage above 33 KV and are similar to power transformer.
    - Placed in oil tanks which serve as insulator & cooling
    - Have higher safety against flashover and have high thermal capacity.
    - Can be used indoor & out door because of small size.

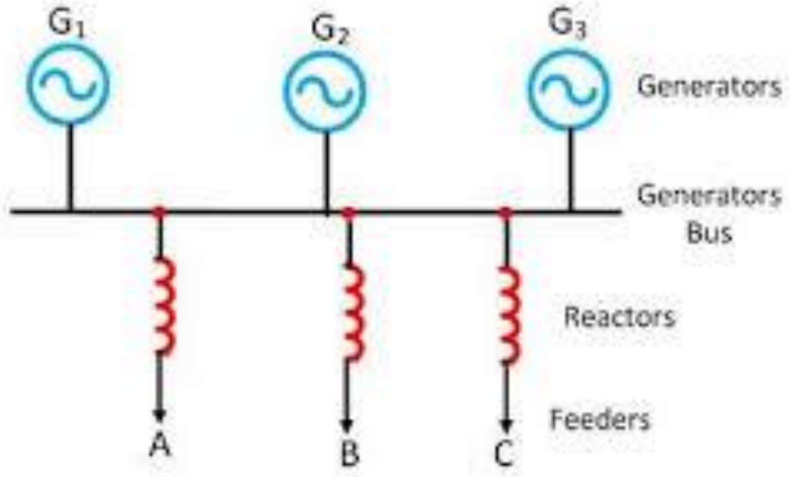
LOCATION FOR CURRENT LIMITING REACTORS

- **Generator reactors**
  - If reactors are connected with the generators in series, they are known as generator reactors.
  - Generator reactors are mainly used with old generators which have low reactance,
  - Modern generator are designed to have sufficient large reactance to protect them even in dead short circuit at their terminals.
  - Generator reactor suffer from following drawbacks
    - Current flowing in the reactor produces constant voltage drop and power loss.
    - If bus bar or feeder fault occurs close to the bus bar, the voltage at the busbar drops to a low value which may result that generator may loose synchronism



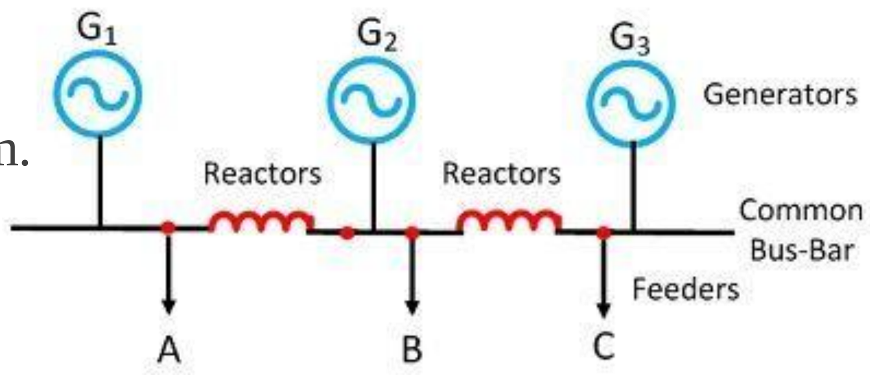
LOCATION FOR CURRENT LIMITING REACTORS

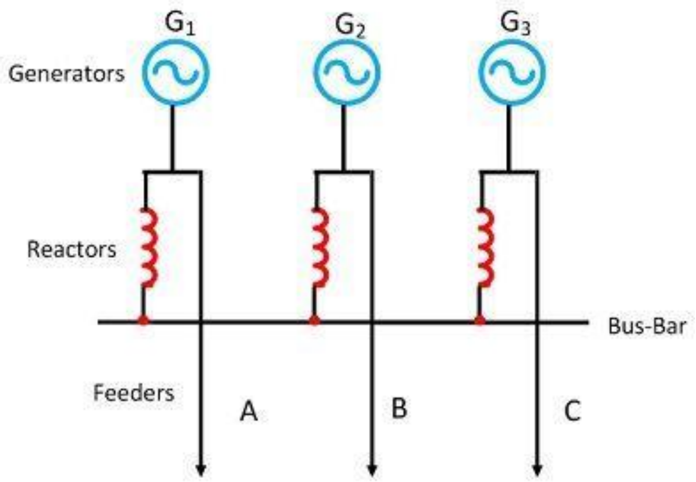
- **Feeder reactors –**
  - When the reactor are connected in series with each feeder, they are known as feeder reactor.
  - The advantage of feeder reactor are
    - The fault on a feeder will not affect other feeders and reduces the chance of generator to lose synchronism.
  - The feeder reactor having following limitations
    - There are voltage drop and power loss in each feeder.
    - If a fault occurs on busbar, no protection for generator.
    - If the number of generators is increased, the size of feeder should also be increased.



LOCATION FOR CURRENT LIMITING REACTORS

- **Bus bar Reactors**
  - Commonly used method where generator station busbar are sectionized and reactor are connected in each section.
  - In normal operation, each generator supplies feeder connected to its sections and no current flow in the reactor
  - If a fault occurs on a feeder only the busbar section to which it is connected is affected.
  - For this two method of reactor connection are used.
    - Ring system
    - Tie bus or tie bar system.





NUMERICAL PROGRAM – 1

- **Program Statement –** *A three phase transmission line operating at 33 KV and having a resistance and reactance of 5 ohms and 20 ohms respectively is connected to a generating station busbar through a 15 MVA step-up transformer which has a reactance of 0.06 pu. Connected to the busbar are two generator, one 10 MVA having 0.10 pu reactance and another 5 MVA having 0.075 pu reactance. Draw the single line diagram and calculate the short circuit MVA and the fault current when a three phase short circuit occurs*
  - *at the high voltage terminal of the transformer.*
  - *at the load end of the transmission line. (Assume the base MVA as 15 MVA & base KV as 33 KV)*

- **Solution –** 6.67 pu; 1750.34 Amps; 0.431 pu; 608.8 Amps.

NUMERICAL PROGRAM – 2

- **Problem statement –** *Three 11 KV solidly grounded generator are connected to three reactors in a tie bus arrangement as shown in figure. The reactance of the generator and reactor are 0.2 pu and 0.1 pu respectively base on 25 MVA base. If there is a symmetrical three phase fault at point F, determine*
  - *Short circuit MVA and*
  - *fault current distribution in the system.*

- **Solution –** SSC – 225 MVA; Total fault current – 11809 Amps; Current (G1) = 6561 Amps; Current (G2) – 2624 Amps; Current (G3) – 2624 Amps.

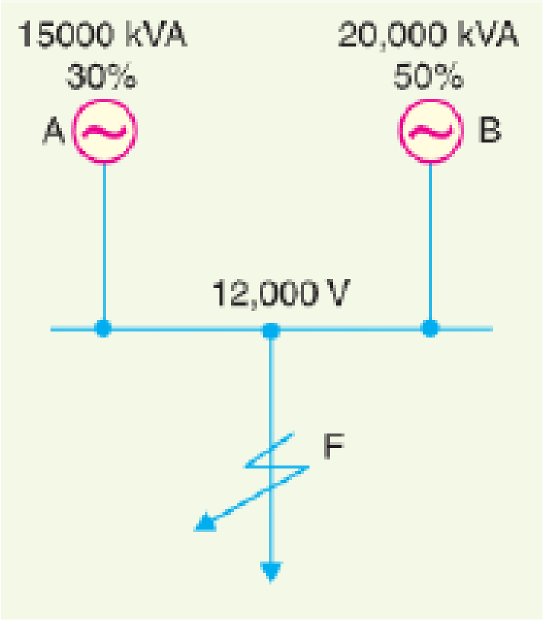
NUMERICAL PROGRAM – 3

- **Problem statement –** *Three 20 MVA generator each with 0.15 pu reactance are connected through three reactors to a common busbar. Each feeder connected to the generator sides of a reactor has 200 MVA circuit breaker. Determine the minimum value of reactor reactance if bus bar voltage is 11 KV. Find also the reactor reactance if the three reactor are connected ring arrangement.*

- **Solution –** X = 0.15 pu or 0.9075 ohms (tie line arrangement); X = 0.45 pu or 2.722 ohms (ring system arrangement)

NUMERICAL PROGRAM – 4

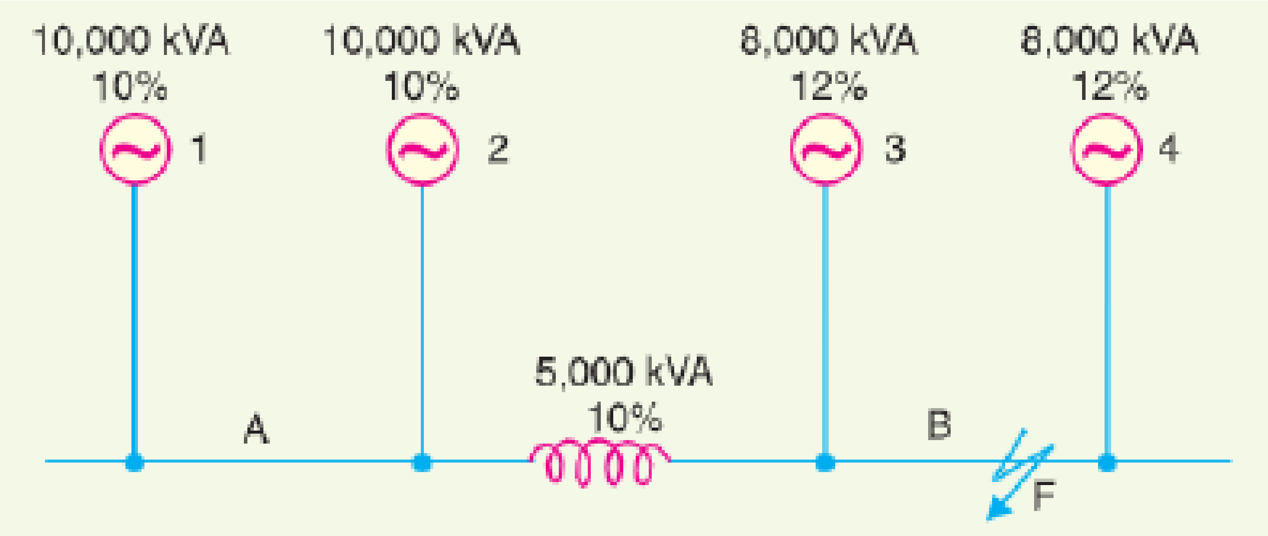
- **Problem Statement –** *Figure shown below represents a single line diagram of a 3 – phase system. The percentage reactance of each alternator is based on its own capacity. Find the short circuit current that will flow for a 3 – phase short circuit at point F. (Assume the base KVA as 15000 KVA)*



- **Solution –** 4330 Amps

NUMERICAL PROGRAM – 5

- **Problem Statement –** *The section bus bars A and B are linked by a bus bar reactor rated at 5000 KVA with 10 % reactance. On bus bar A, there are two generators each of 10000 KVA with 10 % reactance and on B two generators each of 8000 KVA with 12 % reactance. Find the steady MVA fed into a dead short circuit between all phases on B with Bus bar reactor in the circuit.*



- **Solution –** 173.31 MVA

NUMERICAL PROGRAM – 6

- **Problem Statement –** *A 3 Phase alternator can supply a maximum load of 5000 kVA at 6600 V. The machine has internal reactance of 6 %. Find the reactance per phase of the limiting reactor if the apparent power (kVA) on short circuit is not to be exceed 5 times of full load value.*

- **Solution** – 14 % or 1.22 ohms

NUMERICAL PROGRAM – 7

- **Problem Statement –** *A small generating station has two alternators of 3000 kVA and 4500 kVA and percentage reactance of 7 % and 8 % respectively. The circuit breaker have a rupturing capacity of 150 MVA, It is desired to extend the system by a supply form the grid via a transformer of 7500 kVA and 7.5 % reactance. Find the reactance of the reactor connected in the bus bar section to prevent the circuit breaker being overloaded, if a symmetrical short circuit occurs on an outgoing feeder connected to it. Assume the bus voltage = 3300 V.*

- **Solution –** 0.150 ohms

NUMERICAL PROGRAM – 8

- **Problem Statement –** *A 10 MVA, 6.6 kV, 3 phase star connected alternator having a reactance of 20 % is connected through a 5 MVA, 6.6/33kV transformer of 10 % reactance to a transmission line having a resistance and reactance per conductor per kilometer of 0.2 ohms and 1 ohm respectively. Fifty kilometer along the line, a short circuit occurs between the three conductor. Fing the current fed to the fault by the alternator.*

- **Solution –** 1012 Amps