5- Fault

5-1 Introduction

A fault is any abnormal condition in a power system. The steady state operating mode of a power system is balanced 3-phase a.c. .However, due to sudden external or internal changes in the system, this condition is disrupted. When the insulation of the system fails at one or more points or a conducting object comes into contact with a live point, a short circuit or a fault occurs.

Causes of Power System Faults

The causes of faults are numerous, e.g.

· Lightning
· Heavy winds
· Trees falling across lines
· Vehicles colliding with towers or poles
· Birds shorting lines
· Aircraft colliding with lines
· Vandalism
· Small animals entering switchgear
· Line breaks due to excessive loading

5-2 Common Power System Faults

Power system faults may be categorized as one of four types; in order of frequency of occurrence, they are:

· Single line to ground fault
· Line to line fault
· Double line to ground fault
· Balanced three phase faults.

The first three types constitute severe unbalanced operating conditions which involves only one or two phases hence referred to as unsymmetrical faults. In the fourth type, a fault involving all the three phases occurs therefore referred to as symmetrical (balanced) fault.

5-3 Effects Of Power System Faults

Faults may lead to fire breakout that consequently results into loss of property, loss of life and destruction of a power system network. Faults also leads to cut of supply in areas beyond the fault point in a transmission and distribution network leading to power blackouts; this interferes with industrial and commercial activities that supports economic growth, stalls learning activities in institutions, work in offices, domestic applications and creates insecurity at night. All the above results into retarded development due to low gross domestic product realised. It is important therefore to determine the values of system voltages and currents during faulted conditions, so that protective devices may be set to detect and minimize the harmful effects of such contingencies.

5-4 Balanced Fault

Short circuit occur in power systems when equipment insulation fails, due to system over voltages caused by lightning or switching surges, to insulation contamination, or to other mechanical causes.

Fault studies form an important part of power system analysis. The problem consists of determining bus voltages and line currents during various type of faults. Faults in power systems are divided into *three-phase balanced* faults and *unbalanced faults*. The information gained from fault studies are used for proper relay setting and coordination, and used to obtain the rating of the protective switchgears.

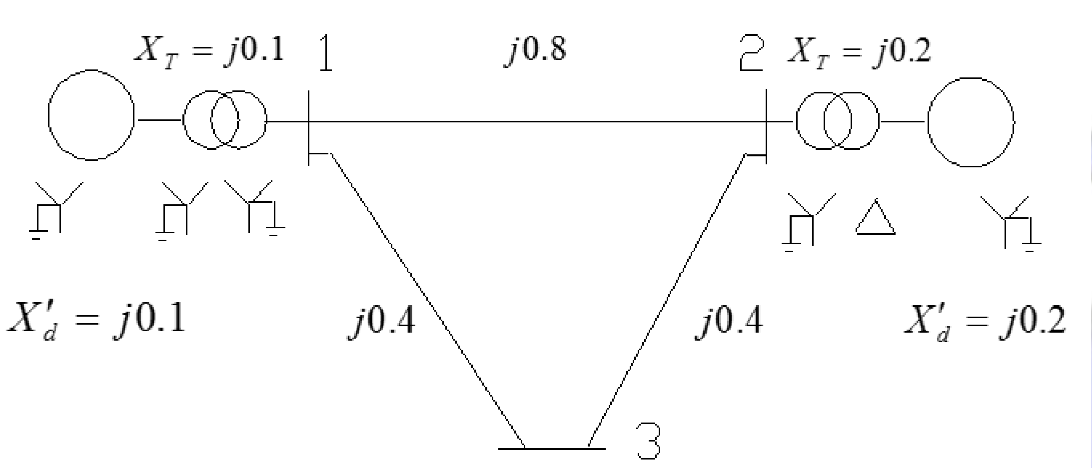
The fault current is determined by the internal voltages of the synchronous machines and by the impedances between the machine voltages and the fault. It may be several orders of magnitude larger than normal operation currents and, if allowed to persist, may cause thermal damage to equipments. Winding and busbars may also suffer mechanical damage due to high magnetic forces during faults. It is therefore necessary to remove faulted sections of a power system from service as soon as possible (for EHV, the fault is clear with in 3 cycles (50ms at 60Hz), and for lower voltage more slowly, with in 5 to 20 cycles.

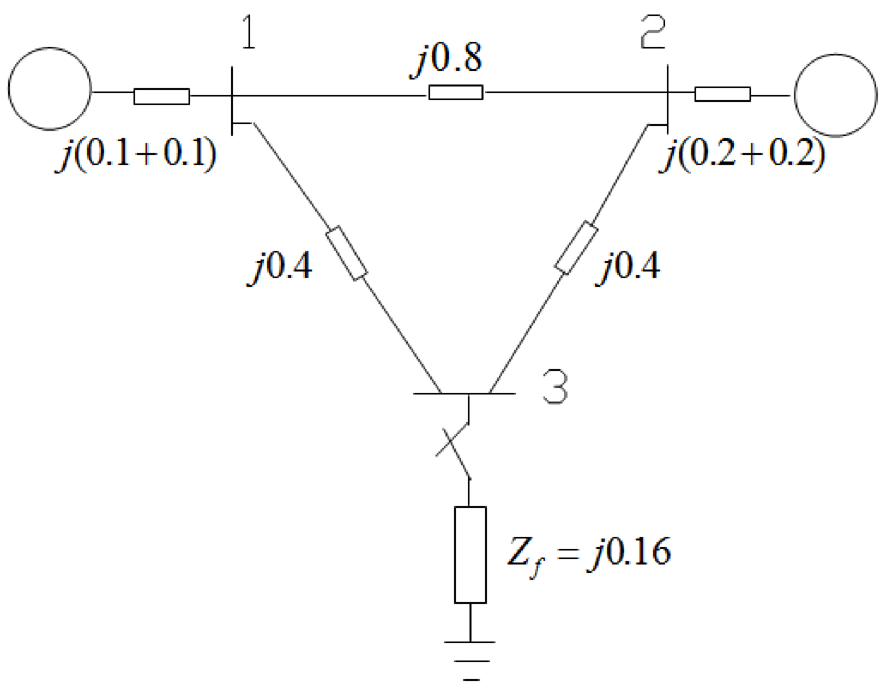
The magnitude of the fault currents depends on the internal impedance of the generators plus the impedance of the intervening circuit.

In course of power system stability, it was shown that the reactance of a generator under short circuit condition is not constant (is a time-varying quantity) and for network analysis three reactances were defined. The sub transient reactance X''_d, for the first few cycles of the short circuit current, transient reactance X'_d, for the next (say) 30 cycles, and the synchronous reactance X_d, thereafter. Since the duration of the short circuit depends on the time of operation of the protective system, it is not always easy to decide which reactance to use. Generally, the sub transient reactance is used for determining the interrupting capacity of the circuit breakers. Transient reactance is used for relay setting and coordination, and for transient stability studies.

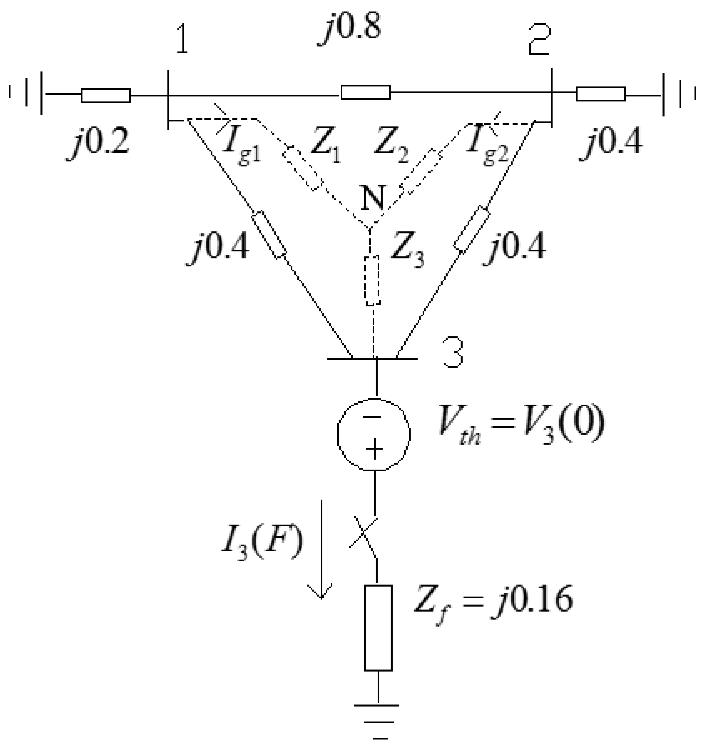
If the fault impedance is zero, the fault is referred to as the *bolted fault* or the *solid fault*. The faulted network can be solved by the Thevenin's method. The procedure is demonstrated in the following example.

In the power system shown in fig. All impedance in per unit on a common 100MVA, the resistances and shunt capacitances are neglected. The system is considered on no-load and the generators are running at their rated voltage and frequency with their emfs in phase. Find the fault current, the bus voltages, and the line currents during the fault when a balanced three-phase fault with a fault impedance $Z_f = 0.16$ per unit, occurs on bus 3.

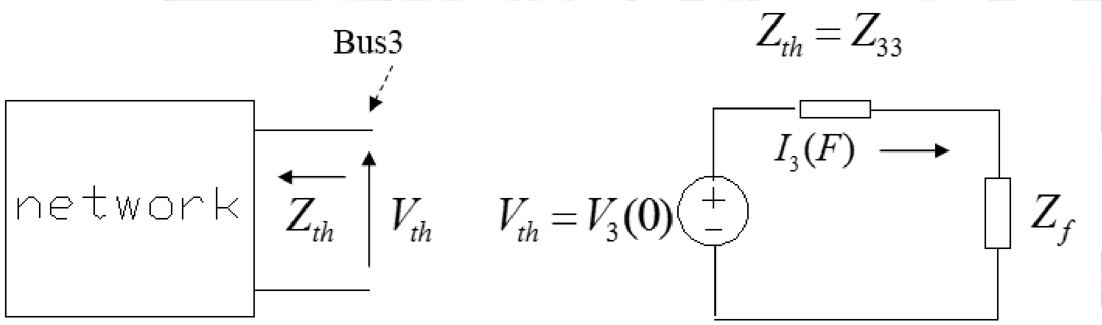




The impedance network for fault at bus 3



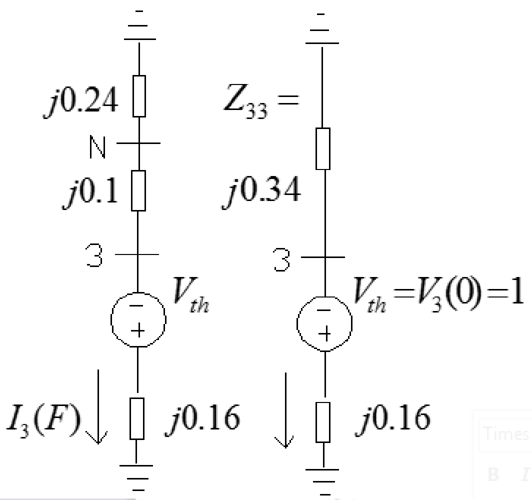
Thevenin's equivalent network



$V_{th} = V_3(0) =$ pre fault bus voltage (obtain from the results of the power flow solution)

$$Z_{th} = Z_{33}$$

$$I_3(F) = \frac{V_3(0)}{Z_{33} + Z_f}$$



$$Z_\Delta \rightarrow Z_Y$$

$$Z_1 = Z_2 = \frac{(j0.4)(j0.8)}{j0.16} = j0.2$$

$$Z_3 = \frac{(j0.4)(j0.4)}{j0.16} = j0.1$$

$$Z_{33} = \left[(Z_1 + j0.2)//(Z_2 + j0.4)\right] + Z_3$$

$$= \frac{(j0.4)(j0.6)}{j0.4 + j0.6} + j0.1 = j0.24 + j0.1 = j0.34$$

The load are neglected, and the generators emfs are assumed equal to the rated value, therefore all the pre-fault bus voltages are equal to 1.0 pu, i.e.: $V_1(0) = V_2(0) = V_3(0) = 1.0 \quad pu$

$$\therefore \quad I_3(F) = \frac{V_3(F)}{Z_{33} + Z_f} = \frac{1.0}{j0.34 + j0.16} = -j2.0 \quad pu$$

$$I_{g1} = \frac{j0.6}{j0.4 + j0.6} I_3(F) = -j1.2 \quad pu$$

$$I_{g2} = \frac{j0.4}{j0.4 + j0.6} I_3(F) = -j0.8 \quad pu$$

For the bus voltage changes:

$$\Delta V_1 = 0 - (I_{g1} \times j0.2) = 0 - (-j1.2)(j0.2) = -0.24 \quad pu$$

$$\Delta V_2 = 0 - (I_{g2} \times j0.4) = 0 - (-j0.8)(j0.4) = -0.32 \quad pu$$

$$\Delta V_3 = I_3(F) \times Z_f - V_3(0) = (-j2)(j0.16) - 1.0 = -0.68 \quad pu$$

The bus voltages during the fault are obtained by superposition of the pre-fault bus voltages and the changes in the bus voltages caused by the equivalent emf connected to the faulted bus $V_3(F)$.

$$V_1(F) = V_1(0) + \Delta V_1 = 1 - 0.24 = 0.76 \ \ pu$$

$$V_2(F) = V_2(0) + \Delta V_2 = 1 - 0.32 = 0.68 \ \ pu$$

$$V_3(F) = V_3(0) + \Delta V_3 = 1 - 0.68 = 0.32 \ \ pu$$

The short circuit-currents in the lines are:

$$I_{12}(F) = \frac{V_1(F) - V_2(F)}{Z_{12}} = \frac{0.76 - 0.68}{j0.8} = -j0.1 \ \ pu$$

$$I_{13}(F) = \frac{V_1(F) - V_3(F)}{Z_{13}} = \frac{0.76 - 0.32}{j0.4} = -j1.1 \ \ pu$$

$$I_{23}(F) = \frac{V_2(F) - V_3(F)}{Z_{23}} = \frac{0.68 - 0.32}{j0.4} = -j0.9 \ \ pu$$

The procedure is summarized in the following steps:

1. The pre-fault bus voltages are obtained from the results of the power flow solution.
2. In order to preserve the linearity feature of the network, loads are converted to constant admittances using the pre-fault bus voltages.
3. The faulted network is reduced into a Thevenin's equivalent circuit as viewed from the faulted bus. Applying Thevenin's theorem, changes in the bus voltages are obtained.
4. Bus voltages during the fault are obtained by superposition of the pre-fault bus voltages and the changes in the bus voltages computed in the previous step.
5. The current during the fault in all branches of the network are then obtained.