JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE	Jaipur Engineering college and research centre, Shri Ram ki Nangal, via Sitapura RIICO Jaipur- 302 022.	**Academic year- 2020-21**

DEPARTMENT OF ELECTRICAL ENGINEERING

Syllabus
Power System Protection

III Year - VI Semester: B. Tech. (Electrical Engineering)

1. Introduction: Objective, scope and outcome of the course.

2. Introduction and Components of a Protection System: Principles of Power System Protection, Relays, Instrument transformers, Circuit Breakers.

3. Faults and Over-Current Protection: Review of Fault Analysis, Sequence Networks. Introduction to over current Protection and over current relay co-ordination.

4. Equipment Protection Schemes: Directional, Distance, Differential protection. Transformer and Generator protection. Bus bar Protection, Bus Bar arrangement schemes.

5. Digital Protection: Computer-aided protection, Fourier analysis and estimation of Phasors from DFT. Sampling, aliasing issues.

6. Modeling and Simulation of Protection Schemes: CT/PT modeling and standards, Simulation of transients using Electro-Magnetic Transients (EMT) programs. Relay Testing.

7. System Protection: Effect of Power Swings on Distance Relaying. System Protection Schemes. Under-frequency, under-voltage and df/dt relays, Out-of- step protection, Synchro-phasors, Phasor Measurement Units and Wide-Area Measurement Systems (WAMS). Application of WAMS for improving protection systems.

POWER SYSTEM PROTECTION

UNIT- III

Fault and Over Current Protection

Faults in Power System

The fault in the power system is defined as the defect in the power system due to which the current is distracted from the intended path. The fault creates the abnormal condition which reduces the insulation strength between the conductors. The reduction in insulation causes excessive damage to the system. The fault in the power system is mainly categorized into two types they are

1. Open Circuit Fault
2. Short Circuit Fault.

The different types of power system fault are shown below.

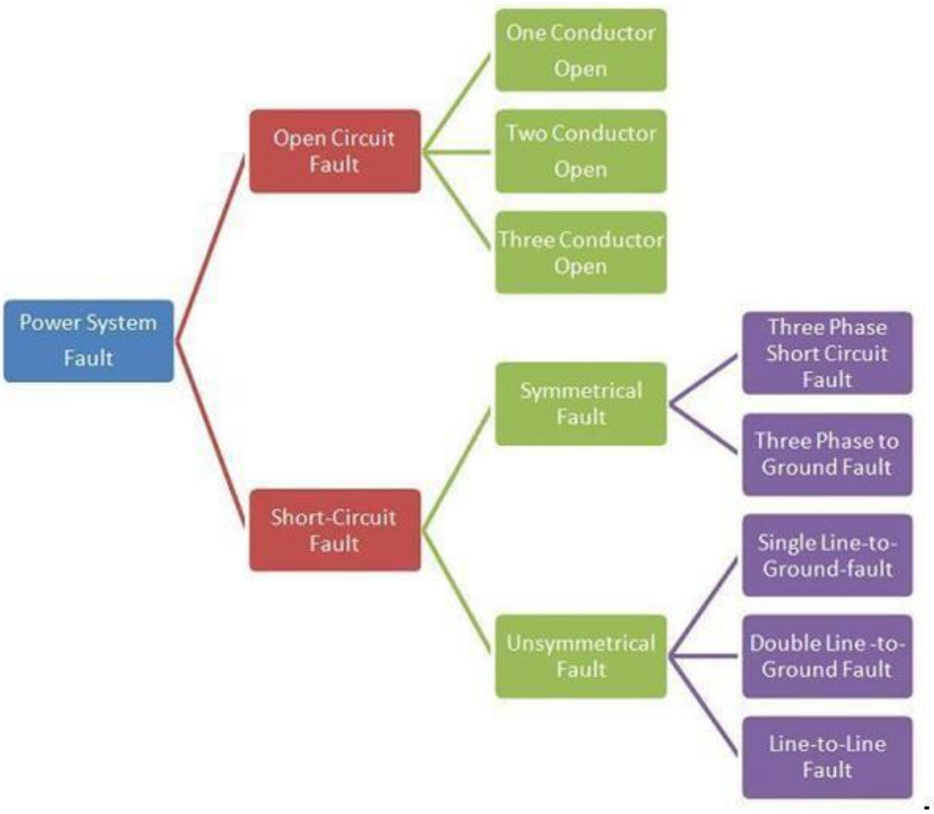


Fig.1: Types of power system fault

The faults in the power system may occur because of the number of natural disturbances like lightning, high-speed winds, earthquake, etc. It may also occur because of some accidents like falling off a tree, vehicle colliding, with supporting structure, aero plane crashing, etc.

1. Open Circuit Fault

The open circuit fault mainly occurs because of the failure of one or two conductors. The open circuit fault takes place in series with the line, and because of this, it is also called the series fault. Such types of faults affect the reliability of the system. The open circuit fault is categorized as

- Open Conductor Fault
- Two conductors Open Fault
- Three conductors Open Fault.

The open circuit fault is shown in the figure below.

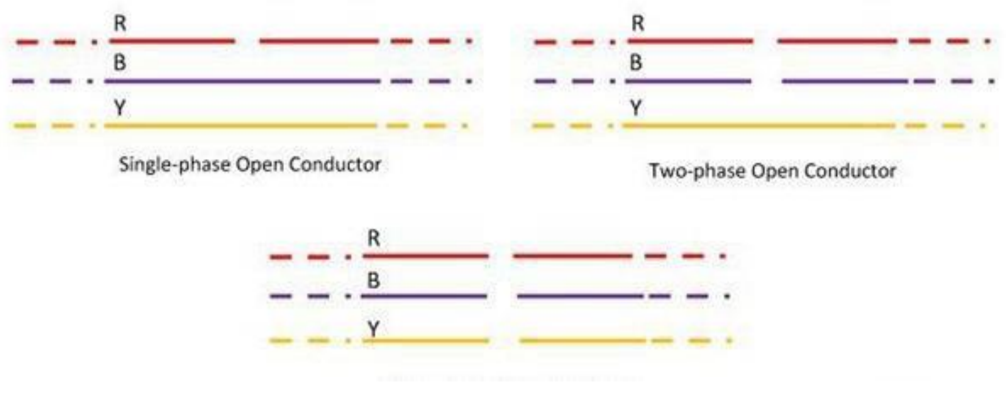


Fig.2: Open circuit faults.

2. Short-Circuit Fault

In this type of fault, the conductors of the different phases come into contact with each other with a power line, power transformer or any other circuit element due to which the large current flow in one or two phases of the system. The short-circuit fault is divided into the symmetrical and unsymmetrical fault.

Symmetrical Fault

The faults which involve all the three phases is known as the symmetrical fault. Such types of fault remain balanced even after the fault. The symmetrical faults mainly occur at the terminal of the generators. The fault on the system may arise on account of the resistance of the arc between the conductors or due to the lower footing resistance. The symmetrical fault is sub-categorized into line-to-line-to-line fault and three-phase line-to-ground-fault

a. Line – Line – Line Fault – Such types of faults are balanced, i.e., the system remains symmetrical even after the fault. The L – L – L fault occurs rarely, but it is the most severe type of fault which involves the largest current. This large current is used for determining the rating of the circuit breaker.

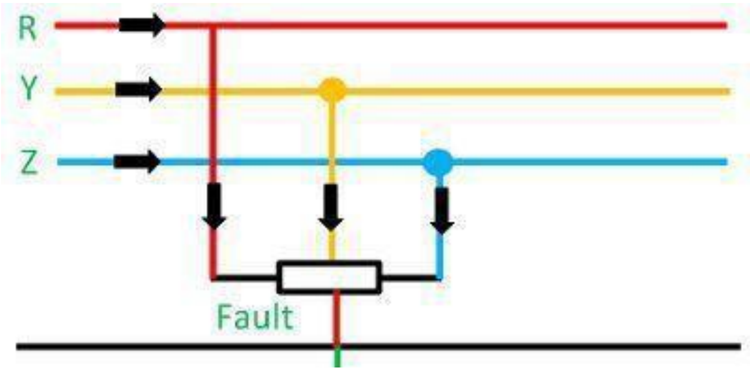


Fig.3: Line – Line – Line Fault

b. L – L – L – G (Three-phase line to the ground fault) – The three-phase line to ground fault includes all the three phase of the system. The L – L – L – G fault occurs between the three phases and the ground of the system. The probability of occurrence of such type of fault is nearly 2 to 3 percent.

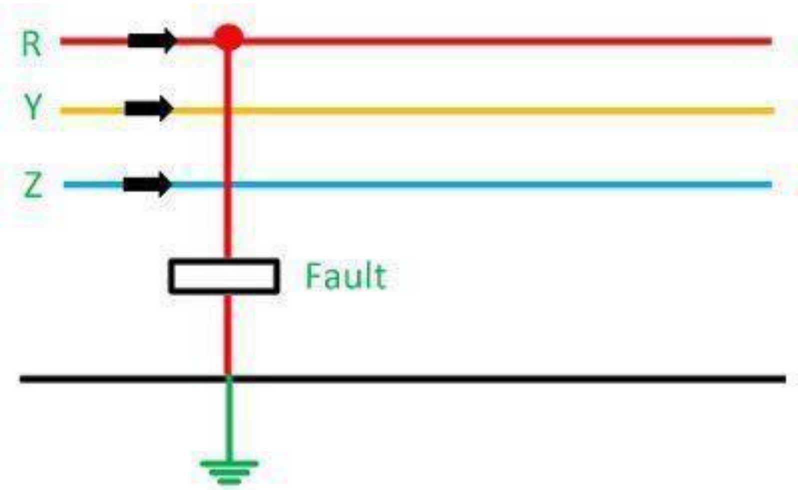


Fig.4: Line – Line – Line –Ground Fault

Unsymmetrical Fault

The fault gives rise to unsymmetrical current, i.e., current differing in magnitude and phases in the three phases of the power system are known as the unsymmetrical fault. It is also defined as the fault which involves the one or two phases such as L- G, L – L, L – L – G fault. The unsymmetrical makes the system unbalanced. It is mainly classified into three types. They are

1. Single Line-to-ground (L – G) Fault
2. Line-to-Line Fault (L – L)
3. Double Line-to-ground (L – L – G) Fault

The unsymmetrical fault is the most common types of fault occur in the power system.

1. Single Line-to-Line Ground – The single line of ground fault occurs when one conductor falls to the ground or contact the neutral conductor. The 70 – 80 percent of the fault in the power system is the single line-to-ground fault.

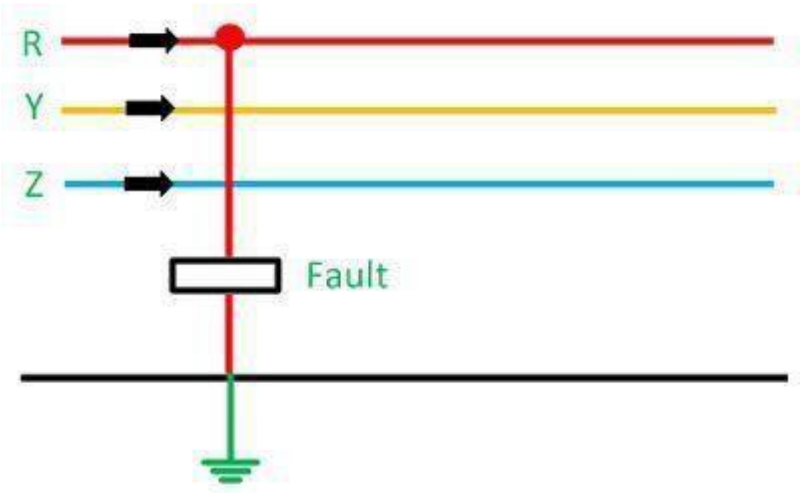


Fig.5: Single line to ground fault.

2. Line – to – Line Fault – A line-to-line fault occurs when two conductors are short circuited. The major cause of this type of fault is the heavy wind. The heavy wind swinging the line conductors which may touch together and hence cause short-circuit. The percentage of such type of faults is approximately 15 – 20%.

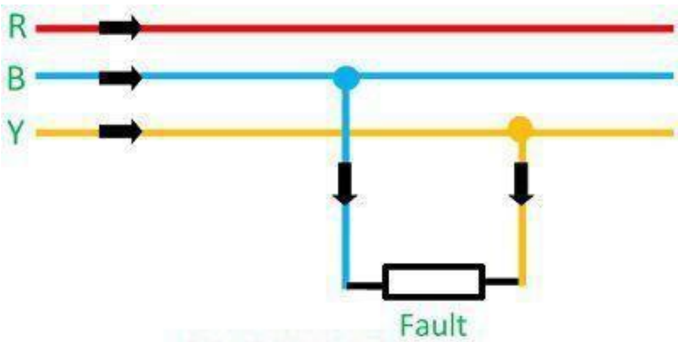


Fig.6: Line to line fault.

3. Double Line – to – line Ground Fault – In double line-to-ground fault, the two lines come in contact with each other along with the ground. The probability of such types of faults is nearly 10 %.

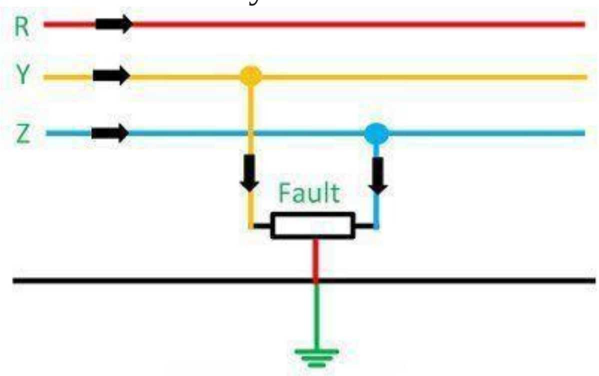


Fig.7: Double line to ground fault.

The symmetrical and unsymmetrical fault mainly occurs in the terminal of the generator, and the open circuit and short circuit fault occur on the transmission line.

Symmetrical Fault Analysis

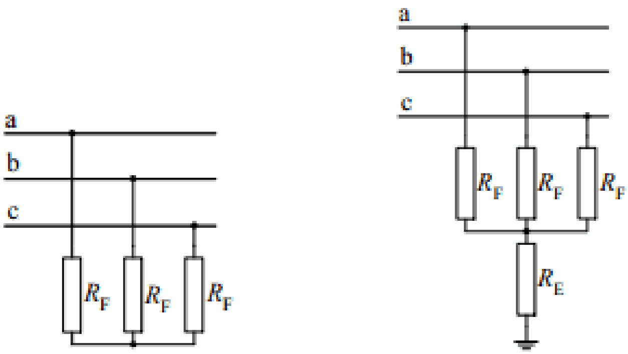


Fig.8: Symmetrical fault.

Three Phase Fault

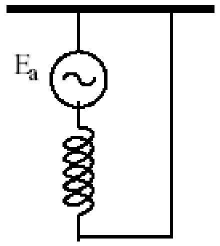
Symmetrical short circuit on Synchronous Machine The selection of a circuit breaker for a power system depends not only upon the current the breaker is to carry under normal operating conditions but also upon the maximum current it may have to carry momentarily and the current it may have to interrupt at the voltage of the line in which it is placed.

In order to approach the problem of calculating the initial current, we need to study the behavior of a synchronous generator when it is short-circuited.When an ac voltage is applied suddenly across a series R-L circuit, the current which flows has two components

1. a steady state sinusoidal varying component of constant amplitude and

2. A non-periodic and exponentially decaying with a time constant of L/R. (**which is also referred as the dc component current**).The initial value of the dc component of current depends on the magnitude of the ac voltage when the circuit is closed.

In such types of faults, all the three phases are short-circuited to each other and often to earth also. Such faults are balanced and symmetrical in the sense that the system remains balanced even after the fault.



Three Phase Fault.

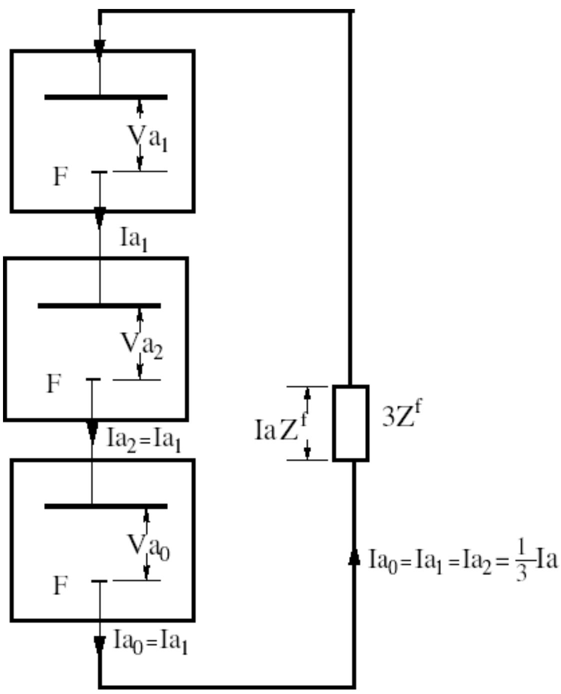


Fig.9: Three Phase Fault.

Three Phase Fault :- For a Three Phase fault only Positive Sequence Network is considered. The fault currents are given by the following equations.

- $I_1 = \frac{V}{Z_1}$ $(solid\ Fault)$
- $I_1 = \frac{V}{Z_1+Z_f}$ $(Fault\ Through\ impendenceZ_f)$

Un-Symmetrical Fault Analysis

Single Line to Ground Fault

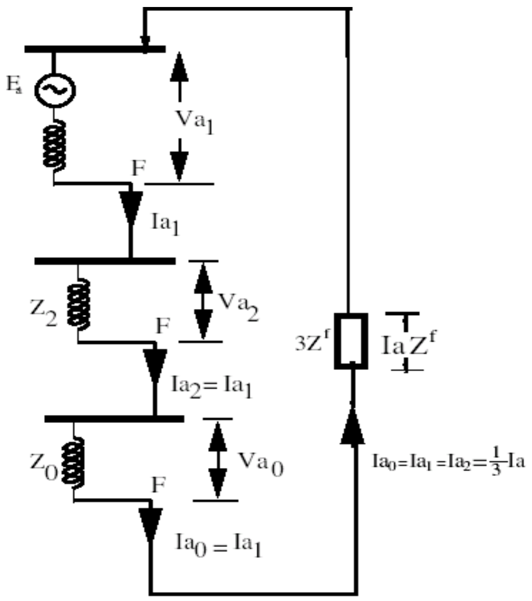


Fig.10: Single Line to Ground Fault.

Single Line To Ground Fault(SLG) :- The Positive Sequence, negetive Sequence and Zero Sequence Fault currents are given by

- $I_1 = I_2 = I_0 = \frac{V}{Z_1+Z_2+Z_0}$ $\quad (Solid\ \ Fault)$
- $I_1 = I_2 = I_0 = \frac{V}{Z_1+Z_2+Z_0+3Z_f}$ $\quad (Fault\ \ Through\ \ impendence\ \ Z_f)$
- $I_{aF} = I_1 + I_2 + I_0 = 3I_1 = 3I_2 = 3I_0$

Double line fault

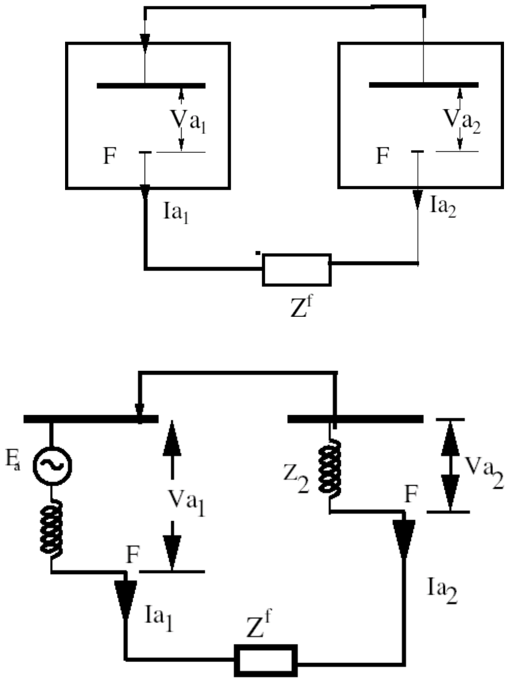


Fig.11: Line to Line Fault.

LL fault :- The Zero Sequence Data is not required for this fault.

- $I_1 = -I_2 = \frac{V}{Z_1+Z_2}$ $\quad (solid\ \ Fault)$
- $I_1 = -I_2 = \frac{V}{Z_1+Z_2+Z_f}$ $\quad (Fault\ \ Through\ \ impendenceZ_f)$

Line to Line Ground Fault (LLG) :-

1. solid Fault :-
   - $I_1 = \frac{V}{Z_1 + \frac{z_2 Z_0}{Z_2 + Z_0}}$
   - $I_2 = -I_1 \frac{Z_0}{Z_2 + Z_0}$
   - $I_0 = -I_1 \frac{Z_2}{Z_2 + Z_0}$

2. Fault Through impendence Z_F
   - $I_1 = \frac{V}{Z_1 + \frac{Z_F}{2} + \frac{(Z_2 + \frac{Z_F}{2})(Z_2 + \frac{Z_F}{2} + 3Z_{FG})}{Z_2 + Z_0 + Z_F + 3Z_{FG}}}$
   - $I_2 = -I_1 \frac{(Z_2 + \frac{Z_F}{2} + 3Z_{FG})}{Z_2 + Z_0 + Z_F + 3Z_{FG}}$
   - $I_0 = -I_1 \frac{(Z_2 + \frac{Z_F}{2})}{Z_2 + Z_0 + Z_F + 3Z_{FG}}$

$Z_f$is Fault impedence between the lines,
While $Z_{FG}$is the Fault impendence to Ground.

Symmetrical Component & Symmetrical Fault Analysis:

Symmetrical Components

A three-phase system is said to be symmetrical when the system viewed from any phase is similar. Thus, in a three-phase symmetrical system the self-impedance of all the three phases are equal and the mutual impedances, if any between the three phases are the same any three phase system having unbalanced phasor quantities can be represented in terms of three phase balanced phasor components as a combination of positive, negative and zero sequence component, which are as follows

$$V_a = V_{a_0} + V_{a_1} + V_{a_2}$$
$$V_b = V_{b_0} + V_{b_1} + V_{b_2}$$
$$V_c = V_{c_0} + V_{c_1} + V_{c_2}$$

Sequence Network Analysis

The analysis matrix helps to decompose the phase quantities into symmetrical components or sequence components.

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \text{......Analysis Matrix}$$

And after we are through with calculation of the fault currents and voltages in terms of the sequence quantities, the synthesis matrix below will be applied to get back the phase current and voltages.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} \text{.......Synthesis Matrix}$$

Operator ‘a’

a is an operator defined as follows :

$a=1\angle 120^0=-0.5+j0.866$
$a^2=1\angle 240^0=-0.5-j0.866$
$a^3=1\angle 360^0=1+j0$
$1 + a + a^2 = 0$

The multiplication of a vector by the operator ‘a’ rotates the vector in the anticlockwise direction by 120^0, the magnitude of the vector is, however, unaffected since the magnitude of the operator a is 1.

The analysis of the unsymmetrical faults conditions involves the three sequence networks of the given power system, namely, the positive, negative and zero sequence networks.

Positive sequence

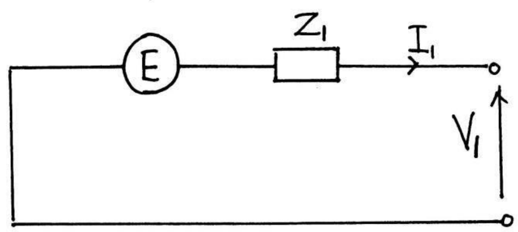


Fig.12: Positive Sequence Network.

Positive sequence network has a driving point emf E

$V_1 = E - I_1Z_1$

Negative sequence Network

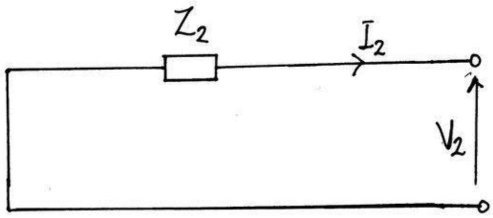


Fig.13: Negative Sequence Network.

Negative sequence network, $V_2 = -I_2Z_2$

Zero sequence Network

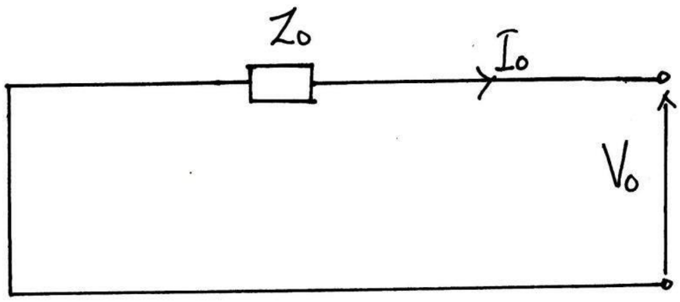


Fig.14: Zero Sequence Network.

Zero sequence network, $V_0 = -I_0Z_0$

E is the pre-fault reference phase voltage at the point of fault and Z1, Z2, and Z0 are the impedances of the positive, negative and zero sequence networks respectively, as measured from the point of fault F.

Like we said earlier, the unsymmetrical faults lead to unbalanced phases, that is different fault current with varying phase angles and if a direct solution is employed, it will prove difficult and rigorous.

The method of symmetrical components substitutes unbalanced phase quantities such as currents and voltages with three separate balanced symmetrical components.

In a three-phase system, the phase sequence is defined as the order in which they pass through a positive maximum. Consider the phasor representation of a three-phase balanced current shown in the figure below.

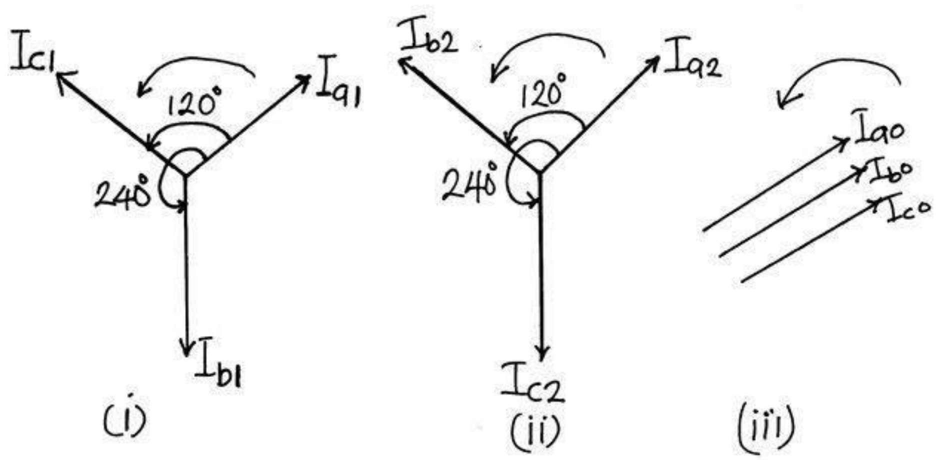


Fig.15: Phase Sequence Network.

Positive Phase Sequence Components

It represents a set of balance phasors $\mathbf{V_{a1}}$, $\mathbf{V_{b1}}$ **&** $\mathbf{V_{c1}}$ these components have three phasors equal in magnitude displaced by 120^o and having same phase sequence as original phasors.

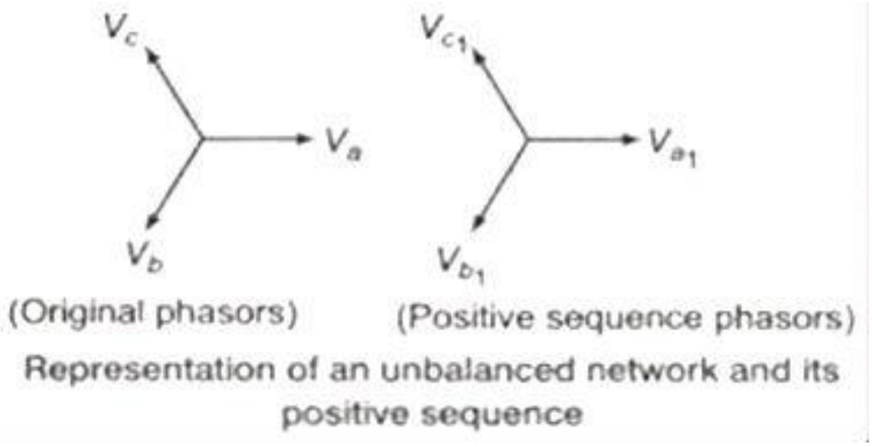


Fig.16: Positive Sequence Network.

Negative Phase Sequence Components

These components have three phasors $\mathbf{V_{a2}}$**,** $\mathbf{V_{b2}}$ **&** $\mathbf{V_{c2}}$ equal in magnitude displaced by 120° but having phase sequence opposite to original phasors. It represents a set of balanced phasors

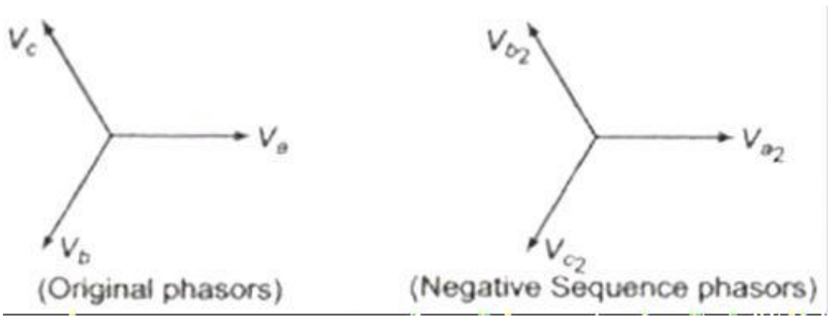


Fig.17: Negative Sequence Network.

Zero Sequence Components

These phasors $\mathbf{V_{ao}}$**,** $\mathbf{V_{bo}}$ **&** $\mathbf{V_{co}}$ are equal in magnitude and having zero phase displacement.

α operator = $e^{+/120^\circ}$

$$= -0.5 + j\,0.866$$

$$\alpha^2 = e^{j240^\circ} = -0.5 - j\,0.866$$

$$\alpha^3 = 1$$

$$\alpha^4 = \alpha$$

$$1 + \alpha + \alpha^2 = 0$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} \text{ or } \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix}$$

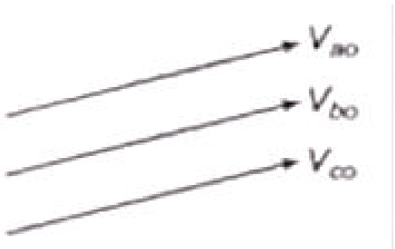


Fig.18: Zero Sequence Network.

$$V_{a_0} = \frac{1}{3}(V_a + V_b + V_c)$$

$$V_{a_1} = \frac{1}{3}(V_a + \alpha V_b + \alpha V_c)$$

$$V_{a_2} = \frac{1}{3}(V_a + \alpha^2 V_b + \alpha V_c)$$

In matrix form

$$\begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \text{ or } \begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Three Phase Power in Terms of Symmetrical Components

$$S_{abc} = 3V_{a_0}I_{a_0}^* + 3V_{a_1}I_{a_1}^* + 3V_{a_2}I_{a_2}^*$$

= sum of symmetrical components power

$$P = 3\left[|V_{a_0}||I_{a_0}| \cos\theta_0 + |V_{a_1}||I_{a_1}| \cos\theta_1 + |V_{a_2}||I_{a_2}| \cos\theta_2 \right]$$

Sequence Impedance

The positive sequence impedance of equipment is the impedance offered by the equipment to the flow of positive sequence current. Similarly, the negative sequence or zero sequence impedance of the equipment is the impedance offered by the equipment to the flow of corresponding sequence current.

Sequence Impedance of a Transmission Line

Positive sequence impedance $Z_1 = Z_s - Z_m$

Negative sequence impedance $Z_2 = Z_s - Z_m$

Zero sequence impedance $Z_0 = Z_s - 2Z_m + 3Z_n$

where, Z_s = Self-impedance per phase

Z_m = Mutual impedances between phases

Sequence Impedance of Synchronous Machine

1. **Positive Sequence, Impedance Z_1** Depending on the time interval of interest one of the three reactances may be used.
   For the subtransient interval, we use subtransient reactance
   $Z_1 = jX_d$
   For the transient interval, we use the transient reactance
   $Z_1 = j X_d'$
   If the steady state value is of interest we have $Z_1 = j X_d$
2. **Negative Sequence Impedance**

$$Z_1 = j \frac{X_d'' + X_q''}{2}$$

3. **Zero Sequence Impedance** (Z_0) Zero sequence current are all in phase and therefore, do not reproduce any rotating field. The zero sequence impedance Z_0 depends upon the type of grounding and the zero sequence impedance per phase of the generator.

Sequence Networks Equations

Sequence Network of Unloaded Alternator

1. **Positive Sequence Network**

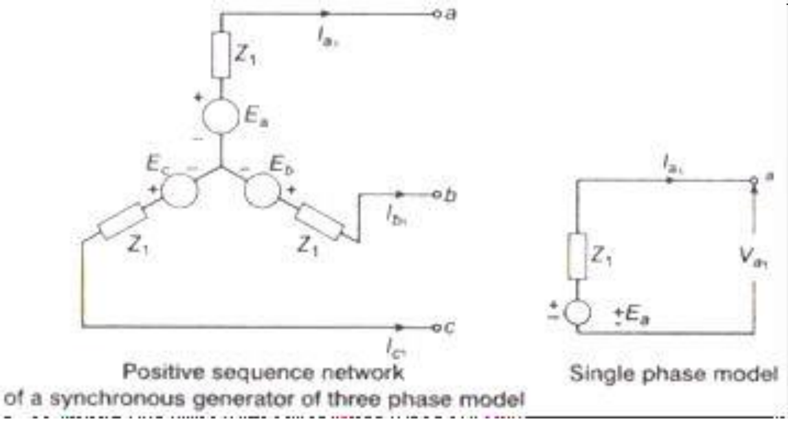
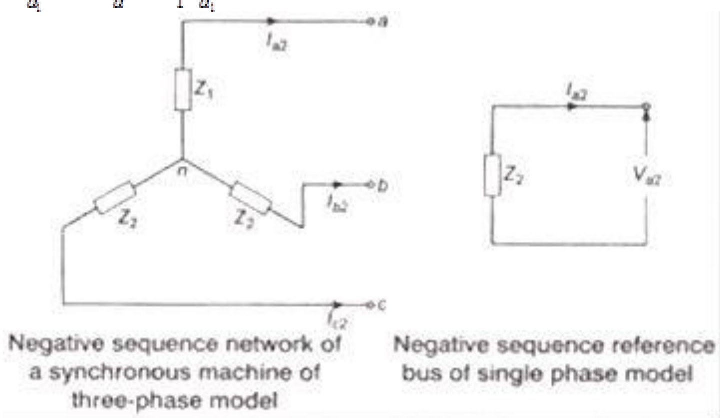


Fig.19: Positive Sequence Network.

2. Negative Sequence Network

$$V_{a_1} = E_a - Z_1 I_{a_1}$$



$$V_{a_2} = -Z_2 I_{a_2}$$

Fig.20: Negative Sequence Network.

3. Zero Sequence Network

$$I_n = I_{a_0} + I_{b_0} + I_{c_0} = 3I_{a_0}$$

$$Z_0 = 3Z_n + Z_{0g}$$

$$V_{a_0} = -Z_0 I_{a_0}$$

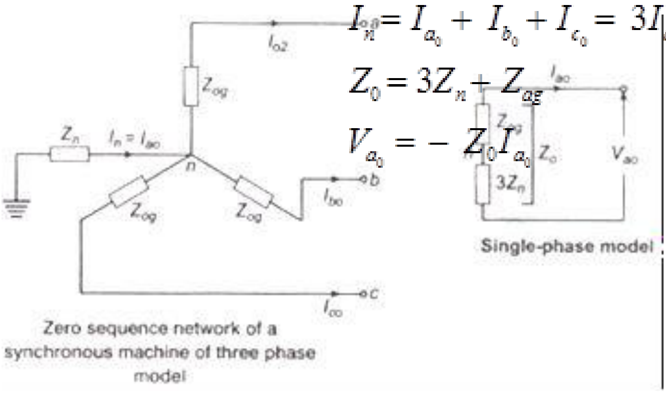


Fig.21: Zero Sequence Network.

Sequence Impedance of Transformers

- Switch *A* is closed when primary winding is star connected with neutral grounded.
- Switch *C* is closed when primary winding is delta connected.
- Switch *B* is closed when secondary winding is star connected with neutral grounded.
- Switch *D* is closed when secondary winding is delta (Δ) connected.

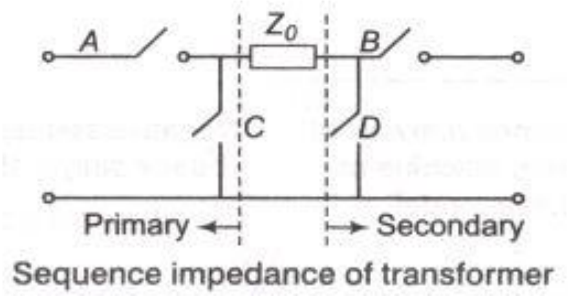


Fig.22: Sequence Impedance of Transformer.

- Keep both *A* and *C* open if when primary winding is star connected with natural isolated (not grounded).
- Keep both *B* and *D* open if when secondary winding is star connected with natural isolated.

where Z_0 = Zero sequence impedance of transformer.

Examples

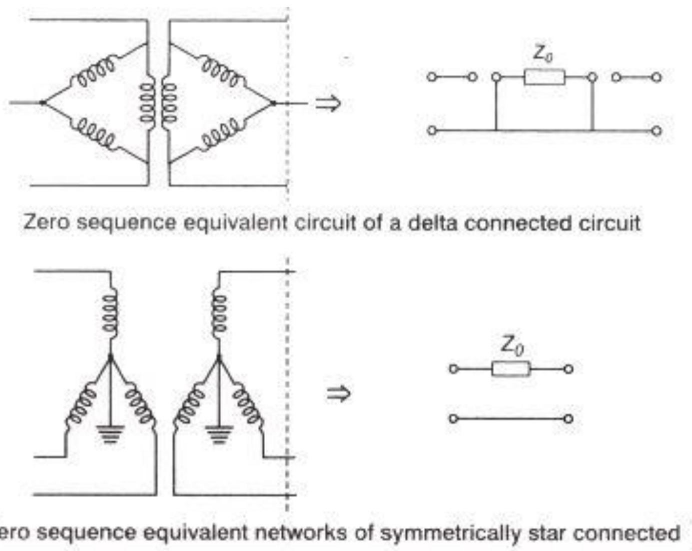


Fig.23: Zero Sequence Impedance Network.

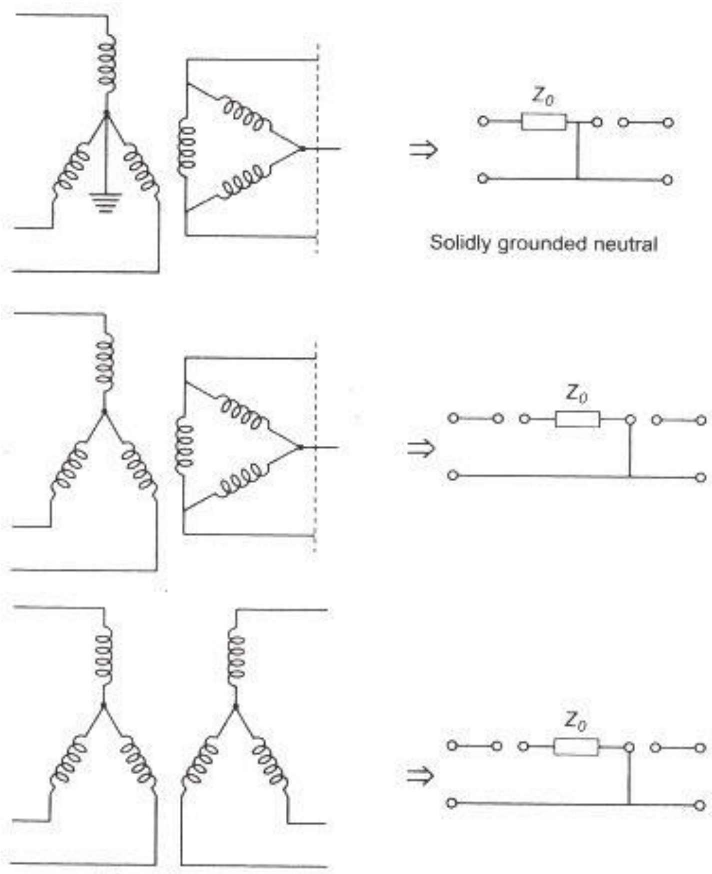


Fig.24: Zero Sequence Impedance Network.

Fault may occur at different points in power system.

Faults that occur on a power system are broadly classified as follows

3-ϕ Sudden Short Circuit of an Unloaded Alternator

Whenever a three-phase short circuit occurs at the terminals of an alternator, the armature current suddenly increases to a large value and voltage across its terminals drops.

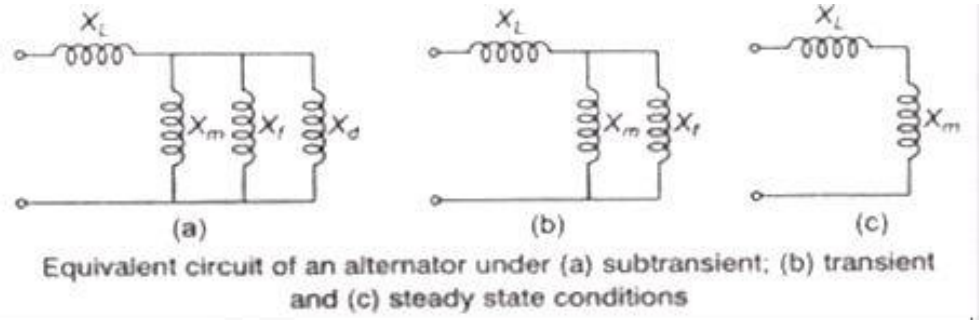


Fig.25: Equivalent Circuit of Alternator.

- **Sub transient fault current**

$$I_f^{''} = \frac{V_1}{X_d^{''}} \quad ....(i)$$

- **Transient fault current**

$$I_f^{'} = \frac{V_t}{X_d^{'}} \quad ...(ii)$$

- **Steady-state fault current**

$$I_t = \frac{V_t}{X_d} \quad ....(iii)$$

Where V_t = RMS voltage from one terminal to neutral at no load

$X_d^{''}$ = Direct axis sub-transient reactance

$$X_d^{''} = X_L + \frac{1}{\frac{1}{X_m} + \frac{1}{X_t} + \frac{1}{X_d}}$$

$X_d^{'}$ = Direct axis transient reactance

$$X_d^{'} = X_L + \frac{1}{\frac{1}{X_m} + \frac{1}{X_t}}$$

X_d = Direct axis synchronous reactance

$X_d = X_L + X_m$

Where X_L = Leakage reactance
X_m = Main winding reactance

X_t = Field winding reactance

X_d = Damper winding reactance

Note: $X_d'' < X_d' < X_d$

Over Current Relay

In an over current relay or o/c relay the actuating quantity is only current. There is only one current operated element in the relay, no voltage coil etc. are required to construct this protective relay.

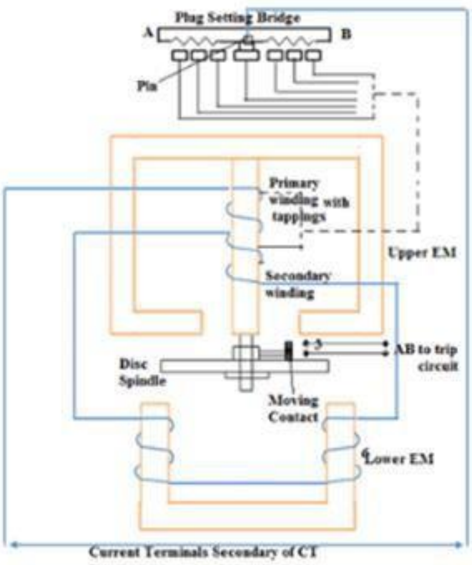


Fig.26: Over Current Relay.

Working Principle of Over Current Relay.

In an over current relay, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force. But when the current through the coil increases, the magnetic effect increases, and after a certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force. As a result, the moving element starts moving to change the contact position in the relay. Although there are different types of overcurrent relays but basic working principle of overcurrent relay is more or less same for all.

Types of Over Current Relay

Depending upon time of operation, there are various types of Over Current relays, such as,

1. Instantaneous over current relay.
2. Definite time over current relay.
3. Inverse time over current relay.

Inverse time over current relay or simply inverse OC relay is again subdivided as inverse definite minimum time (IDMT), very inverse time, extremely inverse time over current relay or OC relay.

Instantaneous Over Current Relay

Construction and working principle of instantaneous over current relay is quite simple.

Here generally a magnetic core is wound by a current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When the current in the coil crosses a preset value, the attractive force becomes enough to pull the iron piece towards the magnetic core, and consequently, the no contacts get closed.

We refer the pre-set value of current in the relay coil as pickup setting current. This relay is referred as instantaneous over current relay, as ideally, the relay operates as soon as the current in the coil gets higher than pick upsetting current. There is no intentional time delay applied. But there is always an inherent time delay which we cannot avoid practically. In practice, the operating time of an instantaneous relay is of the order of a few milliseconds.

Definite Time over Current Relay

This relay is created by applying intentional time delay after crossing pick up the value of the current. A definite time overcurrent relay can be adjusted to issue a trip output at an exact amount of time after it picks up. Thus, it has a time setting adjustment and pickup adjustment.

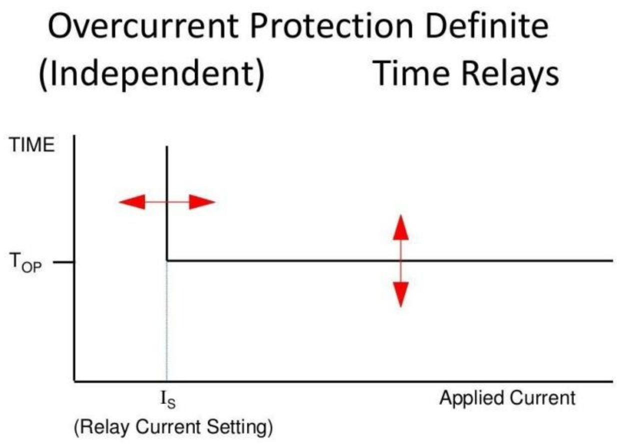


Fig.27: Over Current Relay Characteristic.

Inverse Time Over Current Relay

Inverse time is a natural character of any induction type rotating device. Here, the speed of rotation of rotating part of the device is faster if the input current is more. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay is very suitable for overcurrent protection. If the fault is severe, it will clear the fault faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, the same characteristic can be achieved in microprocessor-based relay also by proper programming.

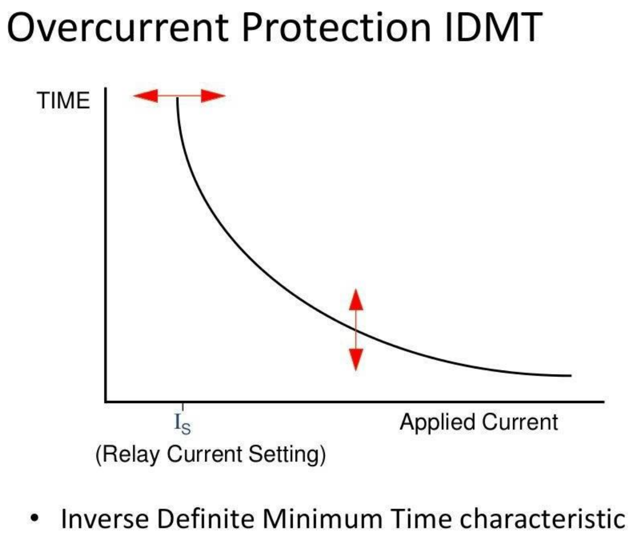


Fig.28: IDMT Over Current Relay Characteristic.

Inverse Definite Minimum Time Over Current Relay or IDMT O/C Relay

Ideal inverse time characteristics cannot be achieved, in an overcurrent relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally. The secondary current enters the relay current coil. But when the CT becomes saturated, there would not be a further proportional increase of CT secondary current with increased system current. From this phenomenon, it is clear that from trick value to certain range of faulty level, an inverse time relay shows specific inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current does not increase further, there would not be any further reduction in time of operation in the relay. We define this time as the minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. That is why the relay is referred as inverse definite minimum time over current relay or simply IDMT relay.

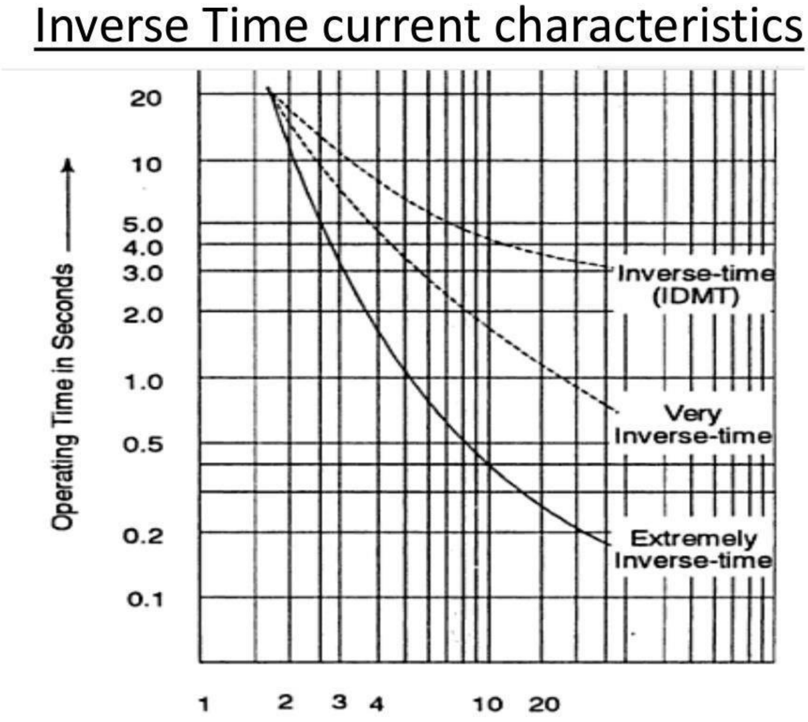


Fig.29: Inverse Time Current Characteristic.

Characteristic of different over current relay.

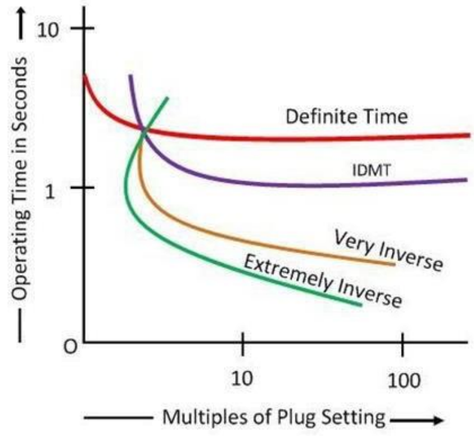


Fig.30: Characteristic of Various Over Current Relay.

Relay Current Setting

- Over current relay – Provided with tappings
- Phase to phase fault protection – 50%-200% -steps of 25%
- If rating of the relay is 5 A

  then 2.5A, 3.75A, 5A, 6.25A,…………, 10A
- Earth fault protection - 20%-80% - steps of 10%
- Normal current rating of earth fault relay 1 A
- Time-current characteristic -current in ampere on X-axis
- Different curves for the same relay for different settings

Plug Setting Multiplier (PSM)

$$PSM = \frac{\text{Secondary current}}{\text{Relay current setting}}$$

$$= \frac{\text{Primary current during fault, i.e. fault current}}{\text{Relay current setting} \times \text{C.T. ratio}}$$

Ex 1: 5 A relay set at 200 %

Relay current setting = 200% of 5 A = 10 A

Secondary current = 10 A (current through relay)

PSM = 10/10 = 1

Ex 2: If relay set at 50 % ; Relay current setting = 50% of 5 A = 2.5 A

Secondary current = 10 A (current through relay)

PSM = 10/2.5 = 4 A

Ex 3: If fault current is 6000 A and CT ratio = 400/5

Then secondary current = 6000/80 = 75 A;

Relay Coordination

In power system protection relay and circuit breakers is the major instrument for large interconnected power system. We need proper protection to isolate the faulted region from healthier network. When two protective apparatus installed in series have certain characteristics, which provide a specified operating sequence, they are said to be coordinated or selective. Relay coordination is an important aspect in the protection system design as coordination schemes must guarantee fast, selective, and reliable relay operation to isolate the power system faulted sections.

Why is Relay Coordination Study and Analysis Performed?

Relay coordination study and analysis is performed to make sure that safety operation of the system are functioning correctly and to avoid the nuisance tripping, as protection is a major concern in any industry and they rely on protective devices for the same. The reason for nuisance tripping is modification of protective devices and their settings at the time of upkeep without performing suitable study and analysis.

The aim of a coordination study is to determine the characteristics, ratings, and settings of over current protective devices which will ensure that minimum

Un faulty load is interrupted when protective devices isolate a fault or overload anywhere in the system. A coordination study should be conducted

- In the early planning stages of a new system to tentatively select protection and utilization equipment
- In the case where an existing system is modified and new loads are installed
- When existing equipment is replaced with higher rated equipment

What is done During a Relay Coordination Study and Analysis?

Mostly relay coordination study and analysis is computer aided. There are several computer programs available for the protection coordination analysis of power system applications. Such programs include short circuit analysis and device time current characteristics. The main purpose of the protective coordination software is to produce one-line diagrams, calculation of relay settings and time current coordination drawings. Software will contain features to model various protective devices, equipment damage curves and store the data for future use. Using the software, the device characteristics can be called from the library and used for the coordination studies.

- **Personal computer** – Either stands alone or connected to a network with sufficient memory is needed for this type of application. Also, a good graphical monitor and laser quality printer is required. By performing the study on a personal computer, several alternatives can be examined before arriving at the final solution. The data can be stored in the computer for future use or verification of the calculations. The one-line drawings, TCC and the output can be printed for a report. Alternatively, these files can be copied and pasted in word processing documents.
- **Graphical display** – The one-line diagram of the electrical circuit and the device coordination curves can be displayed on the graphical monitor for demonstration. Such a display helps to identify the necessary corrections to be performed before getting a printout of the diagrams or graphs.
- **One-line diagram** – A one-line diagram of the electrical circuit for which the coordination is performed is always needed for report preparation. The software can be used to prepare the one-line diagram with the necessary devices shown. Such an approach eliminates the need to deal with the drawing office support for the protection study.
- **Project data files** – A database is a method of storing digital data. The database can be structured to store all the necessary device characteristics, short circuit data and coordination data. These programs can perform calculations of the inrush current, device settings and project details. The project data can be

copied from one computer to another for analysis.

- **Device library** – These programs are equipped with a large library of data from various manufacturers. The library includes models for over current relays, ground relays, static trip breakers, molded case circuit breakers, data for cable damage curve, and data for transformer damage curve, motor overloads and recloses.
- **Interactive data entry** – It is not always possible to have the data available from the device library for the selected study. If the data are not available and if the equation or graphical data are available, then the data can be entered interactively. The data points can be entered item by item and can be saved for future use.

How is Relay Coordination Study and Analysis Done?

One-Line Diagram

If the study is on a new system or already existing system, attain or create a one- line diagram of the system or the part of the system concerned. The diagram should show the following data:

- Apparent power and voltage ratings as well as the impedance ratings and connections of all transformers.
- Normal and emergency switching conditions.
- Nameplate ratings and sub-transient reactance of all major motors and generators as well as transient reactance of synchronous motors and generators, plus synchronous reactance of generators.
- Conductor sizes, types, and configurations.
- Current transformer ratios.
- Relay, circuit breaker and fuse ratings, characteristics, and ranges of adjustment.

Short Circuit Study

Obtain or perform a complete short-circuit study providing momentary and interrupting ratings. It must also contain highest and lowest anticipated fault interrupting duties, as well as inputs from every single short-circuit current source. Gather time–current characteristic curves for each protective device under consideration.

Current Scale Selection

Because the whole aim of the study is to attain time-sequenced tripping of over current protective equipment, the characteristic curve of the device closest to the load is plotted as far to the left of a 4- by 4-cycle graph as possible so that the source side characteristic curves are not packed to the right of the paper. The highest short-circuit current of the system is the right-hand limit of the curves.

Characteristic Curves

The process of plotting the time- current characteristic curves, it must be remembered that all currents must be referred to a common voltage, either primary or secondary, before attempting to determine coordination. On a delta-wye system, the current that the primary fuse sees due to a secondary fault depends on the type of fault, as well as the severity of the fault.

Selective Coordination

The time-current characteristic curves of protective devices should not overlap if selective coordination is to be achieved, nor should the primary device of the transformer trip on inrush. The protective equipment should be set to defend motors, cables and system gear from overlay as well as short-circuit states.