UNIT 1: FAULT ANALYSIS

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

COMMON POWER SYSTEM FAULTS

Power system faults may be categorised 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 fault

The first three types constitutes 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.

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

THEVENIN'S EQUIVALENT CIRCUIT

Thevenin's theorem states that any linear network containing any number of voltage sources and impedances can be replaced by a single emf and an impedance.

The emf is the open circuit voltage as seen from the terminals under consideration and the impedance is the network impedance as seen from these terminals.

This circuit consisting of a single emf and impedance is known as Thevenin's equivalent circuit.

The calculation of fault current can then be very easily done by applying this theorem after obtaining the open circuit emf and network impedance as seen from the fault point.

SYMMETRICAL COMPONENTS

The majority of faults in power systems are asymmetrical. To analyse an asymmetrical fault, an unbalanced 3- phase circuit has to be solved. Since the direct solution of such a circuit is very difficult, the solution can be more easily obtained by using symmetrical components since this yields three (fictitious) single phase networks, only one of which contains a driving emf.

Since the system reactances are balanced the thee fictitious networks have no mutual coupling between them, a fact that is making this method of analysis quite simple.

General principles

Any set of unbalanced 3-phase voltages (or current) can be transformed into 3 balanced sets. These are:

1. A positive sequence set of three symmetrical voltages (i.e. all numerically equal and all displaced from each other by $120^{0)}$ having the same phase sequence *abc* as the original set and denoted by $V_{a1,}V_{b1,}V_{c1}$ as shown in the fig(1a)

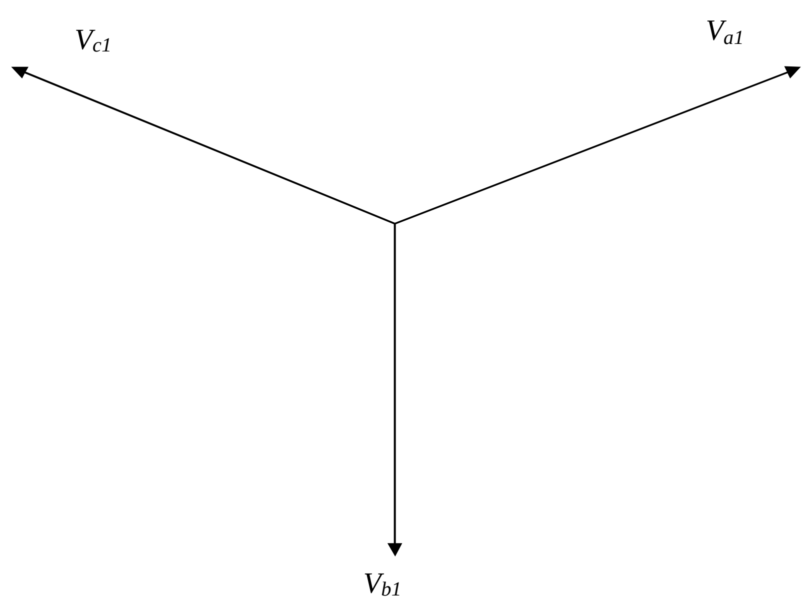


Fig. (a)

2. A negative sequence set of three symmetrical voltages having the phase sequence opposite to that of the original set and denoted by V_{a2}, V_{b2}, V_{c2} as shown in fig(1b)

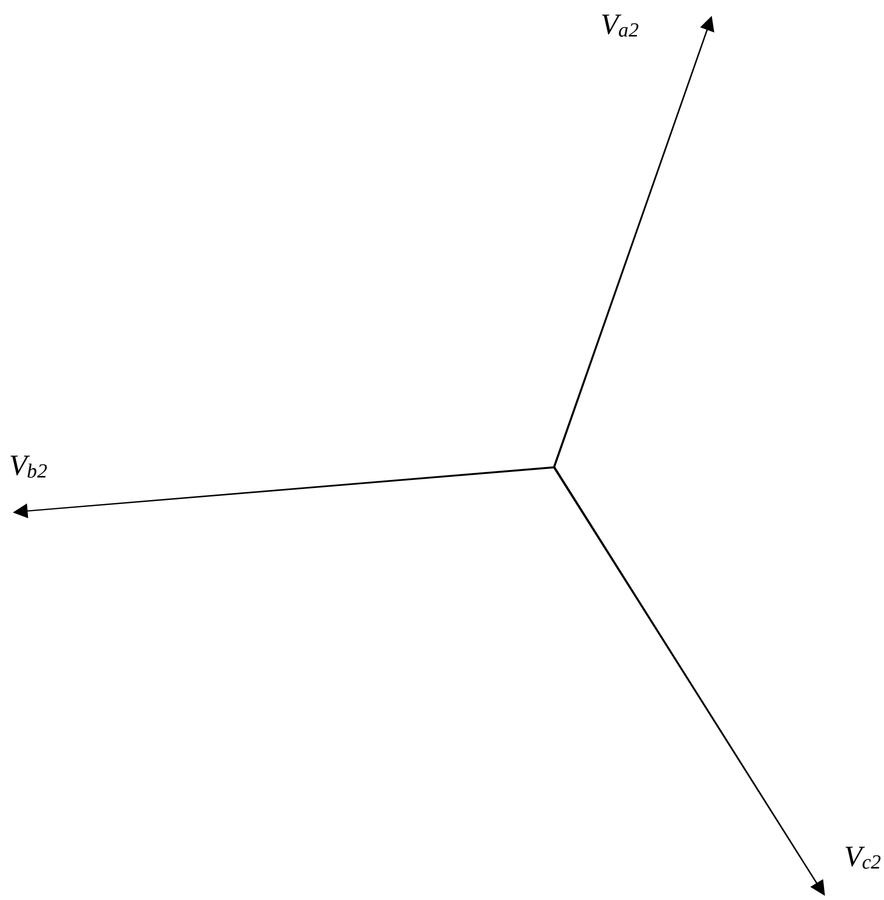


Fig. 1 (b)

3. A zero sequence set of three voltages, all equal in magnitude and in phase with each other and denoted by V_{a0}, V_{b0}, V_{c0} as shown in fig (1c) below:

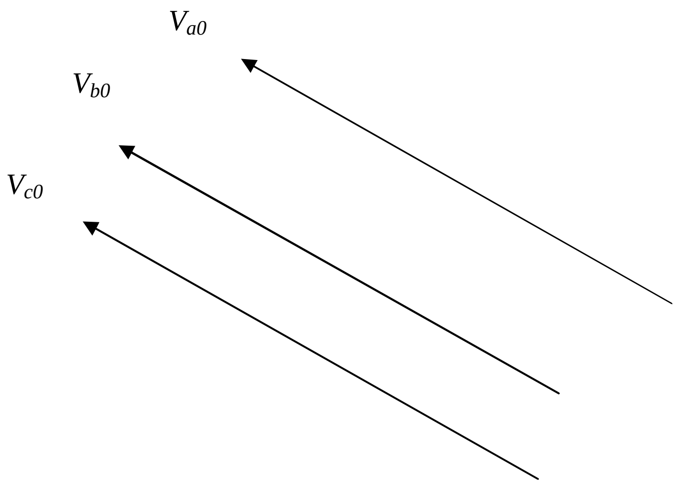


Fig. 1 (c

The positive, negative and zero sequence sets above are known as symmetrical components.

Thus we have,

$V_a = V_{a1} + V_{a2} + V_{a0}$

$V_b = V_{b1} + V_{b2} + V_{b0}$

$V_c = V_{c1} + V_{c2} + V_{c0}$

The symmetrical components application to power system analysis is of fundamental importance since it can be used to transform arbitrarily unbalanced condition into symmetrical components, compute the system response by straightforward circuit analysis on simple circuit models and transform the results back to the original phase variables.

Generally the subscripts 1, 2 and 0 are used to indicate positive sequence, negative sequence and zero sequence respectively.

The symmetrical components do not have separate existence; they are just mathematical components of unbalanced currents (or voltages) which actually flow in the system.

The "a" operator

The operator "a" as used in symmetrical components is one in which when multiplied to a vector, rotates the vector through 120^0 in a positive (anticlockwise) direction without changing the magnitude.

The operator "a" is defined as $1 \angle 120^0$

THREE-SEQUENCE IMPEDANCES AND SEQUENCE NETWORKS

Positive sequence currents give rise to only positive sequence voltages, the negative sequence currents give rise to only negative sequence voltages and zero sequence currents give rise to only zero sequence voltages, hence each network can be regarded as flowing within in its own network through impedances of its own sequence only.

In any part of the circuit, the voltage drop caused by current of a certain sequence depends on the impedance of that part of the circuit to current of that sequence.

The impedance of any section of a balanced network to current of one sequence may be different from impedance to current of another sequence.

The impedance of a circuit when positive sequence currents are flowing is called impedance,

When only negative sequence currents are flowing the impedance is termed as negative sequence impedance.

With only zero sequence currents flowing the impedance is termed as zero sequence impedance.

The analysis of unsymmetrical faults in power systems is carried out by finding the symmetrical components of the unbalanced currents. Since each sequence current causes a voltage drop of that sequence only, each sequence current can be considered to flow in an independent network composed of impedances to current of that sequence only.

The single phase equivalent circuit composed of the impedances to current of any one sequence only is called the sequence network of that particular sequence.

The sequence networks contain the generated emfs and impedances of like sequence.

Therefore for every power system we can form three- sequence network s. These sequence networks, carrying current I_{a1}, I_{a2} and I_{a0} are then inter-connected to represent the different fault conditions.

PHYSICAL SIGNIFICANCE OF SEQUENCE COMPONENTS

This is achieved by considering the fields which results when these sequence voltages are applied to the stator of a 3-phase machine e.g. an induction motor.

If a positive sequence set of voltages is applied to the terminals a, b, c of the machine, a magnetic field revolving in a certain direction will be set up. If now the voltages to the terminals band c are changed by interchanging the leads to terminals b and c, it is known from induction motor theory that the direction of magnetic field would be reversed.

It is noted that for this condition, the relative phase positions of the voltages applied to the motor are the same as for the negative sequence set.

Hence, a negative sequence set of voltages produces a rotating field rotating in an opposite direction to that of positive sequence.

For both positive and negative sequence components, the standard convention of counter clockwise rotation is followed.

The application of zero sequence voltages does not produce any field because these voltages are in phase and the three -phase windings are displaced by 120^0.The positive and the negative sequence set are the balanced one. Thus, if only positive and negative sequence currents are flowing, the phasor sum of each will be zero and there will be no residual current. However, the zero sequence components of currents in the three phases are in phase and the residual current will be three times the zero sequence current of one phase. In the case of a fault involving ground, the positive and negative sequence currents are in equilibrium while the zero sequence currents flow through the ground and overhead ground wires.

SEQUENCE NETWORKS OF SYNCHRONOUS MACHINES

An unloaded synchronous machine having its neutral earthed through impedance, z_n, is shown in fig. 2(a) below.

A fault at its terminals causes currents I_a, I_b and I_c to flow in the lines. If fault involves earth, a current I_n flows into the neutral from the earth. This current flows through the neutral impedance Z_n.

Thus depending on the type of fault, one or more of the line currents may be zero.

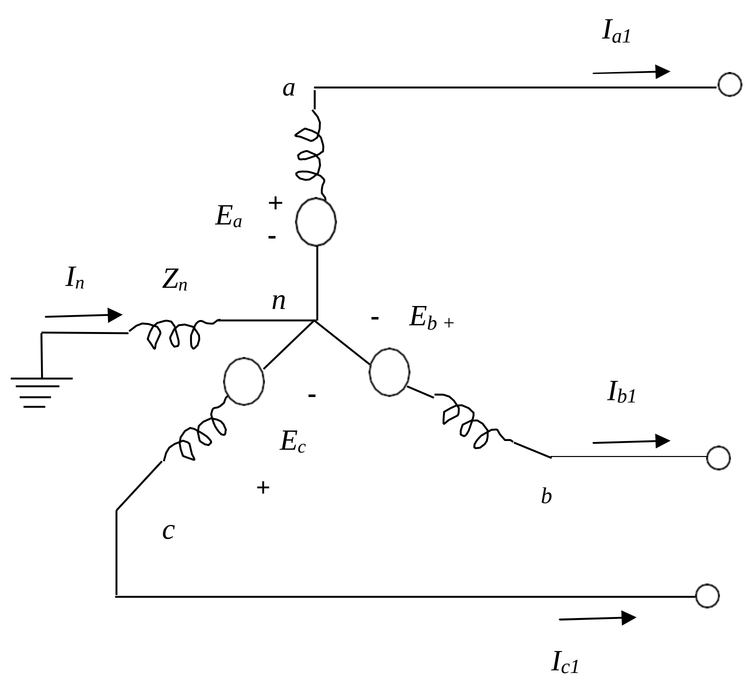


Fig.2 (a)

Positive sequence network

The generated voltages of a synchronous machine are of positive sequence only since the windings of a synchronous machine are symmetrical.

The positive sequence network consists of an emf equal to no load terminal voltages and is in series with the positive sequence impedance Z_1 of the machine. Fig.2 (b) and fig.2(c) shows the paths for positive sequence currents and positive sequence network respectively on a single phase basis in the synchronous machine. The neutral impedance Z_n does not appear in the circuit because the phasor sum of I_{a1}, I_{b1} and I_{c1} is zero and no positive sequence current can flow through Z_n. Since its a balanced circuit, the positive sequence N

The reference bus for the positive sequence network is the neutral of the generator.

The positive sequence impedance Z_1 consists of winding resistance and direct axis reactance. The reactance is the sub-transient reactance X''_d or transient reactance X'_d or synchronous reactance X_d depending on whether sub-transient, transient or steady state conditions are being studied.

From fig.2 (b) , the positive sequence voltage of terminal *a* with respect to the reference bus is given by:

$V_{a1} = E_a - Z_1 I_{a1}$

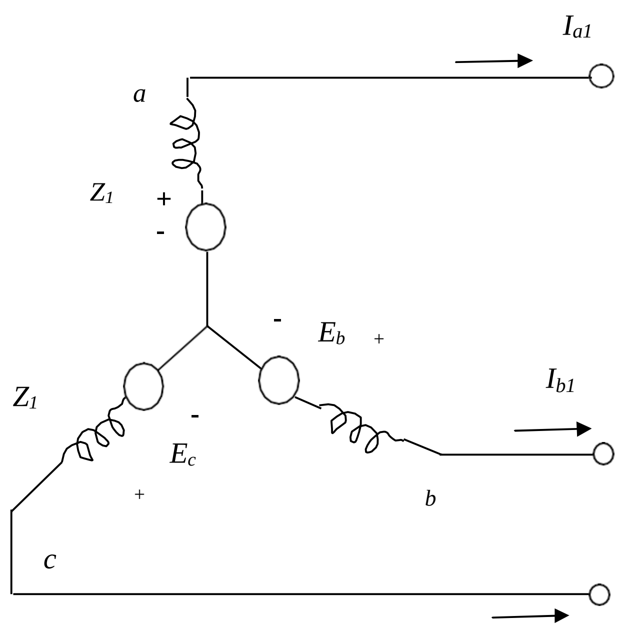


Fig.2 (b)

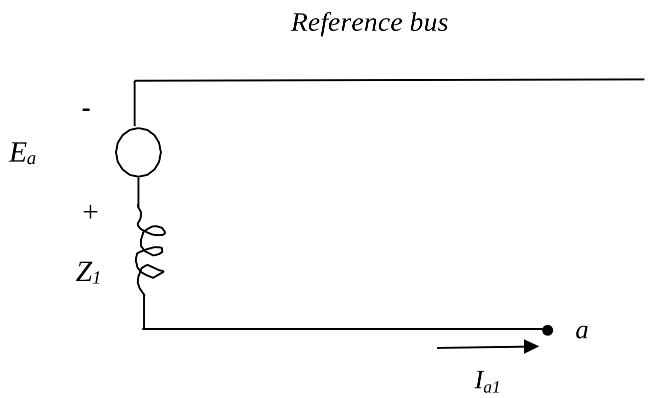


Fig.2(c)

Negative sequence network

A synchronous machine does not generate any negative sequence voltage. The flow of negative sequence currents in the stator windings creates an mmf which rotates at synchronous speed in a direction opposite to the direction of rotor, i.e., at twice the synchronous speed with respect to rotor.

Thus the negative sequence mmf alternates past the direct and quadrature axis and sets up a varying armature reaction effect. Thus, the negative sequence reactance is taken as the average of direct axis and quadrature axis sub-transient reactance, i.e.,

$X_2 = 0.5\ (X''_d + X''_q)$.

It not necessary to consider any time variation of X_2 during transient conditions because there is no normal constant armature reaction to be effected. For more accurate calculations, the negative sequence resistance should be considered to account for power dissipated in the rotor poles or damper winding by double supply frequency induced currents.

The fig.2 (d) and fig.2 (e) shows the negative sequence currents paths and the negative sequence network respectively on a single phase basis of a synchronous machine.

The reference bus for the negative sequence network is the neutral of the machine. Thus, the negative sequence voltage of terminal *a* with respect to the reference bus is given by:

$V_{a2} = -Z_2 I_{a2}$

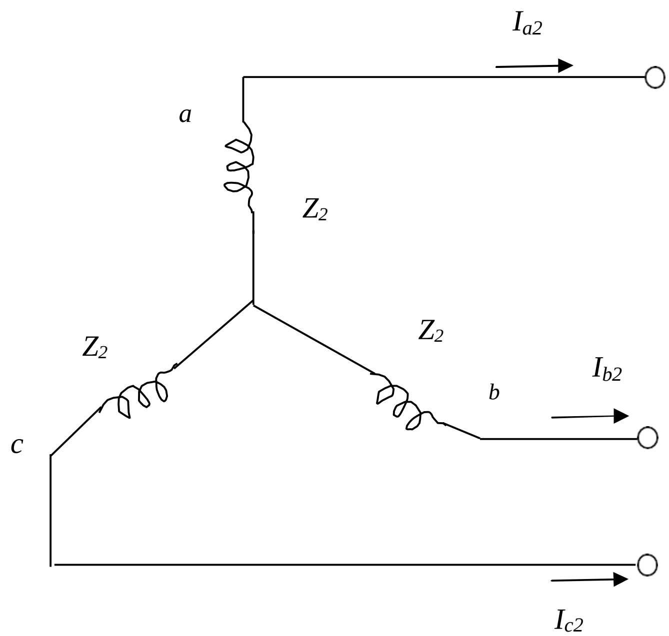


Fig.2 (d)

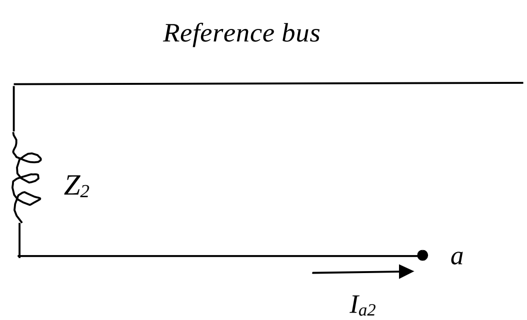


Fig.2 (e)

Zero sequence network

No zero sequence voltage is induced in a synchronous machine. The flow of zero sequence currents in the stator windings produces three mmf which are in time phase. If each phase winding produced a sinusoidal space mmf, then with the rotor removed, the flux at a point on the axis of the stator due to zero sequence current would be zero at every instant.

When the flux in the air gap or the leakage flux around slots or end connections is considered, no point in these regions is equidistant from all the three –phase windings of the stator.

The mmf produced by a phase winding departs from a sine wave, by amounts which depend upon the arrangement of the winding.

The zero sequence currents flow through the neutral impedance Z_n and the current flowing through this impedance is $3I_{a0}$.

Fig.2(f) and fig.2(g) shows the zero sequence current paths and zero sequence network respectively, and as can be seen, the zero sequence voltage drop from point *a* to ground is $-3I_{a0}Z_n - I_{a0}Zg_0$ where Z_{g0} is the zero sequence impedance per phase of the generator.

Since the current in the zero sequence network is I_{a0} this network must have an impedance of $3Z_n + Z_{g0}$. Thus,

$Z_0 = 3Z_n + Z_{g0}$

The zero sequence voltage of terminal *a* with respect to the reference bus is thus:

$V_{a0} = -I_{a0}Z_0$

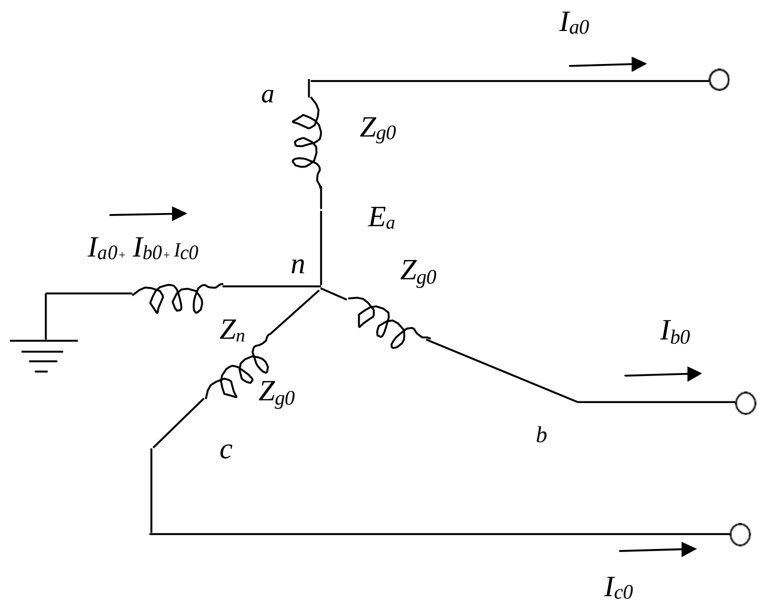
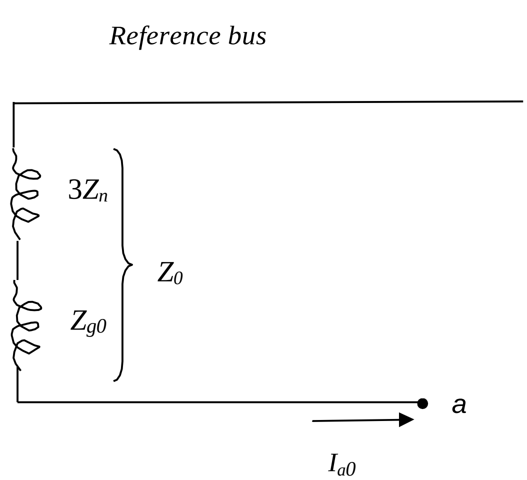

I_{a0}
a
Z_{g0}
E_a
$I_{a0+} I_{b0+} I_{c0}$
n
Z_{g0}
Z_n
I_{b0}
Z_{g0}
c
b
I_{c0}

Fig.2 (f)


Reference bus
$3Z_n$
Z_0
Z_{g0}
a
I_{a0}

-

Fig.2 (g)

SEQUENCE IMPEDANCES OF TRANSMISSION LINE

The positive and negative sequence impedances of linear symmetrical static circuits do not depend on the phase sequence and are, therefore equal. When only zero sequence currents flow in the lines, the currents in all the phases are identical. These currents return partly through the ground and partly through overhead ground wires.

The magnetic field due to the flow of zero sequence currents through line, ground and round wires is very different from the magnetic field due to positive sequence currents. The zero sequence reactance of lines is about 2 to 4 times the positive sequence reactance.

SEQUENCE IMPEDANCES OF TRANSFORMERS

A power system network has a number of transformers for stepping up and stepping down the voltage levels.

A transformer for a 3-phase circuit may consist of three single phase transformers with windings suitably connected in star or delta or it may be a 3-phase unit.

Modern transformers are invariably three-phase units because of their lower cost, lesser space requirements and higher efficiency. The positive sequence impedance of a transformer equals its leakage impedance. The resistance of the windings is usually small as compared to leakage reactance.

For transformers above 1 MVA rating, the reactance and impedance are almost equal. Since the transformer is a static device, the negative sequence impedance is equal to the positive sequence impedance.

The zero sequence impedance of 3-phase units is slightly different from positive sequence impedance. However the difference is very slight and the zero sequence impedance is also assumed to be the same as the positive sequence impedance.

The flow of zero sequence currents through a transformer and hence in the system depends greatly on the winding connections. The zero sequence currents can flow through the winding connected in star only if the star point is grounded. If the star point isolated zero sequence currents cannot flow in the winding.

The zero sequence currents cannot flow in the lines connected to a delta connected winding because no return path is available for these zero sequence currents. However, the zero sequence currents caused by the presence of zero sequence voltages can circulate through the delta connected windings.

FORMATION OF SEQUENCE NETWORKS

A power system network consists of synchronous machines, transmission lines and transformers.

The positive sequence network is the same as the single line reactance diagram used for the calculation of symmetrical fault current. The reference bus for positive sequence network is the system neutral.

The negative sequence network is similar to the positive sequence network except that the negative sequence network does not contain any voltage source. The negative sequence impedances for transmission line and transformers are the same as the positive sequence impedances. But the negative sequence impedance of a synchronous machine may be different from its positive sequence impedance.

Any impedance connected between a neutral and ground is not included in the positive and negative sequence networks because the positive and the negative sequence currents cannot flow through such impedance.

The zero sequence network also does not contain any voltage source. Any impedance included between neutral and ground becomes three times its value in a zero sequence network.

The following are the summary of the rules for the formation of sequence networks:-

- The positive sequence network is the same as single line impedance or reactance diagram used in symmetrical fault analysis. The reference bus for this network is the system neutral.

- The generators in power system produce balanced voltages. Therefore only positive sequence network has voltage source. There are no voltage sources in negative and zero sequence networks.
- The positive sequence current can cause only positive sequence voltage drop. Similarly negative sequence current can cause only negative sequence voltage drop and zero sequence current can cause only zero sequence voltage drop.
- The reference for negative sequence network is the system neutral. However, the reference for zero sequence network is the ground. Zero sequence current can flow only if the neutral is grounded.
- The neutral grounding impedance Z_n appears as $3Z_n$ in the zero sequence network.
- The three sequence networks are independent and are interconnected suitably depending on the type of fault.

UNSYMMETRICAL FAULTS

The basic approach to the analysis of unsymmetrical faults is to consider the general situation shown in the fig.3.0 which shows the three lines of the three- phase power system at the point of fault.

The general terminals brought out are for purposes of external connections which simulate the fault. Appropriate connections of the three stubs represent the different faults, e.g., connecting stub *`a'* to ground produces a single line to ground fault, through zero impedance, on phase *`a'*. The currents in stubs *b* and *c* are then zero and *Ia* is the fault current.

Similarly, the connection of stubs b and *c* produces a line to line fault, through zero impedance, between phases *b* and *c*, the current in stub *a* is then zero and I_b is equal to *Ic*.The positive assignment of phase quantities is important. It is seen that the currents flow out of the system.

The three general sequence circuits are shown in fig.3.1 (a). The ports indicated correspond to the general 3- phase entry port of fig.3.1. A suitable inter- connection of the three- sequence networks depending on the type fault yields the solution to the problem.

The sequence networks of fig.3.1 (a) can be replaced by equivalent sequence networks of fig.3.1 (b) . Z_0, Z_1 and Z_2 indicate the sequence impedances of the network looking into the fault

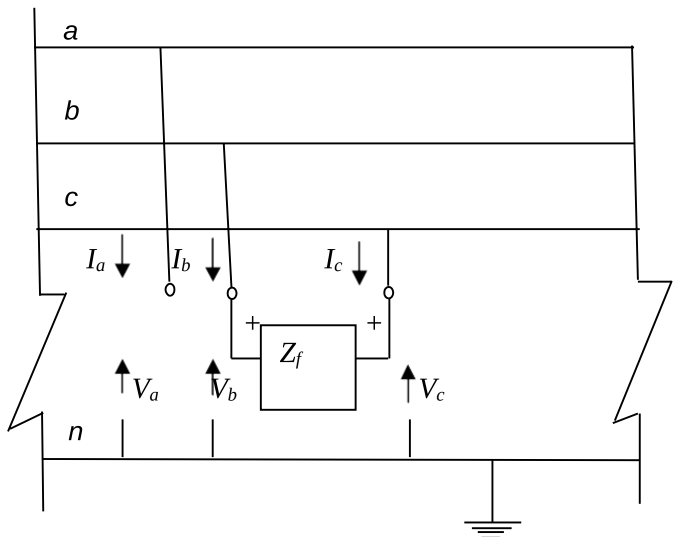


Fig.3.0 General 3- phase access port

General sequence networks

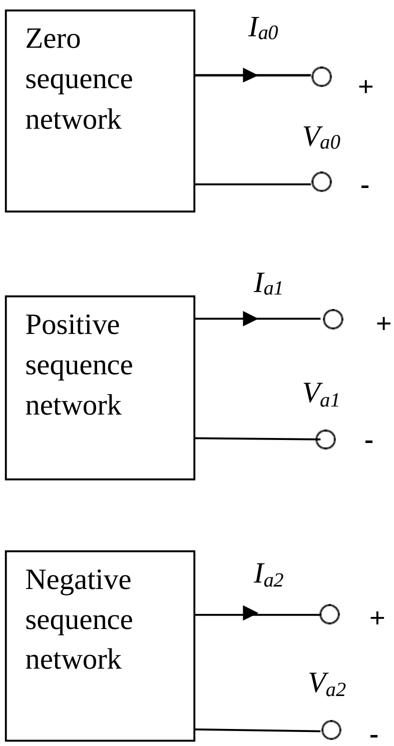


Fig.3.1 (a)

Equivalent sequence networks

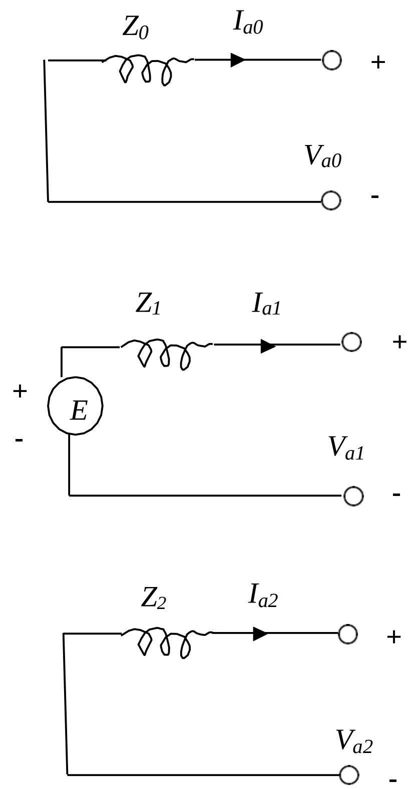


Fig.3.1 (b)

SINGLE LINE TO GROUND FAULT

Typically Z_f is set to zero in all fault studies. I include Z_f in the analysis for the sake of generality. The terminal conditions at the fault point give the following equations:

$I_b = 0$

$I_c = 0$

$V_a = I_a Z_f$

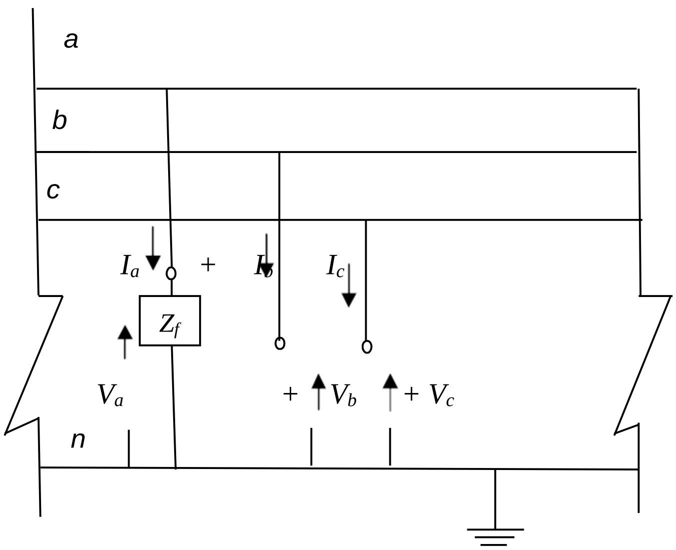


Fig. 3.2

Connections of sequence networks for a single line to ground fault and its simplified equivalent circuit are shown in the fig. 3.3(a) and fig. 3.3 (b) below:

General sequence networks

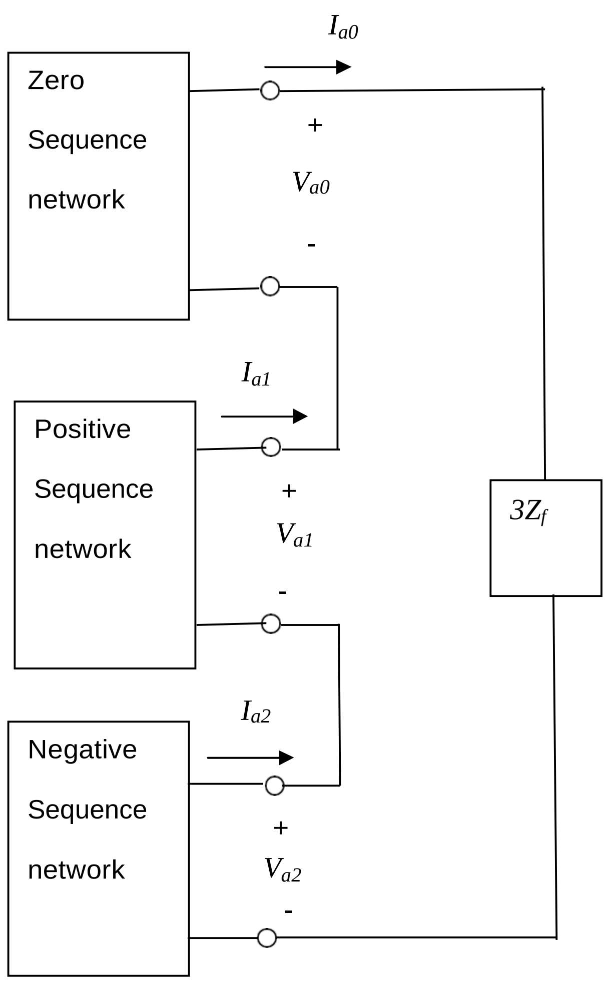


Fig.3.3 (a)

Equivalent sequence networks

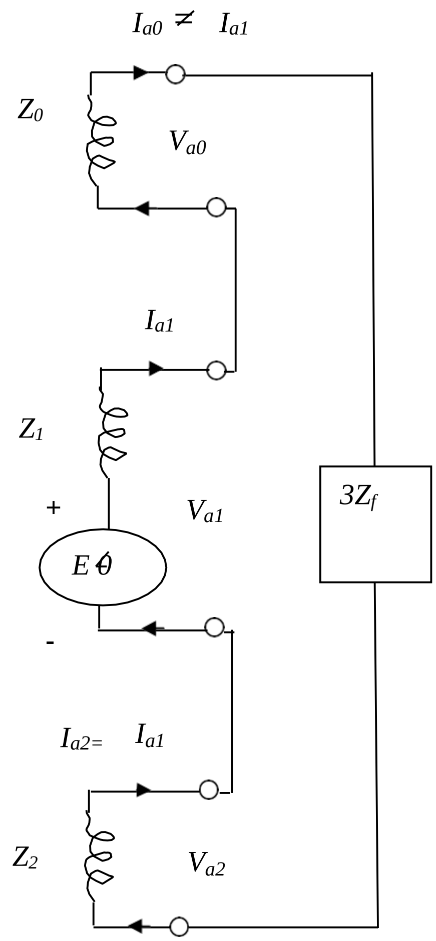


Fig.3.3 (b)

LINE TO LINE FAULT

The termination of the three- phase access port as in the fig.3.4 below simulates a line to line fault through a fault impedance Z_f .

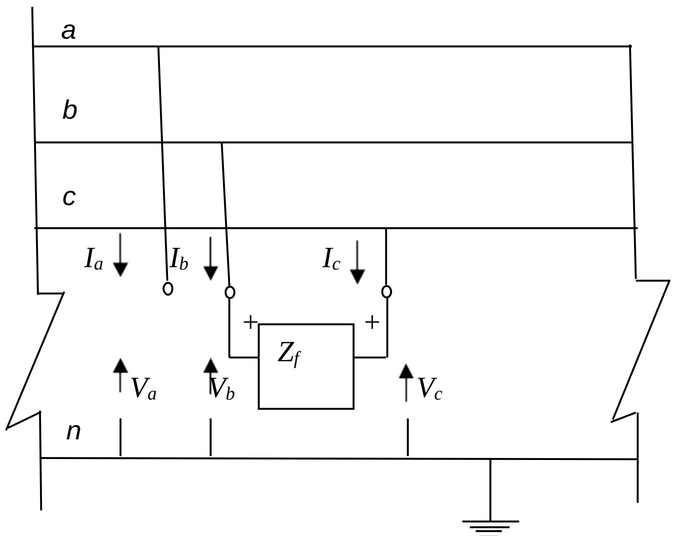


Fig. 3.4

The terminal conditions at the fault point give the following equations,

$I_a = 0$

$I_b = -I_c$

$V_b = V_c + Z_f I_b$

$I_b = -I_c = I_{a0} + a^2 I_{a1} + aI_{a2}$

Connection of sequence networks for a line to line fault and its simplified equivalent circuit are shown in the fig.3.5 (a) and fig.(b) below.

General sequence networks

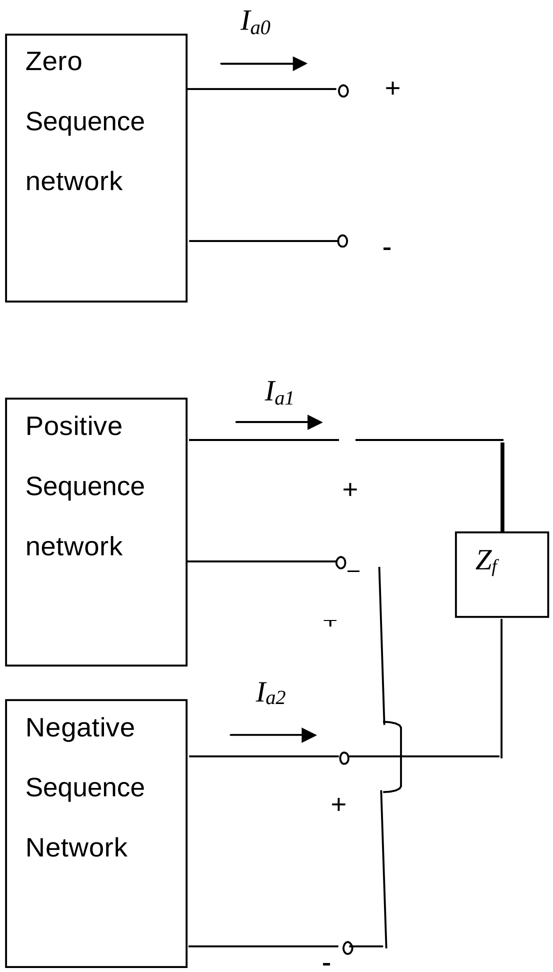


Fig. 3.5 (a)

Equivalent sequence networks

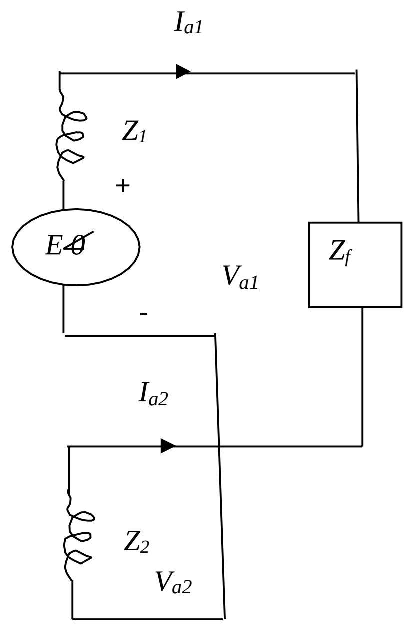


Fig.3.5 (b)

DOUBLE LINE TO GROUND FAULT

The termination of the three- phase access port as shown in fig.3.6 simulates a double line to ground fault through fault impedance Z_f.

The terminal conditions at the fault point give the following equations,

$I_a = 0$

$V_b = V_c = (I_b + I_c) Z_f$

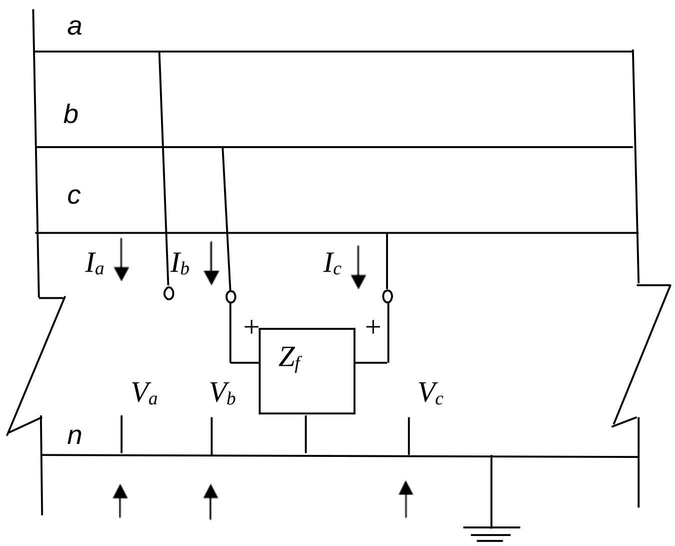


Fig. 3.6

The sequence networks and the equivalent circuit are shown by the Fig.3.7 (a) and Fig. 3.7 (b) below

General sequence networks

Equivalent sequence networks

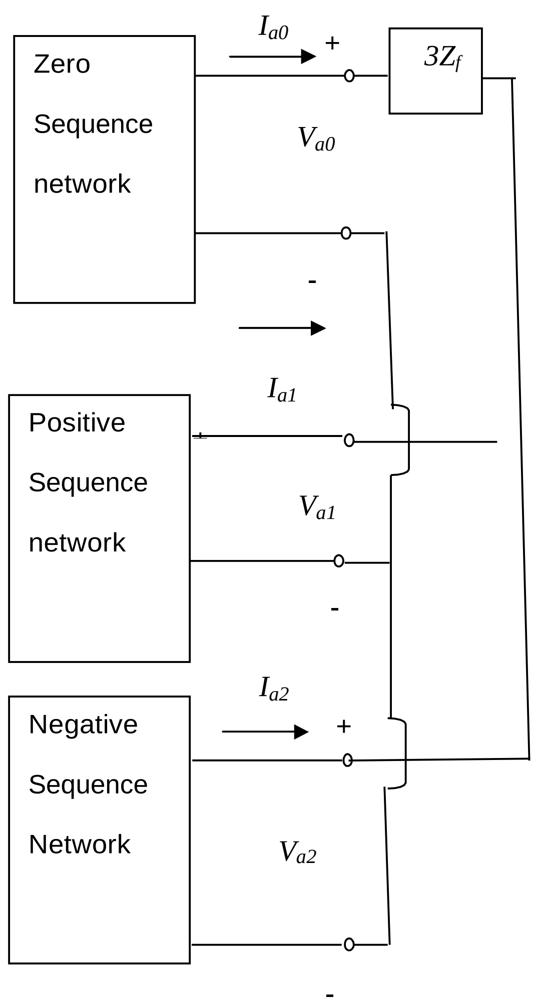


Fig. 3.7(a)

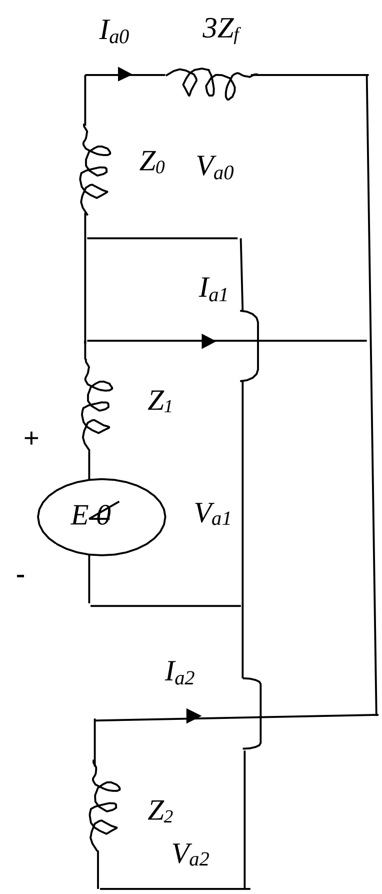


Fig.3.7 (b)

BALANCED THREE PHASE FAULT

This type of fault occurs infrequently, as for example, when a line, which has been made safe for maintenance by clamping all the three phases to earth, is accidentally made alive or when, due to slow fault clearance, an earth fault spreads across to the other two phases or when a mechanical excavator cuts quickly through a whole cable.

It is an important type of fault in that it results in an easy calculation and generally, a pessimistic answer.

The circuit breaker rated MVA breaking capacity is based on 3- phase fault MVA. Since circuit breakers are manufactured in preferred standard sizes e.g. 250, 500, 750 MVA high precision is not necessary when calculating the 3- phase fault level at a point in a power system.

The system impedances are also never known accurately in three phase faults.

UNIT TWO: CIRCUIT BREAKERS

INTRODUCTION:

During the operation of power system, it is often desirable and necessary to switch on or off the various circuits (e.g., transmission lines, distributors, generating plants etc.) under both normal and abnormal conditions. In earlier days, this function used to be performed by a switch and a fuse placed in series with the circuit. However, such a means of control presents two disadvantages.

Firstly, when a fuse blows out, it takes quite sometime to replace it and restore supply to the customers.

Secondly, a fuse cannot successfully interrupt heavy fault currents that result from faults on modern high- voltage and large capacity circuits.

Due to these disadvantages, the use of switches and fuses is limited to low voltage and small capacity circuits where frequent operations are not expected e.g., for switching and protection of distribution transformers, lighting circuits, branch circuits of distribution lines etc.

With the advancement of power system, the lines and other equipment operate at very high voltages and carry large currents. The arrangement of switches along with fuses cannot serve the desired function of switchgear in such high capacity circuits. This necessitates employing a more dependable means of control such as is obtained by the use of circuit breakers.

A circuit breaker can make or break a circuit either manually or automatically under all conditions viz., no-load, full- load and short-circuit conditions.

This characteristic of the circuit breaker has made it very useful equipment for switching and protection of various parts of the power system.

- A circuit breaker is a piece of equipment which can
- Make or break a circuit either manually or by remote control under normal conditions.
- Break a circuit automatically under fault conditions
- Make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault condition.

Operating principle:

A circuit breaker essentially consists of fixed and moving contacts, called Electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

- When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases.

- The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself.

- Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon:

When a short circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) Is sufficient to ionize the air or vaporize and ionize the oil. The ionized air or vapor acts as conductor and an arc is struck between the contacts.
The potential difference between the contacts is quite small and is just sufficient to maintain the arc.

The arc provides a low resistance path and consequently the current in the circuit remains UN interrupted so long as the arc persists.

During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

The arc resistance depends upon the following factors:

Degree of ionization- the arc resistance increases with the decrease in the number of ionized particles between the contacts.

Length of the arc— the arc resistance increases with the length of the arc i.e., separation of contacts.

Cross-section of arc— the arc resistance increases with the decrease in area of X-section of the arc.

Principles of Arc Extinction:

Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are:

- Potential difference between the contacts.
- Ionized particles between contacts taking these in turn.

When the contacts have a small separation, the Potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that Potential difference becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.

The ionized particles between the contacts tend to maintain the arc. If the arc path is demonized, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionized particles from the space between the contacts.

Methods of Arc Extinction (or) Interruption:

- There are two methods of extinguishing the arc in circuit breakers viz.
- High resistance method.

- Low resistance or current zero method

High resistance method:

In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished.
The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in D.C. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by:

Lengthening the arc: The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

Cooling the arc

Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

Reducing X-section of the arc:

If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.
Splitting the arc: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Low resistance or Current zero method:

In this method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking in spite of the rising voltage across the contacts. All Modern high power a.c. circuit breakers employ this method for arc extinction.

In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment. Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as restriking voltage.
If such a breakdown does occur, the arc will persist for another half cycle.
If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will be interrupted.

The rapid increase of dielectric strength of the medium near current zero can be achieved by:

- Causing the ionized particles in the space between contacts to recombine into neutral molecules.

- Sweeping the ionized particles away and replacing them by un ionized particles.

Therefore, the real problem in a.c. arc interruption is to rapidly de ionize the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts.

The de-ionization of the medium can be achieved by:

Lengthening of the gap: The dielectric strength of the medium is proportional to the length of the gap between contacts.

Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

High pressure: If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionization and consequently the dielectric strength of the medium between contacts is increased.

Cooling: Natural combination of ionized particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

Blast effect: If the ionized particles between the contacts are swept away and replaced by UN ionized particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

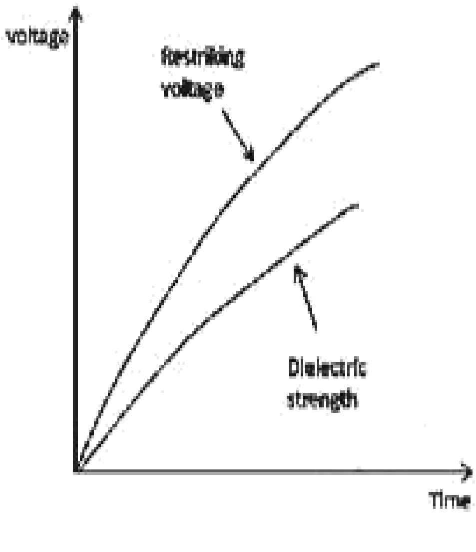
There are two theories to explain the Zero current interruption of the Arc:

Recovery rate theory (Slepain's Theory)

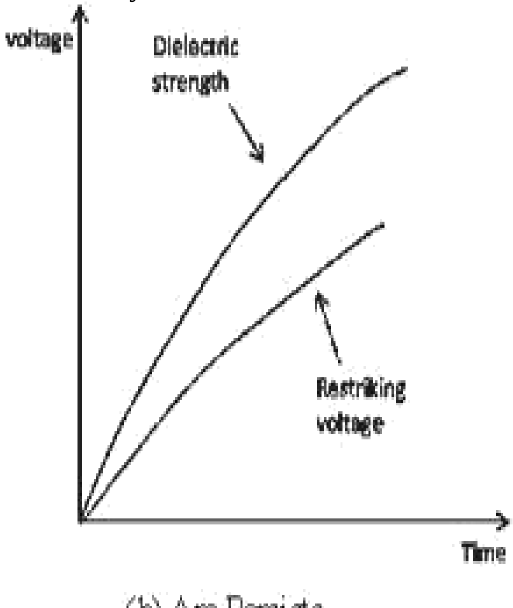
Energy balance theory (Cassie's Theory)

Recovery rate theory (Slepain's Theory):

The arc is a column of ionized gases. To extinguish the arc, the electrons and ions are to be removed from the gap immediately after the current reaches a natural zero. Ions and electrons can be removed either by recombining them in to neutral molecules or by sweeping them away by inserting insulating medium (gas or liquid) into the gap. The arc is interrupted if ions are removed from the gap recovers its dielectric strength is compared with the rate at which the restriking voltage (transient voltage) across the gap rises. If the dielectric strength increases more rapidly than the restriking voltage, the arc is extinguished. If the restriking voltage rises more rapidly than the dielectric strength, the ionization persists and breakdown of the gap occurs, resulting in an arc for another half cycle



(a) Arc Extinguishes



(b) Arc Persists

Important Terms:

The following are the important terms much used in the circuit breaker analysis:

Arc Voltage:

It is the voltage that appears across the contacts of the circuit breaker during the arcing period. As soon as the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called the arc voltage. Its value is low except for the period the fault current is at or near zero current point. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

Restriking voltage

It is the transient voltage that appears across the contacts at or near current zero during arcing period. At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage (Fig. 19.1).

The current interruption in the circuit depends upon this voltage. If the restriking voltage rises more rapidly than the dielectric strength of the medium between the contacts, the arc will persist for another half-cycle. On the other hand, if the dielectric strength of the medium builds up more rapidly than the restriking voltage, the arc fails to restrike and the current will be interrupted.

Recovery voltage:

It is the normal frequency (50 Hz) R.M.S. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

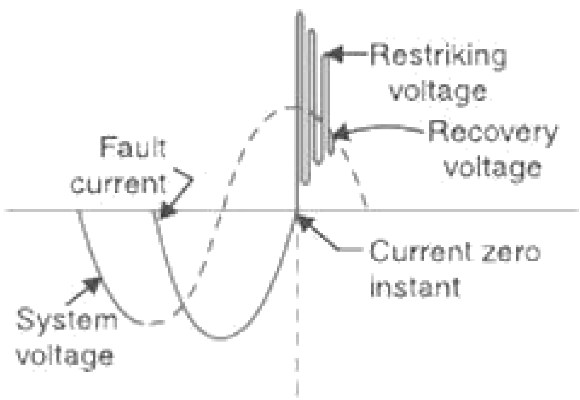


Fig. 19.1

When contacts of circuit breaker are opened, current drops to zero after every half cycle. At some current zero, the contacts are separated sufficiently apart and dielectric strength of the medium between the contacts attains a high value due to the removal of ionized particles. At such an instant, the medium between the contacts is strong enough to prevent the breakdown by the restriking voltage. Consequently, the final arc extinction takes place and circuit current is interrupted. Immediately after final current interruption, the voltage that appears across the contacts has a transient part (See Fig.19.1). However, these transient oscillations subside rapidly due to the damping effect of system resistance and normal circuit voltage appears across the contacts. The voltage across the contacts is of normal frequency and is known as recovery voltage.

Expression for Restriking voltage and RRRV:

The power system contains an appreciable amount of inductance and some capacitance. When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker will result in most of the stored energy dissipated within the circuit breaker, the remainder being dissipated during oscillatory surges in the system. The oscillatory surges are undesirable and, therefore, the circuit breaker must be designed to dissipate as much of the stored energy as possible.

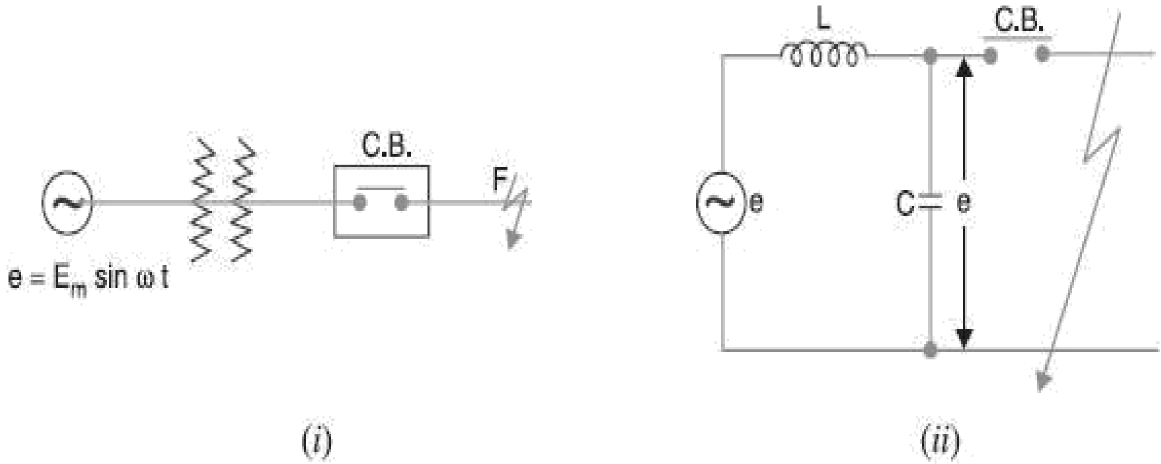


Fig. 19.17

Fig. 19.17 (i) shows a short-circuit occurring on the transmission line. Fig 19.17 (ii) shows its equivalent circuit where L is the inductance per phase of the system up to the point of fault and C is the capacitance per phase of the system. The resistance of the system is neglected as it is generally small.

Rate of rise of re-striking voltage:

It is the rate of increase of re-striking voltage and is abbreviated by R.R.R.V. usually; the voltage is in kV and time in microseconds so that R.R.R.V. is in kV/μ sec.

Consider the opening of a circuit breaker under fault conditions Shown in simplified form in Fig. 19.17 (ii) above. Before current interruption, the capacitance C is short-circuited by the fault and the short-circuit current through the breaker is limited by Inductance L of the system only. Consequently, the short-circuit current will lag the voltage by 90º as shown in Fig. 19.18, where I Represents the short-circuit current and ea represents the arc voltage. It may be seen that in this condition, the *entire generator voltage appears across inductance L

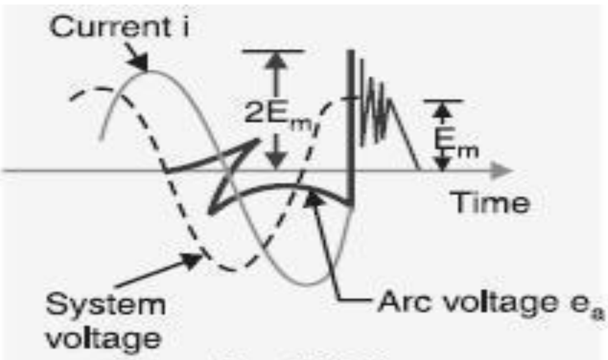


Fig. 19.18

When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage e is suddenly applied to the inductance and capacitance in series.

The voltage across the capacitance which is the voltage across the contacts of the circuit breaker can be calculated in terms of L, C, f_n and system voltage. The mathematical expression for transient condition is as follows.

As $v_c(t) = 0$ at t=0, constant= 0

$v_c(t)=E(1-\cos w_n t)$ or $v_c(t)=E(1-\cos \frac{1}{\sqrt{LC}} t)$ = Restriking voltage

The maximum value of restriking voltage = $2E_{peak}$ = 2 X Peak value of system voltage

The rate of rise of restriking voltage (RRRV) = $\frac{d}{dt}(1-\cos w_n t)$

$=w_n E \sin w_n t$ The

maximum value of RRRV= $w_n E = w_n E_{peak}$

Which appears across the capacitor C and hence across the contacts of the circuit breaker. This transient voltage, as already noted, is known as re-striking voltage and may reach an instantaneous peak value twice the peak phase-neutral voltage i.e. 2 E_m . The system losses cause the oscillations to decay fairly rapidly but the initial overshoot increases the possibility of re-striking the arc.

It is the rate of rise of re-striking voltage (R.R.R.V.) which decides whether the arc will re-strike or not. If is greater than the rate of rise of dielectric strength between the contacts, the arc will re-strike. However, the arc will fail to re-strike if R.R.R.V. is less than the rate of increase of dielectric strength between the contacts of the breaker.

The value of R.R.R.V. depends up on:

1. Recovery voltage
2. Natural frequency of oscillations

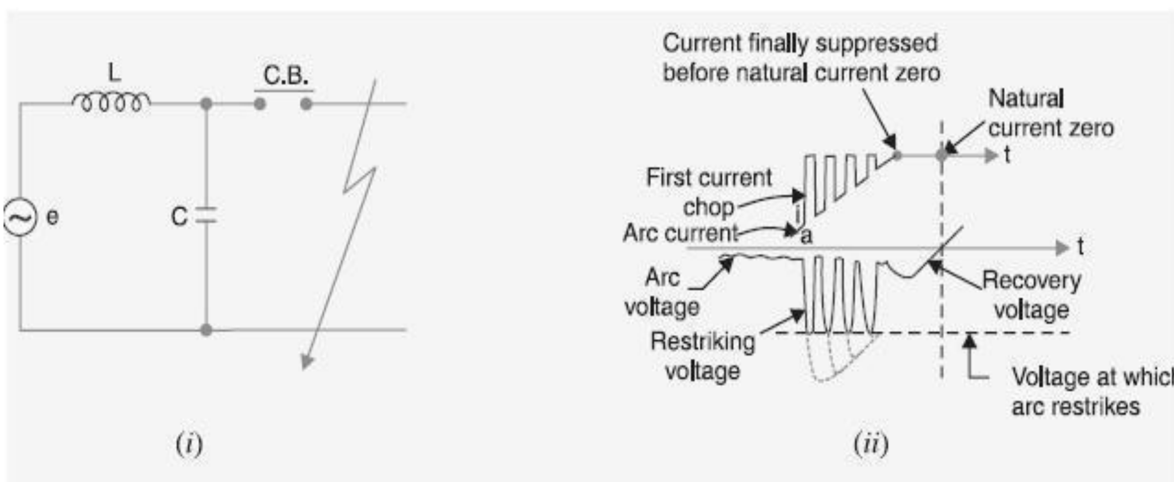
For a short-circuit occurring near the power station bus-bars, C being small, the natural frequency $\mathbf{f_n}$ will be high. Consequently, R.R.R.V. will attain a large value. Thus the worst condition for a circuit breaker would be that when the fault takes place near the bus-bars.

Current chopping:

It is the phenomenon of current interruption before the natural current zero is reached. Current chopping mainly occurs in air-blast circuit breakers because they retain the same extinguishing power irrespective of the magnitude of the current to be interrupted. When breaking low currents (e.g., transformer magnetizing current) with such breakers, the powerful de-ionizing effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is known as current chopping and results in the production of high voltage transient across the contacts of the circuit breaker as discussed below:

Consider again Fig. 19.17 (ii) repeated as Fig. 19.19 (i). Suppose the arc current is i when it is chopped down to zero value as shown by point a in Fig. 19.19 (ii). As the chop occurs at current i, therefore, the energy stored in inductance is $L\ i^2/2$.

The prospective voltage e is very high as compared to the dielectric strength gained by the gap so that the breaker restrike. As the de-ionizing force is still in action, therefore, chop occurs again but the arc current this time is smaller than the previous case. This induces a lower prospective voltage to re-ignite the arc. In fact, several chops may occur until a low enough current is interrupted which produces insufficient induced voltage to re-strike across the breaker gap. Consequently, the final interruption of current takes place.



Excessive voltage surges due to current chopping are prevented by shunting the contacts of the breaker with a resistor (resistance switching) such that re ignition is unlikely to occur. This is explained in Art 19.19

Capacitive current breaking:

Another cause of excessive voltage surges in the circuit breakers is the interruption of capacitive currents. Examples of such instances are opening of an unloaded long transmission line, disconnecting a capacitor bank used for power factor improvement etc. Consider the simple equivalent circuit of an unloaded transmission line shown in Fig.19.20. Such a line, although unloaded in the normal sense, will actually carry a capacitive current I on account of appreciable amount of capacitance C between the line and the earth.

Let us suppose that the line is opened by the circuit breaker at the instant when line capacitive current is zero [point 1 in Fig. 19.21. At this instant, the generator voltage V g will be maximum (i.e. V gm) lagging behind the current by 90º. The opening of the line leaves a standing charge on it (i.e., end B of the line) and the capacitor C1 is charged to V gm. However, the generator end of the line (i.e., end A of the line) continues its normal sinusoidal variations. The voltage V r across the circuit breaker will be the difference between the voltages on the respective sides. Its initial value is zero (point 1) and increases slowly in the beginning. But half a cycle later [point R in Fig. 19.21], the potential of the circuit breaker contact ‗A ‗ becomes maximum negative which causes the voltage across the breaker (V r) to become 2 V gm. This voltage may be sufficient to restrike the arc. The two previously separated parts of the circuit will now be joined by an arc of very low resistance. The line capacitance discharges at once to reduce the voltage across the circuit breaker, thus setting up high frequency transient. The peak value of the initial transient will be twice the voltage at that instant i.e., −4 V gm. This will cause the transmission voltage to swing to −4V gm to + V gm i.e., −3V gm.

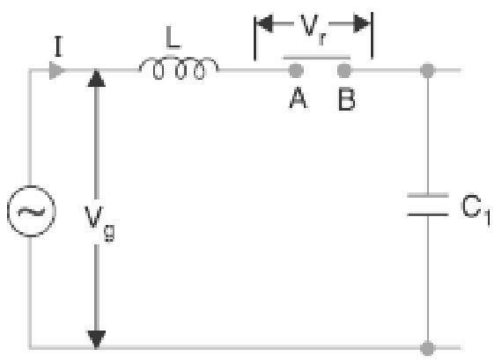


Fig. 19.20

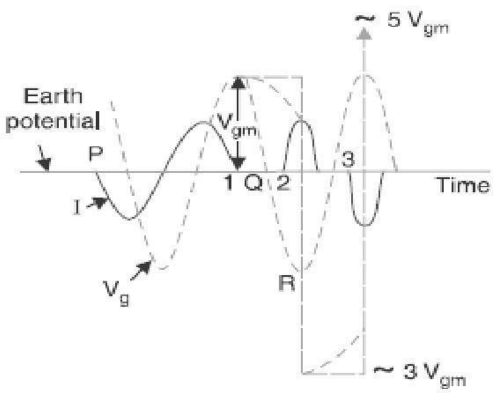


Fig. 19.21

The re-strike arc current quickly reaches its first zero as it varies at natural frequency. The voltage on the line is now −3 Vgm and once again the two halves of the circuit are separated and the line is isolated at this potential. After about half a cycle further, the aforesaid events are repeated even on more formidable scale and the line may be left with a potential of 5V gm above earth potential. Theoretically, this phenomenon may proceed

Infinitely increasing the voltage by successive increment of 2 times V gm.

While the above description relates to the worst possible conditions, it is obvious that if the gap breakdown strength does not increase rapidly enough, successive re-strikes can build up a dangerous voltage in the open circuit line. However, due to leakage and corona loss, the maximum voltage on the line in such cases is limited to 5 V gm.

Resistance Switching:

It has been discussed above that current chopping, capacitive current breaking etc. give rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R connected across the circuit breaker contacts as shown in the equivalent circuit in Fig. 19.22. This is known as resistance switching.

Referring to Fig. 19.22, when a fault occurs, the contacts of the circuit breaker are opened and an arc is struck between the contacts. Since the contacts are shunted by resistance R, a part of arc current flows through this resistance. This results in the decrease of arc current and an increase in the rate of de-ionization of the arc path. Consequently, the arc resistance is increased. The increased arc resistance leads to a further increase in current through shunt resistance. This process continues until the arc current becomes so small that it fails to maintain the arc. Now, the arc is extinguished and circuit current is interrupted.

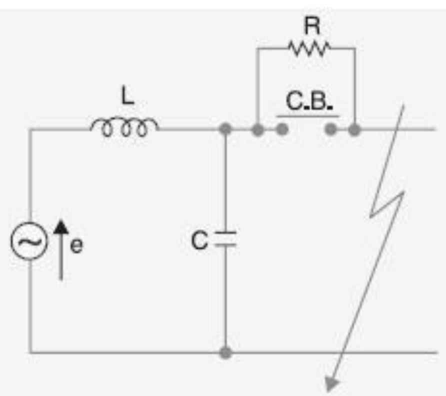


Fig. 19.22

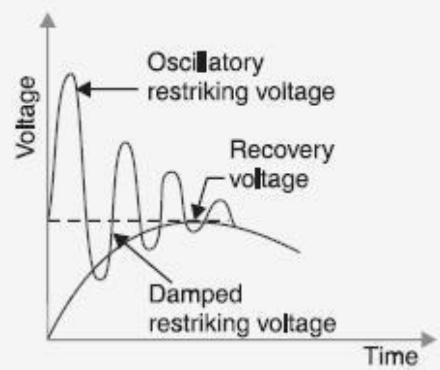


Fig. 19.23

Circuit Breaker Ratings:

A circuit breaker may be called upon to operate under all conditions. However, major duties are imposed on the circuit breaker when there is a fault on the system in which it is connected. Under fault conditions, a circuit breaker is required to perform the following three duties:

(i) It must be capable of opening the faulty circuit and breaking the fault current.

(ii) It must be capable of being closed on to a fault.

(iii) It must be capable of carrying fault current for a short time while another circuit breaker (in series) is clearing the fault.

Corresponding to the above mentioned duties, the circuit breakers have three ratings viz.

1. Breaking capacity
2. Making capacity and
3. Short-time capacity.

Breaking capacity:
It is current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g., power factor, rate of rise of restriking voltage).

The breaking capacity is always stated at the r.m.s. value of fault Current at the instant of contact separation. When a fault occurs, there is considerable asymmetry in the fault current due to the Presence of a d.c. component. The d.c. component dies away rapidly, a typical decrement factor being 0·8 per cycle. Referring to Fig. 19.24, the contacts are separated at DD´ At this instant, the fault current has

x = maximum value of a.c. component y =
d.c. component

Symmetrical breaking current = r.m.s. value of a.c. component $= \frac{x}{\sqrt{2}}$

Asymmetrical breaking current = r.m.s. value of total current

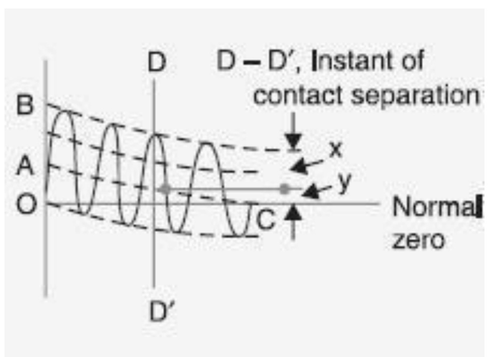


Fig. 19.24

It is a common practice to express the breaking capacity in MVA by taking into account the rated breaking current and rated service voltage. Thus, if I is the rated breaking current in amperes and V is the rated service line voltage in volts, then for a 3-phase circuit,

In India (or Britain), it is a usual practice to take breaking current equal to the symmetrical breaking current. However, American practice is to take breaking current equal to asymmetrical breaking current. Thus the American rating given to a circuit breaker is higher than the Indian or British rating. It seems to be illogical to give breaking capacity in MVA since it is obtained from the product of Short- circuit current and rated service voltage. When the short-circuit current is flowing, there is only a small voltage across the breaker contacts, while the service voltage appears across the contacts only after the current has been interrupted. Thus MVA rating is the product of two quantities which do not exist simultaneously in the circuit.

Making capacity:

There is always a possibility of closing or making the circuit under short circuit conditions. The capacity of a breaker to ―make‖ current depends upon its ability to withstand and close successfully against the effects of electromagnetic forces. These forces are proportional to the square of maximum instantaneous current on closing. Therefore, making capacity is stated in terms of a peak value of current instead of r.m.s. value.

The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaker is known as making capacity.

It may be noted that the definition is concerned with the first cycle of current wave on closing the circuit breaker. This is because the maximum value of fault current possibly occurs in the first cycle only when maximum asymmetry occurs in any phase of the breaker. In other words, the making current is equal to the maximum value of asymmetrical current. To find this value, we must multiply symmetrical breaking current by $\sqrt{2}$ to convert this from r.m.s. to peak, and then by 1·8 to include the ―doubling effect‖ of maximum asymmetry. The total multiplication factor becomes $\sqrt{2} \times 1{\cdot}8 = 2{\cdot}55$.

Making capacity =2·55 X Symmetrical breaking capacity

Short-time rating:

It is the period for which the circuit breaker is able to carry fault current while remaining closed. Sometimes a fault on the system is of very temporary nature and persists for 1 or 2 seconds after which the fault is automatically cleared. In the interest of continuity of supply, the breaker should not trip in such situations. This means that circuit breakers should be able to carry high current safely for some specified period while remaining closed i.e., they should have proven short-time rating. How ever, if the fault persists for duration longer than the specified time limit, the circuit breaker will trip, disconnecting the faulty section.

The short-time rating of a circuit breaker depends upon its ability to withstand The electromagnetic force effects and The temperature rise.

The oil circuit breakers have a specified limit of 3 seconds when the ratio of symmetrical breaking current to the rated normal current does not exceed 40. However, if this ratio is more than 40, then the specified limit is 1 second

Normal current rating:

It is the r.m.s. value of current which the circuit breaker is capable of carrying continuously at its rated frequency under specified conditions. The only limitation in this case is the temperature rise of current-carrying parts.

CIRCUIT BREAKER

Classification of Circuit Breakers:

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF6) or vacuum. Accordingly, circuit breakers may be classified into:

1. **Oil circuit breakers:** which employ some insulating oil (e.g., transformer oil) for arc extinction?
2. **Air-blast circuit breakers:** in which high pressure air-blast is used for extinguishing the arc.
3. **Sulphur hexafluoride circuit breakers:** in which Sulphur hexafluoride (SF6) gas is used for arc extinction.
4. **Vacuum circuit breakers:** in which vacuum is used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

Oil Circuit Breakers:

In such circuit breakers, some insulating oil (e.g., transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts (See Fig. 19.2). The arc extinction is facilitated mainly by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts. Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current †interrupted

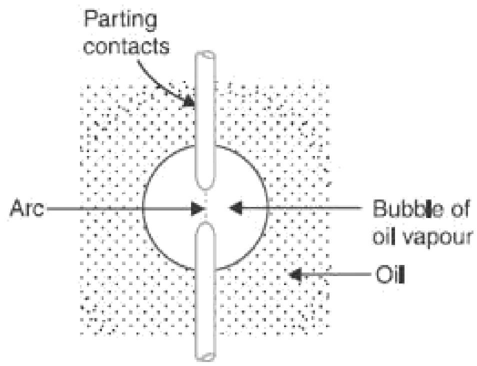


Fig. 19.2

The advantages of oil as an arc quenching medium are:

1. It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
2. It acts as an insulator and permits smaller clearance between live conductors and earthed components.
3. The surrounding oil presents cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium are*:*

1. It is inflammable and there is a risk of a fire.
2. It may form an explosive mixture with air
3. The arcing products (e.g., carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers:

The oil circuit breakers find extensive use in the power system. These can be classified into the following types:

1. Bulk oil circuit breakers
2. Low oil circuit breakers

Bulk oil circuit breakers:

Which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the current conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into:

1. Plain break oil circuit breakers
2. Arc control oil circuit breakers.

In the former type, no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

Plain Break Oil Circuit Breakers:

A plain-break oil circuit breaker involves the simple process of separating the contacts under the whole of the oil in the tank. There is no special system for arc control other than the increase in length caused by the separation of contacts. The arc extinction occurs when a certain critical gap between the contacts is reached. The plain- break oil circuit breaker is the earliest type from which all other circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil up to a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure in the dome of the circuit breaker. It also absorbs the mechanical shock of the upward oil movement. Fig. 19.3 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series

Under normal operating conditions, the fixed and moving contacts remain closed and the breaker carries the normal circuit Current. When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck which vaporizes the oil mainly into hydrogen gas.

The arc extinction is facilitated by the following processes:

The hydrogen gas bubble generated around the arc cools the arc column and aids the deionization of the medium between the contacts.

Disadvantages

There is no special control over the arc other than the increase in length by separating the moving contacts.
Therefore, for successful Interruption, Long arc length is necessary.
These breakers have long and inconsistent arcing times.

These breakers do not permit high speed interruption.

Due to these disadvantages, plain-break oil circuit breakers are used only for low voltage applications where high breaking-capacities are not important. It is a usual practice to use such breakers for low capacity installations for Voltages

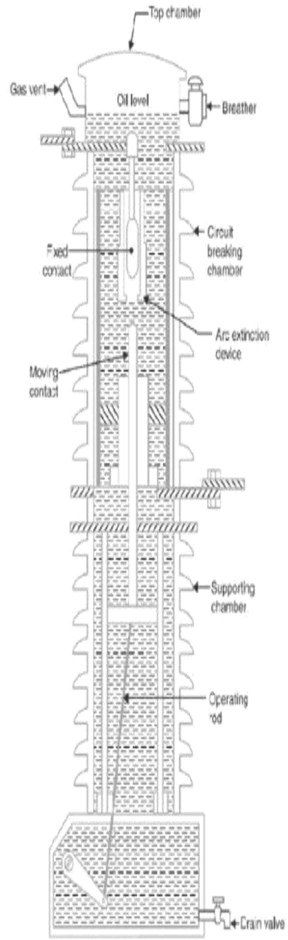


Fig. 19.7 Low-oil Circuit Breaker

not exceeding 11 kV.

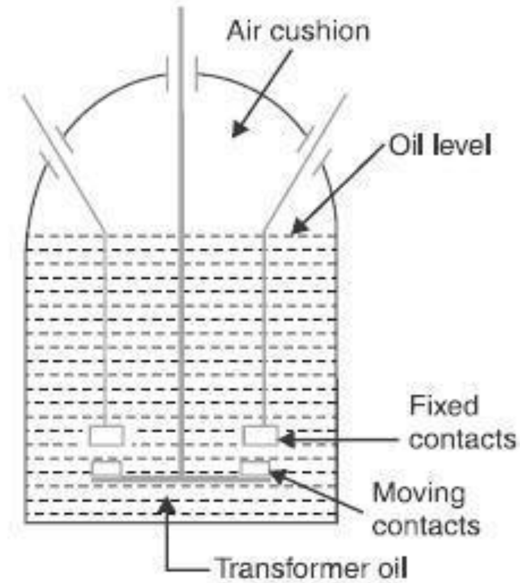


Fig. 19.3

Low Oil Circuit Breakers:

In the bulk oil circuit breakers discussed so far, the oil has to perform two functions. Firstly, it acts as an arc quenching medium and secondly, it insulates the live parts from earth. It has been found that only a small percentage of oil is actually used for arc extinction while the major part is utilized for insulation purposes. For this reason, the quantity of oil in bulk oil circuit breakers reaches a very high figure as the system voltage increases. This not only increases the expenses, tank size and weight of the breaker but it also increase the fire risk and maintenance problems.

The fact that only a small percentage of oil (about 10%) in the bulk oil circuit breaker is actually used for arc extinction leads to the question as to why the remainder of the oil, that is not immediately surrounding the device, should not be omitted with consequent saving in bulk, weight and fire risk. This led to the development of low-oil circuit breaker. A low oil circuit breaker employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for arc extinction. As regards quenching the arc, the oil behaves identically in bulk as well as low oil circuit breaker. By using suitable arc control devices, the arc extinction can be further facilitated in a low oil circuit breaker

Air-Blast Circuit Breakers:

These breakers employ a high pressure *air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

Types of Air-Blast Circuit Breakers:

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into:

1. **Axial-blast type** in which the air-blast is directed along the arc path as shown in Fig. 19.8(i).
2. **Cross-blast type** in which the air-blast is directed at right angles to the arc path as shown in Fig. 19.8 (ii).
3. **Radial-blast type** in which the air-blast is directed radially as shown in Fig. 19.8 (iii).

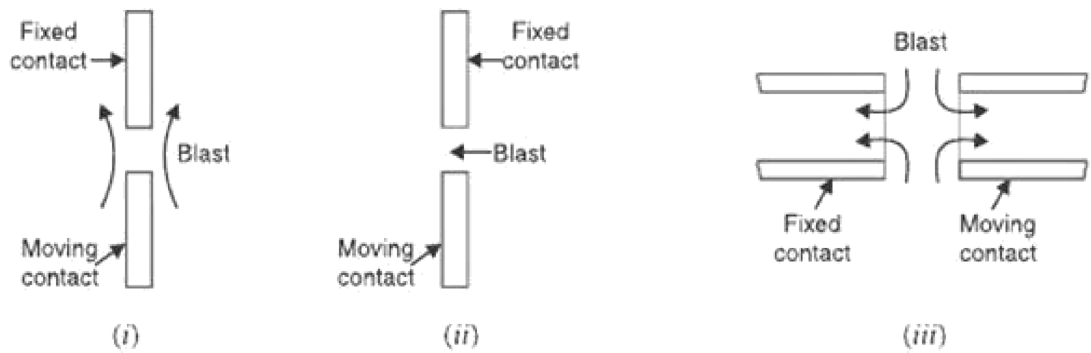


Fig. 19.8

Axial-blast air circuit breaker:

Fig 19.9 shows the essential components of a typical axial blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.

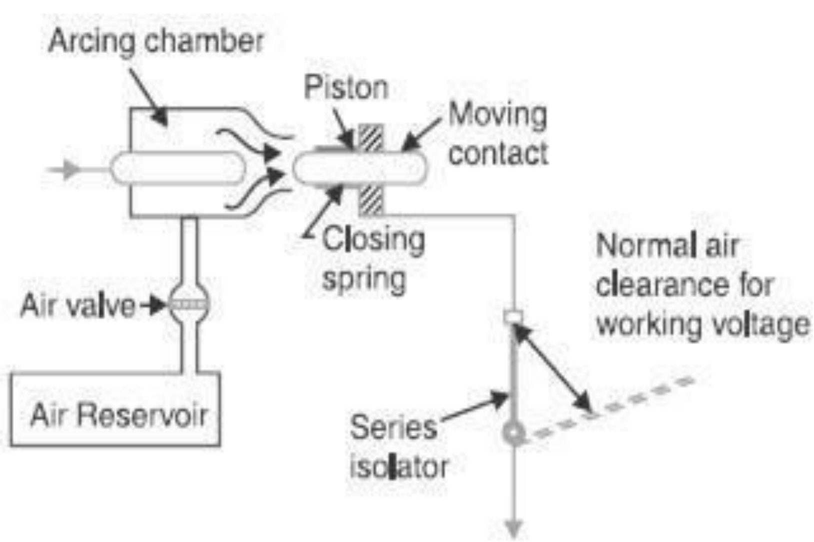


Fig. 19.9

When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and an arc is struck. At the same time, high pressure air blast flows along the arc and takes away the ionized gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

It may be noted that in such circuit breakers, the contact separation required for interruption is generally small (1·75 cm or so). Such a small gap may constitute inadequate clearance for the normal service voltage. Therefore, an isolating switch is incorporated as a part of this type of circuit breaker. This switch opens immediately after fault interruption to provide the necessary clearance for insulation.

Sulphur Hexafluoride (SF6) Circuit Breaker

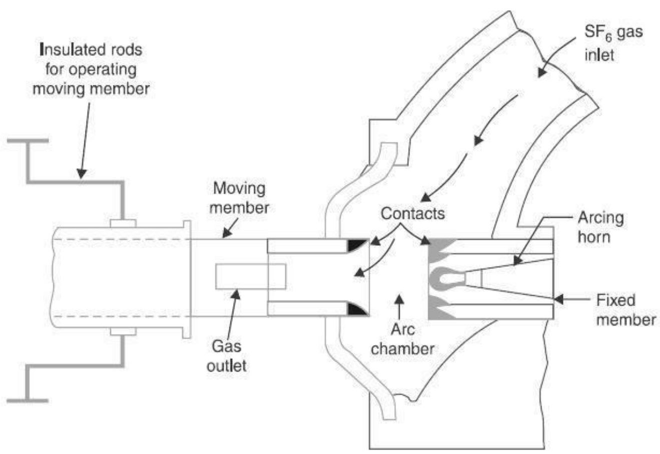


Fig. 19.11

Construction:

Fig. 19.11 shows the parts of a typical SF6 circuit breaker. It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF6 gas. This chamber is connected to SF6 gas reservoir. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF6 gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF6 gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF6 gas is Costly, it is reconditioned and reclaimed by suitable auxiliary system after each operation of the breaker.

Working:

In the closed position of the breaker, the contacts remain surrounded by SF6 gas at a pressure of about 2·8 kg/cm. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF6 gas at 14 kg/cm pressure from the reservoir to the arc interruption chamber. The high pressure flow of SF6 rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (i.e., after arc extinction), the valve is closed by the action of a set of springs

Advantages:

Due to the superior arc quenching properties of SF6 gas, the SF6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below:

1. Due to the superior arc quenching property of SF6, such circuit breakers have very short arcing time.
2. Since the dielectric strength of SF6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
3. The SF6 circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker
4. The closed gas enclosure keeps the interior dry so that there is no moisture problem.
5. There is no risk of fire in such breakers because SF6 gas is non-inflammable.
6. There are no carbon deposits so that tracking and insulation problems are eliminated.
7. The SF6 breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.
8. Since SF6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists e.g., coal mines

Disadvantages:

1. SF6 breakers are costly due to the high cost of SF6.
2. Since SF6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose.

Applications:

A typical SF6 circuit breaker consists of interrupter units each capable of dealing with currents up to 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system

voltage. SF6 circuit breakers have been developed for voltages 115 kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

Vacuum Circuit Breakers (VC B):

In such breakers, vacuum (degree of vacuum being in the range from 10 to 10 torr) is used as the arc quenching medium. Since vacuum offers the highest insulating strength, it has far superior arc quenching properties than any other medium. For example, when contacts of a breaker are opened in vacuum, the interruption occurs at first current zero with dielectric strength between the contacts building up at a rate thousands of times higher than that obtained with other circuit breakers.

Principle:

The production of arc in a vacuum circuit breaker and its extinction can be explained as follows:
When the contacts of the breaker are opened in vacuum (10 to 10 torr), an arc is produced between the contacts by the ionization of metal vapours of contacts. However, the arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arc quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum

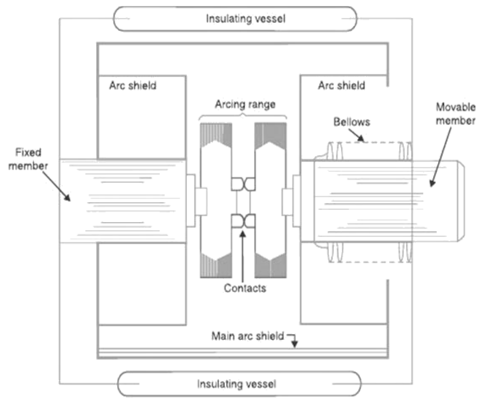


Fig. 19.12

Construction:

Fig. 19.12 shows the parts of a typical vacuum circuit breaker. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

Working:

When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionization of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0·625 cm).

Vacuum circuit breakers have the following advantages:

1. They are compact, reliable and have longer life.
2. There is no generation of gas during and after operation.
3. They can interrupt any fault current. The outstanding feature of a V C B is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

4. They require little maintenance and are quiet in operation.
5. They have low arc energy.
6. They have low inertia and hence require smaller power for control mechanism.

Applications:

For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas

UNIT THREE: PROTECTIVE RELAYS & APPLICATION

Fundamentals of Power System Protection

The purpose of an Electric Power System is to generate and supply electrical energy to consumers. The power system should be designed and managed to deliver this energy to the utilization points with both reliability and economically

The capital investment involved in power system for the generation, transmission and distribution is so great that the proper precautions must be taken to ensure that the equipment not only operates as nearly as possible to peak efficiency, but also must be protected from accidents

Zones and types of Protection system

Zones of Protection system

- An electric power system is divided into several zones of protection. Each zone of protection, contains one or more components of a power system in addition to two circuit breakers.
- When a fault occurs within the boundary of a particular zone, then the protection system responsible for the protection of the zone acts to isolate (by tripping the Circuit Breakers) every equipment within that zone from the rest of the system.
- The circuit Breakers are inserted between the component of the zone and the rest of the power system. Thus, the location of the circuit breaker helps to define the boundaries of the zones of protection.

Primary Protection

– The primary protection scheme ensures fast and selective clearing of any fault within the boundaries of the circuit element, that the zone is required to protect. Primary Protection as a rule is provided for each section of an electrical installation.

However, the primary protection may fail. The primary cause of failure of the Primary Protection system are enumerated below.

- Current or voltage supply to the relay.
- D.C. tripping voltage supply
- Protective relays

- Tripping circuit
- Circuit Breaker

Back-up Protection

Back-up protection is the name given to a protection which backs the primary protection whenever the later fails in operation. The back-up protection by definition is slower than the primary protection system. The design of the back-up protection needs to be coordinated with the design of the primary protection and essentially it is the second line of defense after the primary protection system.

Protection System Requirements and some basic terminologies used

- The fundamental requirements for a protection system are as follows:

Reliability: It is the ability of the protection system to operate correctly. The reliability feature has two basic elements, which are dependability and security. The dependability feature demands the certainty of a correct operation of the designed system, on occurrence of any fault. Similarly, the security feature can be defined as the ability of the designed system to avoid incorrect operation during faults. A comprehensive statistical Method based reliability study is required before the protection system may be commissioned. The factors which affect this feature of any protection system depends on some of the following few factors.

a) Quality of Component used

b) Maintenance schedule

c) The supply and availability of spare parts and stocks

d) The design principle

e) Electrical and mechanical stress to which the protected part of the system is subjected to.

Speed: Minimum operating time to clear a fault in order to avoid damage to equipment. The speed of the protection system consists primarily of two time intervals of interest.

a) The Relay Time: This is the time between the instant of occurrence of the fault to the instant at which the relay contacts open.

b) The Breaker Time: This is the time between the instant of closing of relay contacts to the instant of final arc extinction inside the medium and removal of the fault.

Selectivity: This feature aims at maintaining the continuity of supply system by disconnecting the minimum section of the network necessary to isolate the fault. The property of selective tripping is also known as "discrimination". This is the reason for which the entire system is divided into several protective zones so that minimum protion of network is isolated with accuracy. Two examples of utilization of this feature in a relaying scheme are as follows

a) Time graded systems

b) Unit systems

Sensitivity: The sensitivity of a relay refers to the smallest value of the actuating quantity at which the relay operates detecting any abnormal condition. In case of an overcurrent

relay, mathematically this can be defined as the ratio between the short circuit fault current (I_s) and the relay operating current (I_o). The value of I_o , should not be too small or large so that the relay is either too sensitive or slow in responding.

Stability: It is the quality of any protection system to remain stable within a set of defined operating scenarios and procedures. For example the biased differential scheme of differential protection is more stable towards switching transients compared to the more simple and basic Merz Price scheme in differential protection

Adequacy: It is economically unviable to have a 100% protection of the entire system in concern. Therefore, the cost of the designed protection system varies with the criticality and importance of the protected zone. The protection system for more critical portions

is generally costly, as all the features of a good protection system is maximized here. But a small motor can be protected by a simple thermally operated relay, which is simple and cheap. Therefore, the cost of the protection system should be adequate in its cost.

Classification and construction of relays

Classification

Protection relays can be primarily classified in accordance with their construction, the actuating signal and application and function

According to the Construction principle

Depending upon the principle of construction, the following four brad categories are found.

- Electromechanical
- Solid State
- Microprocessor

Electromechanical relays

These relays are constructed with electrical, magnetic & mechanical components & have an operating coil & various contacts,& are very robust & reliable. Based on the construction, characteristics, these are classified in three groups.

Attraction relays

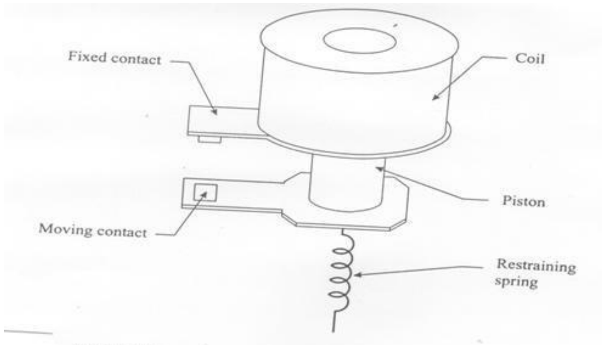
Attraction relays can be AC & DC and operate by the movement of a piece of iron when it is attracted by the magnetic field produced by a coil. There are two main types of relays:

1. The attracted armature type
2. Solenoid type relay

Attracted armature relays

- Consists of a bar or plate (made of iron) that pivots when it is attracted towards the coil.
- The armature carries the moving part of the contact ,which is closed or opened, according to the design, when the armature is attracted to the coil.

3. Solenoid type relays
   In this a plunger or a piston is attracted axially within the field of the solenoid. In this case, the piston carries the moving contacts.



Solenoid-type relay

Classification of induction relays

1. Shaded pole relay

2. Watthour- meter type relay

3. Cup type relay

The air gap flux produced by the current flowing in a single coil is split into two out of phase components by a so called „Shading Ring" generally of copper, that encircles part of the pole face of each pole at the air gap.

- The shading ring may be replaced by coils if control of operation of the shaded pole relay is desired.
- The inertia of the disc provides the time delay characteristics.
  Watt hour –meter structure
- This structure gets its name from the fact that it is used in watt hour meters.
- As shown in the top figure below, it contains two separate coils on two different magnetic circuit, each of which produces one of two necessary fluxes for driving the rotor, which is also a disc

Induction-cup

- This type of relay has a cylinder similar to a cup which can rotate in the annular air gap between the poles & the fixed central core. The figure is shown above.
- The operation of this relay is similar to that of an induction motor with salient poles for

the windings of the stator.

- The movement of the cup is limited to a small amount by the contact & the stops.
- A special spring provides restraining torque.
- The cup type of relay has a small inertia & is therefore principally used when high speed operation is required, for example in instantaneous units.

General Torque equation of Relay

Before understanding about different other relays, it is first necessary to know the general torque equation that defines any relay. The following equation defines torque in general.

$$T = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \tau) + K_4$$

Where, θ is the power factor angle and τ is the angle of maximum torque.

As seen from the equation, the component of torques may be proportional to current, voltage, power and combination of the three quantities. The constant K_4 is meant for the spring constant of the relay. Depending upon the type of relay, the one or several of the four constants K_1–K_4 are either zero or non zero. In the subsequent discussions this will be elaborated when different types of relays are discussed.

Overcurrent Relays

- Protection against excess current was naturally the earliest protection systems to evolve
- From this basic principle has been evolved the graded over current system, a discriminate fault protection.
- “over current” protection is different from “over load protection”.
- Overload protection makes use of relays that operate in a time related in some degree to the thermal capability of the plant to be protected.
- Over current protection, on the other hand, is directed entirely to the clearance of the faults, although with the settings usually adopted some measure of overload protection is obtained.

- In terms of the general torque equation the over current relay has both constants K_2 and K_3 equal to zero. Therefore, the equation becomes

$$T = K_1 I^2 + K_4$$

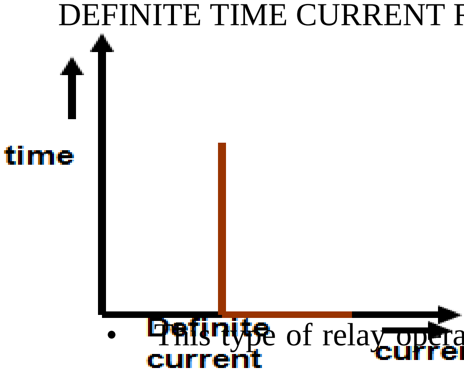
1.6.1 Types of over current relays

- Based on the relay operating characteristics , overcurrent relays can be classified into three groups
  - Definite current or instantaneous
  - Definite time
  - Inverse time

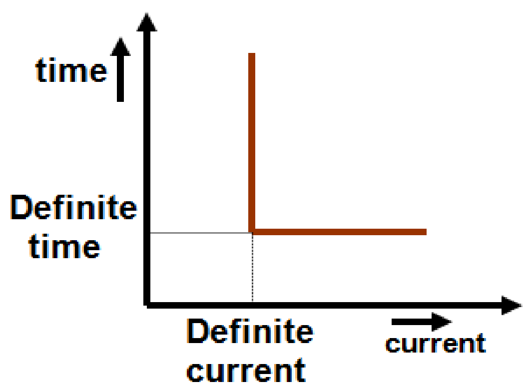
DEFINITE-CURRENT RELAYS

- This type of relay operates instantaneously when the current reaches a predetermined value.

DEFINITE TIME CURRENT RELAYS



- This type of relay operates after a definite time when the current reaches a pre- determined value.



INVERSE TIME RELAYS

- The fundamental property of these relays is that they operate in a time that is inversely proportional to the fault current. Inverse time relays are generally classified in accordance with their characteristic curve that indicates the speed of operation.
- Inverse-time relays are also referred as inverse definite minimum time or IDMT over

current relays

SETTING THE PARAMETERS OF TIME DELAY OVERCURRENT RELAY

Pick-up setting

The pick-up setting, or plug setting, is used to define the pick-up current of the relay, and fault currents seen by the relay are expressed as multiples of plug setting.

- Plug setting multiplier (PSM) is defined as the ratio of the fault current in secondary Amps to the relay plug setting.
- For phase relays the pick-up setting is determined by allowing a margin for overload above the nominal current, as in the following expression

Pick-up setting = (OLF x I_{nom}) / CTR

Where, OLF = Overload factor that depends on the element being protected. I_{nom} = Nominal circuit current rating, and CTR = CT Ratio

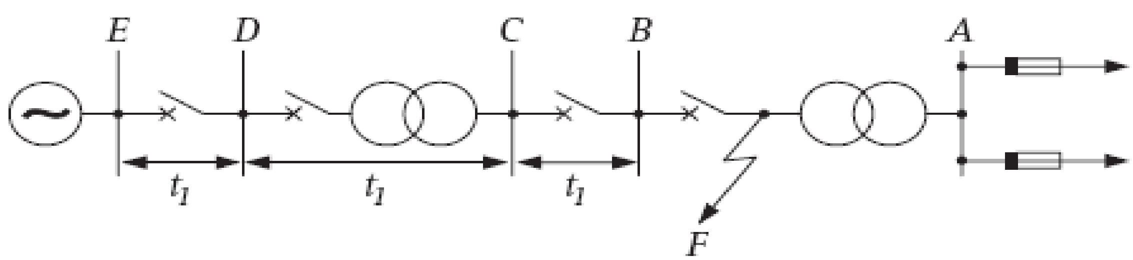
Time dial setting

- The time-dial setting adjusts the time –delay before the relay operates whenever the fault current reaches a value equal to, or greater than the relay setting.
- The time-dial setting is also referred to as time multiplier setting (TMS)

DISCRIMINATION BY TIME

In this method an appropriate time interval is given by each of the relays controlling the CBs in a power system to ensure that the breaker nearest to the fault location opens first.

A simple radial distribution system is considered to illustrate this principle



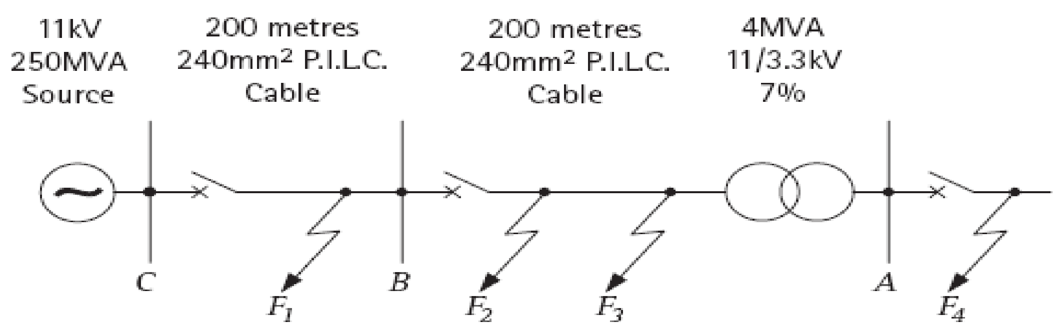
A radial distribution system with time-discrimination

- The main disadvantage of this method of discrimination is that the longest fault clearance time occurs for faults in the section closest to the power source, where the fault level is highest.

DISCRIMINATION BY CURRENT

- Discrimination by current relies on the fact that the fault current varies with the position of the fault, because of the difference in impedance values between the source and the fault.

- The relays controlling CBs are set to operate at suitably tapered values such that only the relay nearest the fault trips its circuit breaker.



Inverse time over current relay characteristic is evolved to overcome the limitations imposed by the independent use of either time or over current coordination. Directional Over Current Relays

1. When fault current can flow in both the directions through the relay, at its location. Therefore, it is necessary to make the relay respond for a particular defined direction, so that proper discrimination is possible. This can be achieved by introduction of directional control elements.

2. These are basically power measuring devices in which the system voltage is used as a reference for establishing the relative phase of the fault current.

Basically, an AC directional relay can recognize certain difference in phase angle between two quantities, just as a D.C. directional relay recognize difference in polarity

1.7.1The polarizing quantity of a directional relay

1. It is the reference against which the phase angle of the other quantity is compared. Consequently the phase angle of the polarizing quantity must remain fixed when other quantity suffers wide change in phase angle.

2. The voltage is chosen as the "polarizing" quantity in the current-voltage induction type directional relay.

3. Four pole induction cup construction is normally used.

Distance relay

Distance relay is used for the protection of transmission line & feeders

In a distance relay, instead of comparing the local line current with the current at far end of line, the relay compares the local current with the local voltage in the corresponding phase or suitable components of them

Principle of operation of distance relay

1. The basic principle of measurement involves the comparison of fault current seen by the relay with the voltage at relaying point; by comparing these two quantities.
2. It is possible to determine whether the impedance of the line up to the point of fault is greater than or less than the predetermined reach point impedance

There are two types of torques

1. Restraining torque

$$T_r \alpha V_F^2$$

2. Operating torque

$$T_0 \alpha I_F^2$$

The relay trips when T_0 greater than T_r

$$KI^2 > V^2$$

F F

$$\frac{V_F}{I_F} < \sqrt{K}$$

The constant K depends on the design of the electromagnets.

Types of distance relay

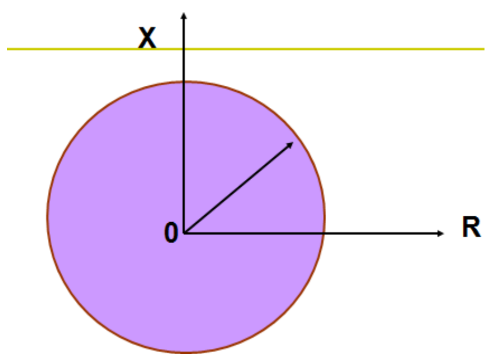
Distance relays are classified depending on their operating characteristic in the R-X plane

- Impedance Relay
- Mho Relay
- Reactance Relay

IMPEDANCE RELAY:

The torque equation T, for such a relay the current actuates the operating torque and the voltage actuates the restraining torque, with the usual spring constant K_4.

$$T = K I^2 + K V^2 + K$$



Considering K_2 to be negative (as it produces the restraining torque) and neglecting the torque component due to spring, the equation represents a circle in the R-X plane.

DISADVANTAGE OF IMPEDANCE RELAY

1. It is not directional.

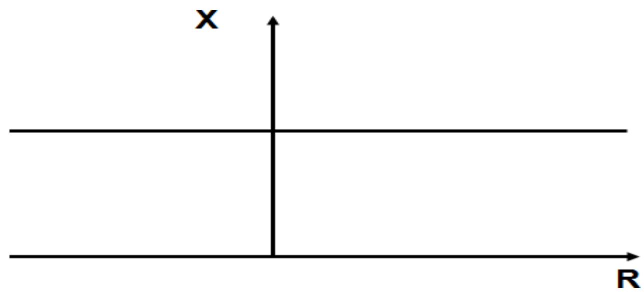
2. It is affected by the Arc resistance

3. It is highly sensitive to oscillations on the power system, due to large area covered by its circular characteristic

REACTANCE RELAY

The reactance relay is basically a directional restrained overcurrent relay. Therefore, the actuating quantity is current and the equation becomes as follows, where the constant K_2 is zero.

$$T = K_1 I^2 + K_3 VI \cos(\theta - \tau) + K_4$$



R . This relay has a larger coverage of R-X plane and therefore it is least affect ted by condition of power swing.

$Z = K$

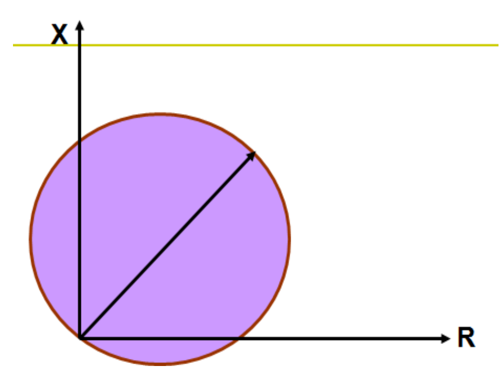
In the above equation, constant K_1 is positive as the current produces operating torque and K_3 is negative as the power direction produces restraining torque. In the above equation the angle τ is considered as 90^0. So the equation derives to

$$T = K I^2 - K VI \cos(\theta - 90) + K \geq 0$$

resembles a horizontal line parallel to the R-axis with constant X value. The portion below the line gives the operating zone of the relay.

1. The reactance relay is designed to measure only reactive component of the line reactance.

2. The fault resistance has no affect on the reactance relay



MHO RELAY

The Mho relay combines the properties of impedance and directional relays. Its characteristic is inherently directional and the relay only operates for faults in front of the relay location. In terms of the torque equation the relay characteristics can be obtained by making the constant

K_1 equal to zero. It is basically a voltage restrained directional relay and the torque equation becomes.

$$T = K\ VI\ Cos(\theta - \tau) - K\ V^2 - K \geq 0$$

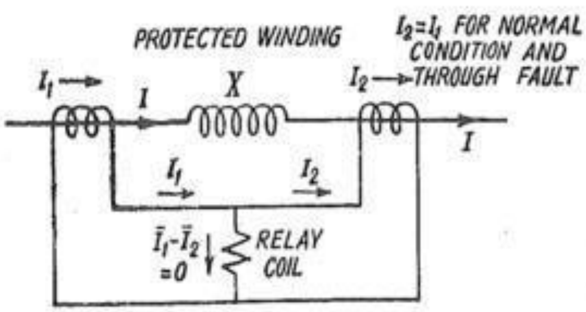
3

Differential Relay

One of the most prevalent and successful method of protecting a circuit is to arrange relays to compare the currents entering and leaving it, which should be the same under normal conditions and during an external fault. Any difference current must be flowing in to a fault within the protected circuit

Principle of circulating current differential (MERZ-PRIZE) protection

The figure below illustrates the principle of differential protection of generator and transformer, X is the winding of the protected machine. Where there is no internal fault, the current entering in X is equal in phase and magnitude to current leaving X. The CT's have such a ratio that during the normal conditions or for external faults (Through Faults) the secondary current of CT's are equal. These current say I_1 and I_2 circulate in the pilot wire. The polarity connections are such the current I_1 and I_2 are in the same direction of pilot wire during normal condition or external faults. Relay operation coil is connected at the middle of pilot wires. Relay unit is of over current type



For Through Fault
Fig. 1 (a). Principle of circulating current relay of generators, transformers.

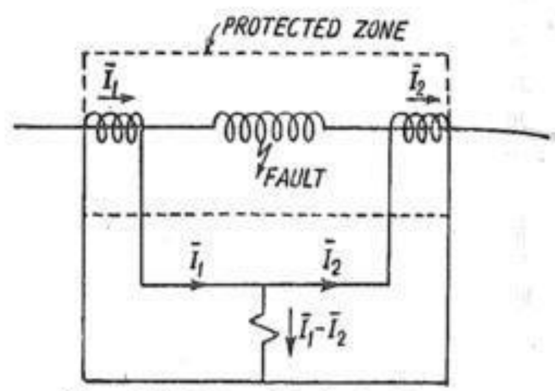


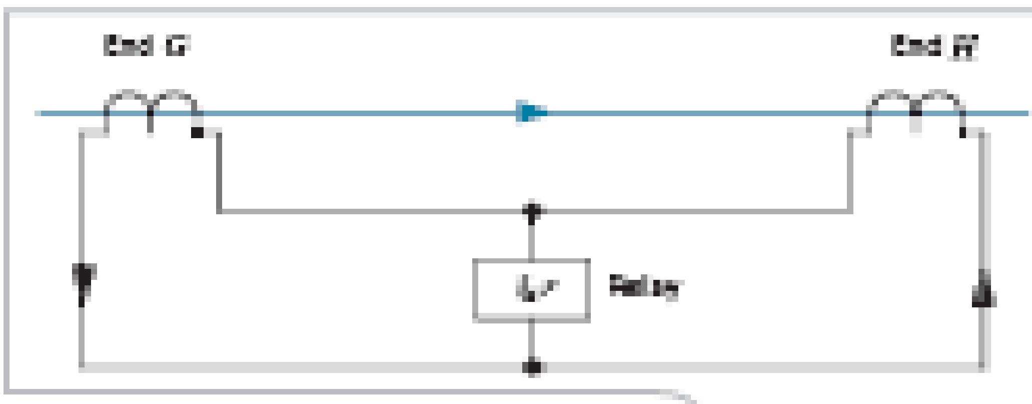
Fig. 1 (b). Internal Fault : $I_1 - I_2 \neq 0$.

During normal condition and external fault the protection system is balanced and the CT's ratios are such that secondary currents are equal. These current circulate in pilot wires. The vector differential current I_1-I_2 which flow through the relay coil is zero.

I_1-I_2 = 0 (normal condition or external faults)

This balance is disturbed for internal faults. When fault occurs in the protected zone, the current entering the protected winding is no more equal to the leaving the winding because some current flows to the fault. The differential I_1-I_2 flows through the relay operating coil and the relay operates if the operating torque is more than the restraining torque.

The current I_1 and I_2 circulate in the secondary circuit. Hence CT's does not get damaged. Polarities of CT's should be proper, otherwise the currents I_1 and I_2 would add up even for normal condition and mal operate the relay.



Differential Protection current balance

- When this system is applied to electrical equipment (Generator stator windings, Transformer, Bus bars etc.) it is called differential current protection.
- When it is applied to lines and cables it is called pilot differential protection because pilot wires or an equivalent link or channel is required to bring the current to the relay from the remote end of the line.

The CTs at both ends of the protected circuit connected so that for through load or through fault conditions current circulates between the interconnected CTs. The over-current relay is normally connected across equipotential points and therefore doesn"t operate.

- Circulating current balance methods are widely used for apparatus protection where CTs are within the same substation area and interconnecting leads between CTs are short (e.g. generator stator windings, Transformer, Bus bars etc.)

- The circulating current balance method is also called longitudinal differential protection or Merz-Price differential protection system.

- The current in the differential relay would be proportional to the phasor difference between the currents that enter and leave the protected circuit. If the current through the relay exceeds the pick-up value, then the relay will operate.

Demerits of a Differential Relay(Merz Price Scheme)

1. **Unmatched characteristics of C.T.s** : Though the saturation is avoided, there exist difference in the C.T. characteristics due to ratio error at high values of short circuit currents. This causes an appreciable difference in the secondary currents which can operate the relay. So the relay operates for through external faults.

This difficulty is overcome by using percentage differential relay. In this relay, the difference in current due to the ratio error exists and flows through relay coil. But at the same time the average current ($I_1 + I_2/2$) flows through the restraining coil which produces enough restraining torque. Hence relay becomes inoperative for the through faults.

2. **Ratio change due to tap change**: To alter the voltage and current ratios between high voltage and low voltage sides of a power transformer, a tap changing equipment is used. This is an important feature of a power transformer. This equipment effectively alters the turns ratio. This causes unbalance on both sides. To compensate for this effect, the tapping can be provided on C.T.s also which are to be varied similar to the main power transformer. But this method is not practicable.

The percentage differential relays ensure relays ensure the stability with respect to the amount of unbalance occurring at the extremities of the tap change range.

3. **Difference in lengths of pilot wires**: Due to the difference in lengths of the pilot wires on both sides, the unbalance condition may result. The difficulty is overcome by connecting the adjustable resistors in pilot wires on both sides. These are called balancing resistors. With the help of these resistors, equipotential points on the pilot wires can be adjusted. In percentage differential relays the taps are provided on the operating coil and restraining coil to achieve an

accurate balance.

4. **Magnetizing current inrush**: When the transformer is energized, the condition initially is of zero induced E.m.f. A transient inflow of magnetizing current occurs in to the transformer. This current is called magnetizing inrush current. This current may be as great as 10 times the full load current of the transformer. This decays very slowly and is bound to operate differential protection of the transformer falsely, because of the temporary difference in magnitude of the primary and secondary currents.

The factors which affect the magnitude and direction of the magnetizing inrush current can be one of the following reasons.

a. Size of the transformer.

b. Size of the power system

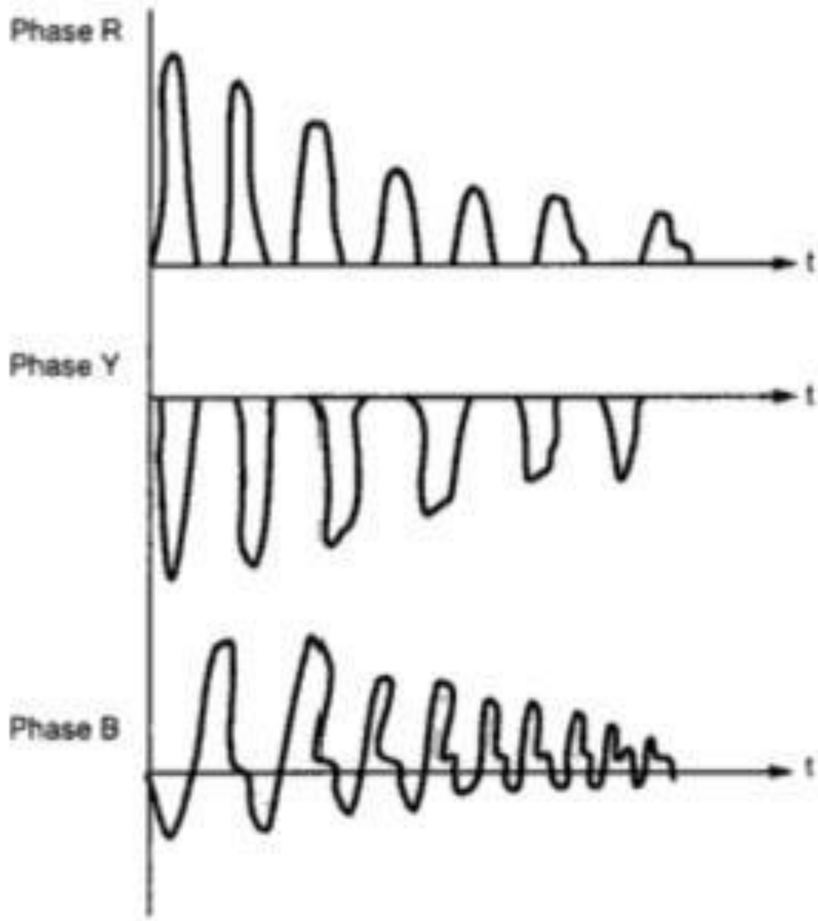
c. Type of magnetic material used for the core.

d. The amount of residual flux existing before energizing the transformer.

e. The method by which transformer is energized.

If the transformer is energized when the voltage wave is passing through zero, the magnetizing current inrush is maximum. At this instant, the current and flux should be maximum in highly inductive circuit. And in a half wave flux reversal must take place to attain maximum value in the other half cycles. If the residual flux exists, the required flux may be in same or opposite direction. Due to this magnetizing current inrush is less or more. If it is more, it is responsible to saturate the core which further increases its component.

This current decays rapidly for first few cycles and then decays slowly. The time constant L/R of the circuit is variable as inductance of circuit varies due to the change in permeability of the core. The losses in the circuit damp the inrush currents. Depending on the size of the transformer, the time constant of



inrush current varies from 0.2 sec to 1 sec.

The waveforms of magnetizing inrush current in three phases are shown in the figure below

Biased or per cent Differential Relay

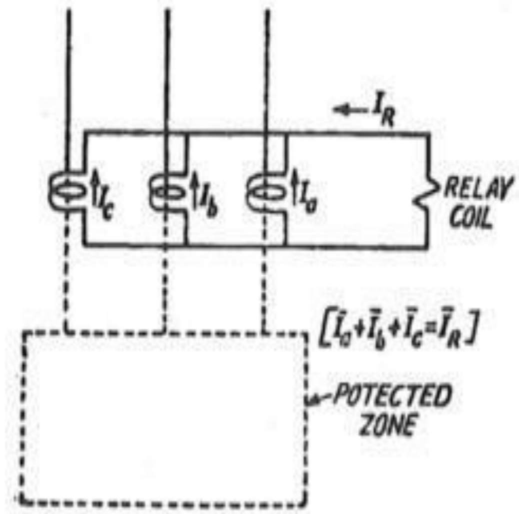
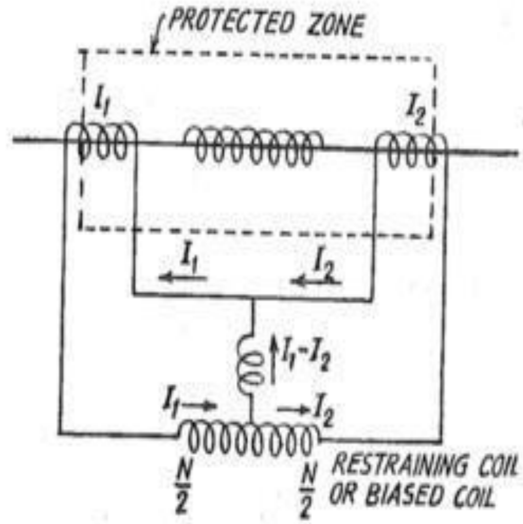


Fig. 2. Differential Protection of 3-phase circuit.



$$\text{A.T.} = \left(\frac{I_1 + I_2}{2}\right)N$$

Fig. 3. Per cent Differential Relay. (Biased Differential Relay.)

The reason for using this modification in the circulating current scheme, is to overcome the trouble arising out of differences in CT ratios for high values of external short circuit currents. The percentage differential relay has an additional restraining coil connected in the pilot wire as shown in the above figure.

In this relay the operating coil is connected to the mid-point of the restraining coil. The restraining torque therefore is proportional to the sum of ampere turns in its two halves, i.e $(I_1N/2) + (I_2N/2)$ which gives the average restraining current of $(I_1 + I_2)/2$ in N turns. For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal- operation. The operating characteristic of the relay is given in the figure below.

The ratio of differential operating current to average restraining current is a fixed percentage and the value of which decides the nature of the characteristics. Therefore, the relay is also called 'percentage differential relay'.

The relay is also called 'Biased differential relay' because the restraining coil (bias coil) biases the main flux by some additional flux.

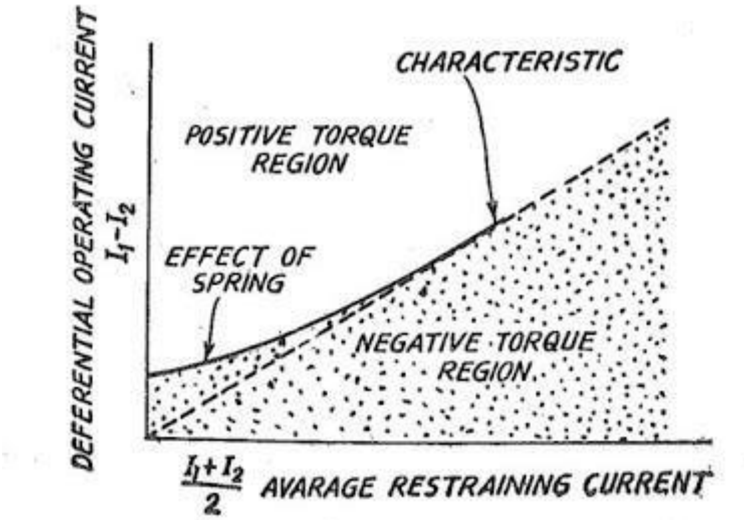


Fig. 4. Operating characteristic of differential relay.

The percentage of biased differential relay has a rising single pick up characteristic. As the magnitude of through current increases, the restraining current decreases.

UNIT IV: STATIC & DIGITAL RELAYS

Static relays

Advantages of static relays

- Due to the amplification of energizing signals obtainable, the sources need only provide low power. Therefore the size of the associated current and voltage transformers could be reduced.
- Improved accuracy and selectivity.
- Fast operation of relays and hence fast clearance of faults.
- Flexibility of circuitry would allow new and improved characteristics.
- The relays would be unaffected by the number of operations.

Basic circuits employed

- Timers
- Phase comparators
- Amplitude Comparator
- Level detectors
- Integrators
- Polarity detectors

High reliability operational amplifiers are used for realizing the basic components of static relays.

Numerical protection

Numerical relays are technically superior to the conventional type relays. Their general characteristics are :

- Reliability
- Self diagnosis
- Event and disturbance records

- The digital relay does not record the analog signal,but only samples of the signal, which are spread in time.
- the mathematics of discrete signal processing is used.
- The relay is programmed to apply various forms of digital signal processing algorithms to the observed samples and based on the results of these computations,the decision to trip is made.

Different components of a digital relay

i) Isolation transformer and surge protection circuit

ii) Multiplexor and S/H circuits

iii) Anti Aliasing Filters

iv) Digital Input and Output systems.

v) Central Processing unit

vi) Event Storage system

vii) Signal conditioning circuit.

viii) Communication Peripherals

ix) Power Supply Block

x) Sampling Clock

Isolation transformer and surge protection circuit:

Since the digital circuits are highly vulnerable to switching and lightening surge therefore, proper isolation of the circuits with isolation transformer and surge protection circuit is required.

Multiplexors and S/H Circuits:

Multiplexors and sample and hold (S/H) circuits are required for converting the analog signals to digital. The widely accepted Shannon‟s sampling theorem is used for sampling the analog signal.

Anti Aliasing Filter

The anti aliasing filters are basically low pass filters are basically low pass filters which block unwanted frequencies.

The Digital input output system

This system actually gathers data and status reports of C.B. contacts status, other relay states, reset signals etc. Also the output systems generate and provide the tripping, alarm and any other control signal.

Central Processing Unit

It is the core component of the system which performs all the logics and algorithms regarding different characteristics, maintains timing function and communicates with the external device. Therefore, this the most vital block of the numerical system.

Event Storage System, RAM, ROM, EPROM:

The RAM store the input sample data temporarily and buffer data permanently. It is processed during the execution of relay algorithm. The ROM stores the relay algorithm permanently.
EPROM is used to store certain parameters such as the relay setting, or any other relevant data. The event storage system basically stores the historical data such as fault related data, transient data, event time data.

Communication Peripherals:

The relay setting, data uploading and event data recording are done through various communication peripherals following a protocol IEC61850, which increases inner coordination between the relays among the local and remote substation equipment.

STATIC RELAYS

Introduction:

A static relay employ solid state components like transistors, diodes, ICs and other electronic components etc for the measurement or comparison of electrical quantities and gives a signal to close the trip circuit when threshold condition is reached. The tripping device may be of electronic or electromagnetic. This static relays consist of comparator circuit which compares two or more currents or voltages and gives and output signal to a slave relay or a thyristor circuit. The slave relay is an electromagnetic relay which finally closes the contacts of the trip circuit. The static relay that consists of slave relay are called as Semi – static relays. The relays employing Thyristor circuit are pure Static relays.

Advantages of Static relays:

1. Long life.
2. High resistance to shock and vibration.
3. Burden on C.T.s and P.T.s. is reduced as they consume less power and in most cases they draw power from the auxiliary DC supply.
4. Fast response.
5. Less maintenance due to the absence of moving parts and bearings.
6. Frequent operations cause no deterioration.
7. Quick resetting and absence of overshoot.
8. Compact size.
9. Greater sensitivity as amplification can be provided easily.
10. Logic circuits can be used for complex protective schemes. As they take decisions to operate under specified conditions.

11. Complex relaying characteristics can easily be obtained.

Disadvantages of static relays:

1. Sensitive to temperature: their characteristics may vary with variation in temperature. To avoid effect of temperature thermistors and digital techniques etc are used.
2. Sensitive to voltage transients: the semiconductor components may get damage due to voltage spikes. To avoid the effect of voltage transients filters and shielding are employed.
3. Need of auxiliary power supply. This can be supplied by a battery or a stabilized power supply.

<u>Types of static relays:</u>

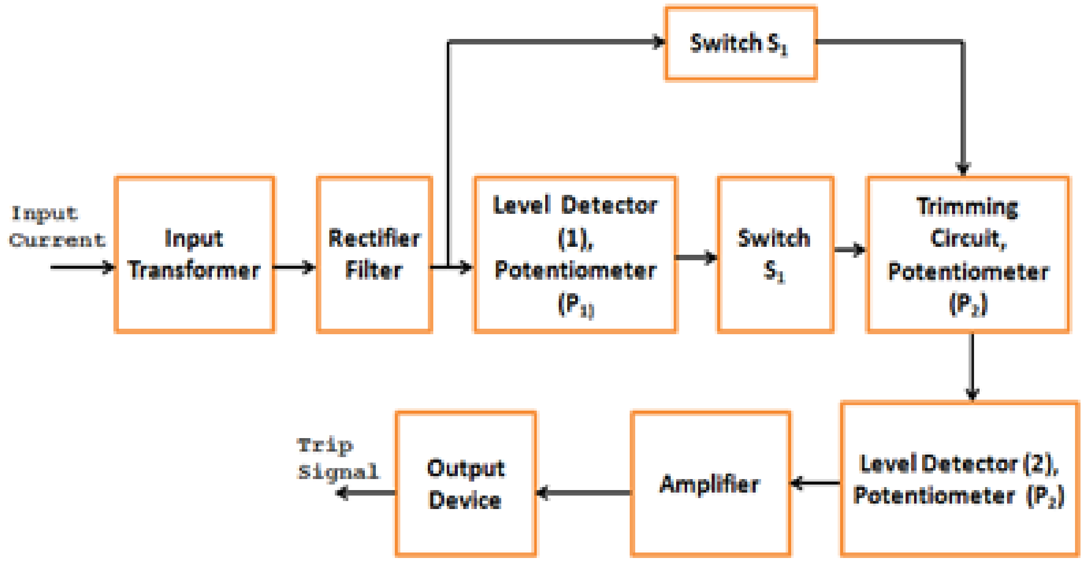
Definite time static relay:

The detailed circuit for the definite time over current relay is as shown.

The time of operation definite time over current relay is constant and doesn't depend upon the severity of fault. The function of the input current is only to initiate the charging of a capacitor and there after the circuit's acts by itself till the breaker is tripped.

Operation:

The potentiometers P_1 is to adjust the pickup value of the relay and P_2 to adjust the operating time of the relay. Under normal operating conditions the transistor T_1 is conducting due to the bias voltage applied from the supply voltage V_C through resistor R_3. There by the capacitor C is short circuited due to the conduction of the transistor T_1.Whenever fault current exceeds the pickup value set by the potentiometer P_1, the rectified voltage is applied to the base emitter junction of T_1 through resistance R_2 which thereby is reverse biased and therefore, T_1 is switched off. The capacitor C starts charging from the supply voltage V_C through resistance R_4. Since the supply voltage is of constant magnitude, the capacitor C is charged through R_4 to a certain voltage in a fixed time which exceeds the emitter settings of transistor T_2 fixed by the potentiometer P_2. Transistor T_2 starts conducting which forces transistor T_3 to conduct, thereby the trip coil of the breaker is energized and the breaker operates. When healthy conditions are restored the transistor T_1 starts conducting, thus short circuiting the capacitor C and the relay will reset.


Switch S_1
Input Current
Input Transformer
Rectifier Filter
Level Detector (1), Potentiometer (P_1)
Switch S_1
Trimming Circuit, Potentiometer (P_2)
Trip Signal
Output Device
Amplifier
Level Detector (2), Potentiometer (P_2)