UNIT – 4

PRINCIPLES OF CIRCUIT BREAKERS

Introduction

Where fuses are unsuitable or inadequate, protective relays and circuit breakers are used in combination to detect and isolate faults. Circuit breakers are the main making and breaking devices in an electrical circuit to allow or disallow flow of power from source to the load. These carry the load currents continuously and are expected to be switched ON with loads (making capacity). These should also be capable of breaking a live circuit under normal switching OFF conditions as well as under fault conditions carrying the expected fault current until completely isolating the fault side (rupturing/breaking capacity). Under fault conditions, the breakers should be able to open by instructions from monitoring devices like relays. The relay contacts are used in the making and breaking control circuits of a circuit breaker, to prevent breakers getting closed or to trip breaker under fault conditions as well as for some other interlocks. Purpose of circuit breakers (switchgear) The main purpose of a circuit breaker is to:

• Switch load currents

• Make onto a fault

• Break normal and fault currents

• Carry fault current without blowing itself open (or up!) i.e. no distortion due to magnetic forces under fault conditions.

The important characteristics from a protection point of view are:

• The speed with which the main current is opened after a tripping impulse is received

• The capacity of the circuit that the main contacts are capable of interrupting.

The first characteristic is referred to as the 'tripping time' and is expressed in cycles.

Modern high-speed circuit breakers have tripping times between three and eight cycles.

The tripping or total clearing or break time is made up as follows:

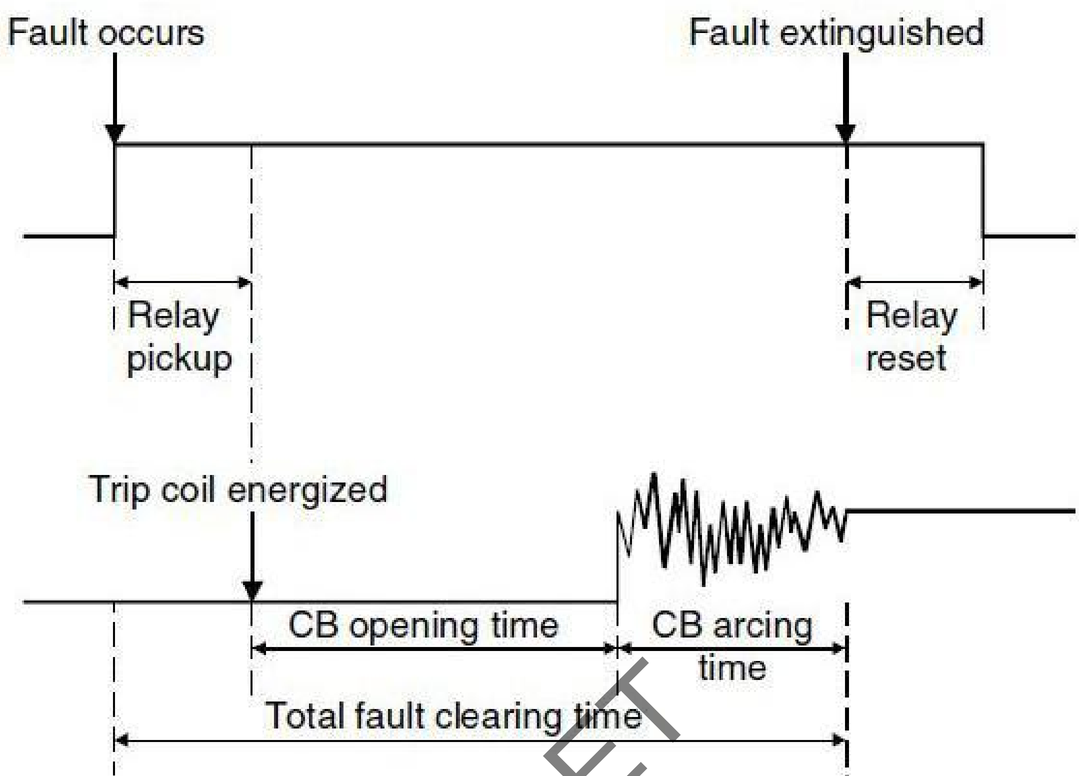
• Opening time:

The time between instant of application of tripping power to the instant of separation of the main contacts.

• Arcing time: The time between the instant of separation of the main circuit breaker contacts to the instant of arc extinction of short-circuit current.

The second characteristic is referred to as 'rupturing capacity' and is expressed in MVA. The selection of the breaking capacity depends on the actual fault conditions expected in the system and the possible future increase in the fault level of the main source of supply.

•Total break or clearing time



Requirement of circuit breakers

Introduction

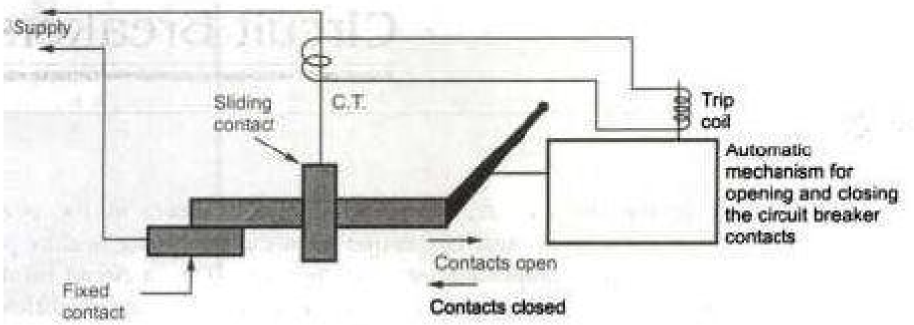
As already seen in the last chapter, whenever any fault occurs in the power system then that part of the system must be isolated from the remaining healthy part of the system. This function is accomplished by circuit breakers Thus a circuit breaker will make or break a circuit either manually or automatically under different conditions such as no load, full load or short circuit. Thus it proves to be an effective device for switching and protection of different parts of a power system. In earlier days fuse was included in. the protective system. But due to some limitations they are not used in practice now a day. The main difference between a fuse and circuit breaker is that under fault condition the fuse melts and it is to be replaced whereas the circuit breaker :an close or break the circuit without replacement.

Requirements of Circuit Breaker: The power associated with the circuit breakers is large and it forms the link between the consumers and suppliers. The necessary requirements of circuit breakers are as follows, 1. The normal working current and the short circuit current must be safely interrupted by the circuit breaker. 2. The faulty section of the system must be isolated by circuit breaker as quickly as possible keeping minimum delay. 3 It should not operate with flow of over current during healthy conditions. 4.The faulty circuit only must be isolated without affecting the healthy one.

Basic principle of operation of a circuit breaker

The Fig. Shows the elementary diagram of a circuit breaker. It consists of two contacts a fixed contact and a moving contact. A handle is attached at the end of the moving contact. It can be operated manually or automatically. The automatic operation needs a separate mechanism which consists of a trip coil. The trip coil is energized by secondary of current transformer. The terminals of the circuit breaker are bought to the supply.

Basic action of circuit breaker



Under normal working conditions the e.m.f produced in the secondary winding of the transformer is insufficient to energize the trip coil completely for its operation. Thus the contacts remain in closed position carrying the normal working current. The contacts can be opened manually also by the handle. Under abnormal or faulty conditions high current in the primary winding of the current transformer induces sufficiently high e.m.f in the secondary winding so that the trip coil is energized. This will start opening motion of the contacts. This action will not be instantaneous as there is always a time lag between the energization of the trip circuit and the actual opening of the contacts. The contacts are moved towards right away from fixed contact. As we have seen already the separation of contacts will not lead to breaking or interruption of circuit as an arc is struck between the contacts. The production of arc delays the current interruption and in addition to this it produces large amount of heat which may damage the system or the breaker. Thus it becomes necessary to extinguish the arc as early as possible in minimum time, so that heat produced will lie within the allowable limit. This will also ensure that the mechanical stresses produced on the parts of circuit breaker are less the time interval which is passed in between the enervation of the trip coil to the instant of contact separation is called the opening time. It is dependent on fault current level. The time interval from the contact separation to the extinction of arc is called arcing time It depends not only on fault current but also on availability of voltage for maintenance of arc and mechanism used for extinction of arc.

Phenomena of arc, properties of arc, initiation and maintenance of arc

Formation of an Arc: Under faulty conditions heavy current flows through the contacts of the circuit breaker they are opened. As soon as the contacts start separating, the area of contact decreases which will increase the current density and consequently rise in the temperature. The medium between the contacts of circuit breaker may be air or oil. The heat which is produced in the medium is sufficient enough to ionize air or oil which will act as conductor. Thus an arc is struck between the contacts. The p.d. between the contacts is sufficient to maintain the arc. So long as the arc is remaining between the contacts the circuit is said to be uninterrupted. The current flowing between the contacts depends on the arc resistance. With increase in arc resistance the current flowing will be smaller. The arc resistance depends on following factors,

a) Degree of ionization: If there is less number of ionized particles between the contacts then the arc resistance increases.

b) Length of arc: The arc resistance is a function of length of arc which is nothing but separation between the contacts. More the length more is the arc resistance.

c) Cross-section of arc: If the area of cross-section of the arc is less then arc resistance is large. Initiation of Arc There must be some electrons for initiation of an arc when fault occurs circuit breaker contacts start separating from each other and the electrons are emitted

which are produced by following methods. By high voltage gradient at the cathode, resulting in field emission by increase of temperature resulting in thermionic emission. By High Voltage Gradient As the moving contacts start separating from each other, the area of contact and pressure between the separating contacts decreases. A high fault current causes potential drop (of the order)between the contacts which will remove the electrons from cathode surface. This process is called field emission.

By Increase of Temperature With the separation of contacts there is decrease in contact area which will increase the current density and consequently the temperature of the surface as seen before which will cause emission of electrons which is called thermal electron emission. In most of the circuit breakers the contacts are made up of copper which is having less thermionic emission. Maintenance of an Arc In the previous section we have seen the initiation of the arc by field emission emission. The electrons while travelling towards anode collide with another electron to dislodge them and thus the arc is maintained. The ionizing is lactated by,

i) High temperature of the medium around the contacts due to high current densities. Thus the ii) kinetic energy gained by moving electrons is increased.

ii) The increase in kinetic energy of moving electrons due to the voltage gradient which dislodge more electrons from neutral molecules. iii) The separation of contacts of circuit breaker increases the length of path which will increase number of neutral molecules. This will decrease the density of gas which will increase free path movement of the electrons.

Arc Extinction It is essential that arc should be extinguished as early as possible. There are two methods of extinguishing the arc in circuit breakers which are namely,

a) High resistance method b) Low resistance or current zero method

High Resistance Method In high resistance method the arc resistance is increased with time. This will reduce the current to such a value which will be insufficient to maintain the arc thus the current is interrupted and the arc is extinguished. This method is employed in only d.c circuit. The resistance of the arc may he increased by lengthening the arc, cooling the arc, reducing the cross-section of the arc and splitting the arc. These methods will be discussed in detail later in this chapter.

Low Resistance Method

The low resistance or current zero method is employed for arc extinction in ac. circuits. In this method arc resistance is kept low until current zero where extinction of arc takes place naturally and is prevented from restriking. This method is employed in many of the modern a.c. circuit breakers.

Low Resistance or Zero Point Extinction

This method is used in ac. arc interruption. -I he current becomes zero two tires in a cycle. So at each current zero point the arc vanishes for small instant and again it appears. But in auxillary circuit breakers the arc is interrupted at a current zero point. The space between the contacts is ionized quickly if there is fresh unionized medium such as oil or fresh air or SF, gas between the contacts at current zero point. This will make dielectric strength of the contact space to increase such that arc will be interrupted and discontinued after current zero. This action produces high voltage across the contacts which are sufficient to reestablish the arc. Thus the dielectric strength must be building more than the restricting voltage for faithful interruption of arc. Then the arc is extinguished at next current zero. While designing the circuit breakers the care is taken so as to
remove the hot gases from the contact space immediately after the arc. So that it can be filled by fresh dielectric medium having high dielectric strength. In summary we can say that the arc extinction process is divided in thee parts, a) Arcing phase b) Current zero phase c) Post arc phase In arcing phase, the temperature of the contact space is increased due to the arc. The heat produced must be removed quickly by providing radial and axial flow to gases. The arc can not be broken abruptly but its diameter can be reduced by the passage of gas over the arc. When ax. Current wave is near its zero, the diameter of the arc is very less and consequently arc is extinguished. This is nothing but current 7ero phase. Now in order to avoid the reestablishment of arc, the contact space must be filled with dielectric medium having high dielectric strength.

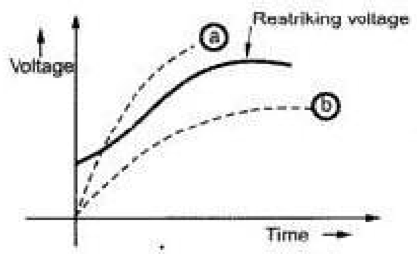
This is post arc phase in which hot gases are removed and fresh dielectric medium is introduced. Arc Interruption Theories There are two main theories explaining current zero interruption of arc

I) Recovery Rate Theory or Slepian's Theory

2) Energy balance theory or Cassie's Theory

Slepian's Theory Slepian described the process as a race between the dielectric strength and restriking voltage. After every current zero, there is a column of residual ionized gas. This may cause arc to strike again by developing necessary restriking voltage and this voltage stress is sufficient to detach electrons out of their atomic orbits which releases great heat. Si in this theory rate at which positive ions and electrons recombine to form neutral molecules is compared with rate of rise of restriking voltage. Due to recombination dielectric strength of gap gets recovered. So rate of recovery of dielectric strength is compared with rate of rise of restriking voltage. If the restriking voltage rises more rapidly than the dielectric strength, gap space breaks down and arc strikes again persists. In the Fig.

a) Rate of dielectric strength is more than restriking voltage. b) Rate of dielectric strength is less ------ -0 than rate of rise of restriking voltage. The assumption made while developing this theory is that the restriking voltage and rise of dielectric strength are comparable quantities which is not quite correct the second drawback is that the theory does not consider the energy relations in the arc extinction. The arcing phase is not covered by this

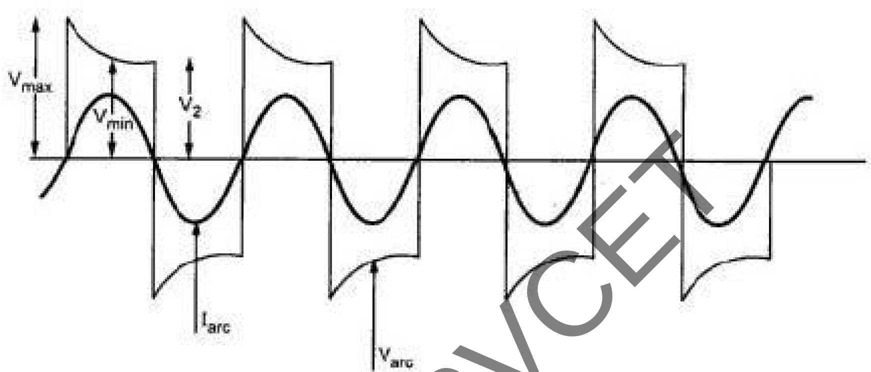


theory so it is incomplete.

Cassie's Theory Alternative explanation of above process s afforded by Cassie's theory or also called Energy balance theory. Cassie suggested that the reestablishment of arc or interruptions of an arc both are energy balance process. If the energy input to an arc continues to increase, the arc restrikes and if not, arc gets interrupted. Theory makes the following assumptions

a) Arc consists of a cylindrical column having uniform temperature at its cross section. The energy distributed in the column is uniform b) The temperature remains constant.

c) The cross section of the arc adjusts itself to accommodate the arc current.
d) Power dissipation is proportional to cross sectional area of arc column interruption theories -
slepian's theory and energy balance theory.
Breakdown occurs if power fed to the arc s more than power loss. The theory is true for high currents. Immediately after current zero, contact space contains ionized gas and therefore has a finite post zero resistance. Now there is rising restriking voltage. This rising res. triking voltage
causes a current to flow between the contacts. Due to this current flow, power gets dissipated as heat in the contact space of circuit breaker. Initially when restriking voltage is zero, automatically current and hence power is zero. It is again zero when the space has become fully deionize and resistance between the contacts is infinitely high. In between these two extreme limits, power dissipated rises to a maximum. If the heat so generated exceeds the rate at which heat can be removed from contact space, ionization will persist and breakdown will occur, giving an arc for another half cycle.



Re -striking voltage, recovery voltage, Rate of rise of Re striking voltage

Transient Recovery Voltage The transient recovery while has effect on the behavior of circuit breaker. This voltage appears between the contacts immediately after final arc interruption. This causes high dielectric stress between the contacts. If this dielectric strength of the medium between the contacts does not build up faster than the rate of rise of the Transient recovery voltage then the breakdown takes place which will cause restriking of arc Thus it is very important that the dielectric strength of the contact space must build very rapidly that rate of rise of transient recovery voltage so that the Interruption of current by the circuit breaker takes place successfully. The rate of rise of this transient voltage depends on the circuit parameters and the type of the switching duty invoked. The rate of building up of the dielectric strength depends on the effective design of the interrupter and the circuit breaker. If it is desired to break the capacitive currents while opening the capacitor banks, there may appear a high voltage across the contacts which can cause re ignition of the arc after initial arc extinction. Thus if contact space breaks down within a period of one fourth of a cycle from initial arc extinction the phenomenon is called Reigniting. Moving contacts of circuit breakers move a very small distance from the fixed contacts then reigniting may occur without overvoltage. But the arc gets extinguished in the next current zero by which time moving contacts should be moved by sufficient distance from fixed contacts. Thus the re ignition is in a way not harmful as it will not lead to any overvoltage beyond permissible limits. If the breakdown occurs after one fourth of a cycle, the phenomenon is called Restrike. In restriking, high voltage appear across the circuit breaker contacts during capacitive current breaking. In restrikes, voltage will go on increasing which may lead to damage of circuit breaker. Thus the circuit breakers used for capacitors should be free from Restrike I.e. they' should have adequate rating.

Effect of Different Parameters on Transient Recovery Voltage (TRV)

As seen from the previous section, after the final current, zero high frequency transient voltage appears across the circuit breaker poles which is superimposed on power frequency system voltage and tries to restrike the arc. This voltage may last for a few tens or hundreds of microseconds. If the shape of this TRV is seen on the oscilloscope then it can be seen that it may be oscillatory, non-oscillatory or a combination of two depending upon the characteristics of the circuit and the circuit breaker. The waveform is as shown in the

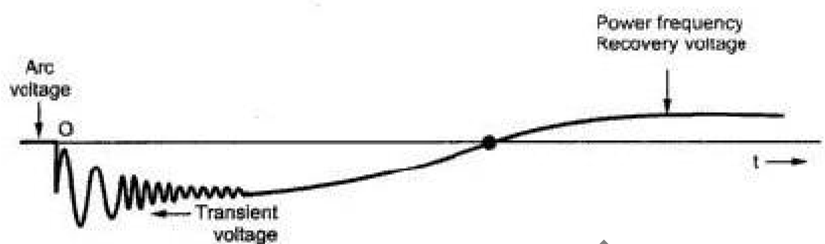
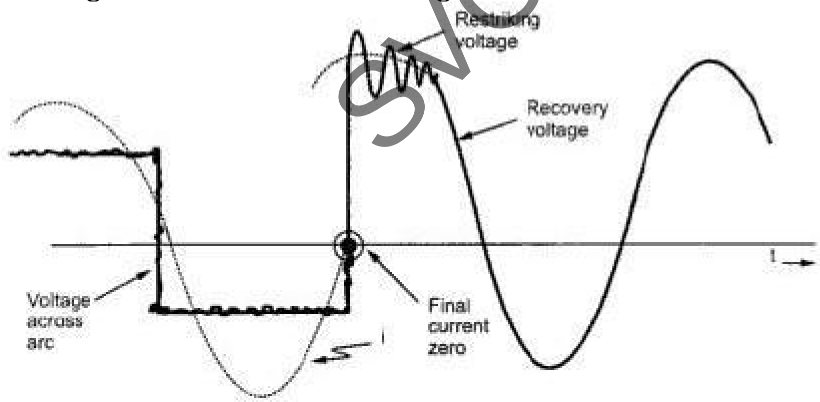


Fig.

Transient voltage Shape of transient recovery voltage This voltage has a power frequency component and an oscillatory transient component. The oscillatory component is due to inductance and capacitance in the circuit. The power frequency component is due to the system voltage. This is shown in the Fig.



Zero power factor If we consider zero power factor currents, the peak voltage E is impressed on the circuit breaker contacts at the current

zero instant This instantaneous voltage gives more transient and provides high rate of rise of TRV. Hence if the p.f. is low then interrupting of such current is difficult.

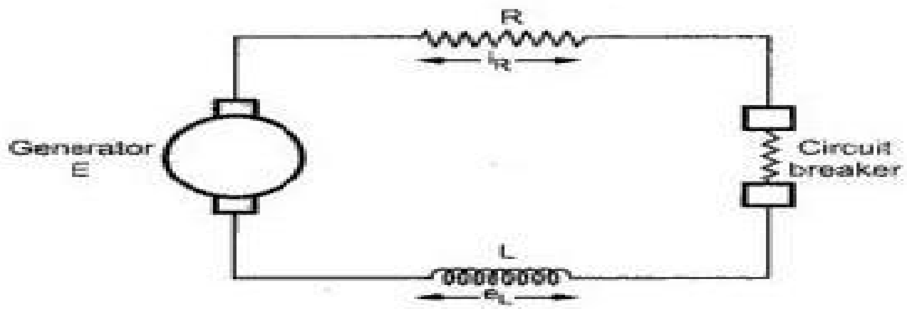
Recovery Voltage As seen previously it is the voltage having normal power frequency which appears after the transient voltage.

Effect of Reactance Drop on Recovery Voltage Home fault is taking place let us consider that the voltage appearing across circuit breaker is V. As the fault current increases, the voltage drop in reactance also increases. After fault clearing the voltage appearing say V2 is slightly less than V,. The system takes some time to regain the original value.

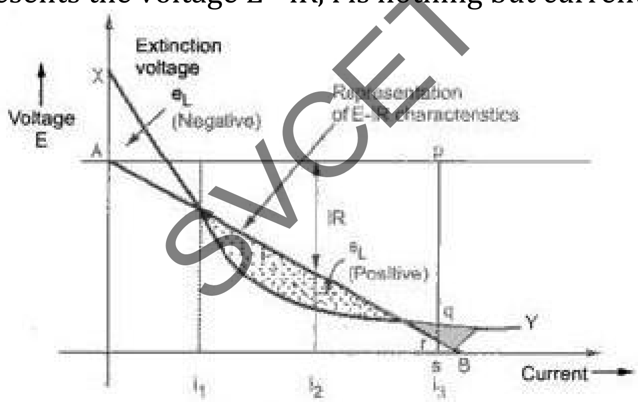
Affect of Armature Reaction on Recovery Voltage Me short circuit currents are at lagging power factor. These lagging p.f. currents have a demagnetizing armature reaction in alternators.Thus the induced end of alternators decreases To regain the original value this emf takes some time. Thus the frequency component of recovery voltage is less than the normal value of system voltage.

DC circuit breaking, AC circuit breaking

D.C. Circuit Breaking The breaking in case of d.c. can be explained as follows. For this, we will consider a circuit which will consist of generator with voltage E, resistance R. inductor L and the circuit breaker as shown in the Fig.



The voltage-current relationship can be represented as shown in the graph it could be seen that curve AB represents the voltage E - iR, i is nothing but current at any instant. The curve



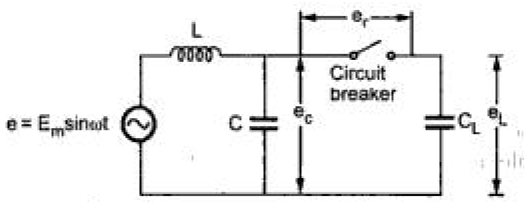
XY represents the
voltage-current characteristics of the arc for decreasing currents.

Voltage-current relationship When the circuit breaker starts opening it carries the load current I. In the graph shown the current is shown to be reduced respectively. Section represents voltage drop i3R whereas qs represent arc voltage which is greater than available voltage. The arc becomes unstable and the difference in voltage is supplied by inductance L across which the voltage is L. For decreasing values of t currents this voltage is negative and according to Lenz's law it tries to maintain the arc.

The voltage across inductance L is seen to be positive in the region of currents i, mid i2 since the arc characteristics lies below the curve AB. The arc current in this region tries to increase so interruption of current is not possible in this region. Afterwards the arc is lengthened with Increase in contact separation which will raise the arc voltage above the curve AB. The operation in case of d.c. circuit breakers is said to be ideal if the characteristics of the arc voltage are above the curve AB even in the region of currents i1 and i2. This is shown in the fig.. Fig. Arc voltage characteristics It can be seen that arc voltage is greater than E - lit and the balance between the voltages is supplied by the voltage across the inductance el, which is proportional to d i rate of change of current dI. Thus the function of the circuit breaker is to raise the arc characteristics without affecting its stability. This is done by reducing the arcing time which is the time from contact separation to final extinction of arc. But it will increase extinction voltage. Hence compromise between arcing time and arc extinction voltage is made.

A.C. Circuit Breaking There is a difference between breaking in case of d c. and ac. circuits. In ac. circuits the current passes through zero twice in one complete cycle. When the currents are reduced to zero the beakers are operated to cut-off the current. This will avoid the striking of the arc. But this conditions is difficult to achieve and very much expensive. The restriking of arc when current is interrupted is dependent on the voltage between the contact gap at that instant which will in turn depend on power factor. Higher the power
factor, lesser is the voltage appearing across the gap than its peak value.

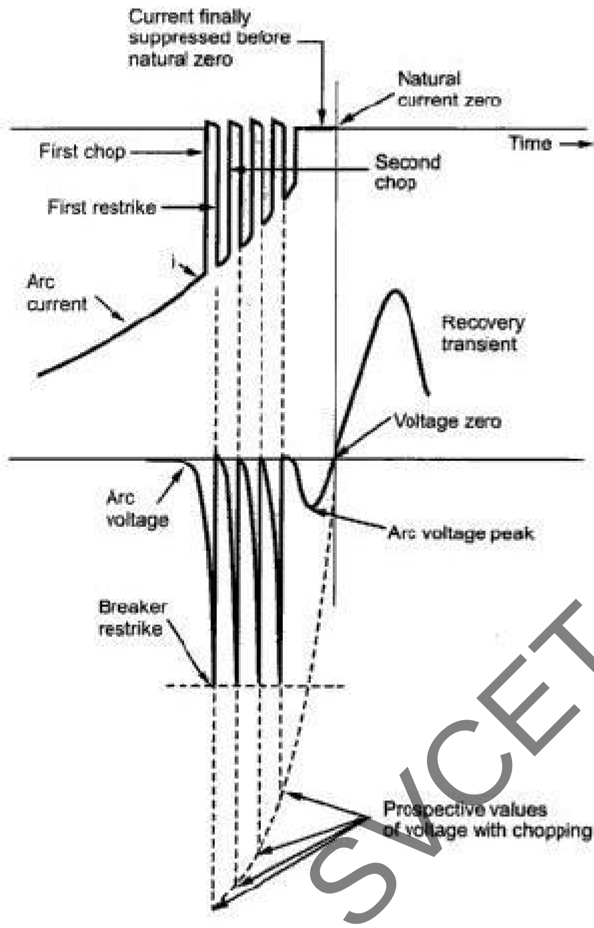
Current chopping, capacitance switching, resistance switching



In power systems capacitor banks are used in the network which supplies reactive power t leading power factors there are various aspects like long transmission where it is required interrupt the capacitive current which is difficult. To understand this difficulty let us consider a simple circuit shown in the Fig

The value of load capacitance CL is greater than C. The voltage across a capacitor cannot change instantaneously. The currents supplied to the capacitor are generally small and interruption of such currents take place at first current zero. Also at the beginning, the rate of rise of recovery voltage is low and increases slowly. Whenever such circuit is opened a charge is trapped in the capacitance Ct The voltage across the load capacitance will hold the same value when circuit was opened. This voltage is making but peak of supply voltage as power factor angle is nearly 90° leading. After opening the circuit the voltage Vc across the capacitance C oscillates and approaches a new steady value. But due to small value of capacitance C. the value attained is close to the supply voltage. The recovery voltage Cr is nothing but difference between and CL.

Its initial value is zero as the circuit breaker will be closed and increases slowly in the beginning. When Vc reverses after half cycle, the recovery voltage is about twice the normal peak value. Therefore it is possible that at this instant arc may restrike as the electrical strength between the circuit breaker contacts is not sufficient. The circuit will be reclosed and et oscillates at a high frequency. supply voltage at this instant will be at its negative peak; therefore a high frequency oscillation takes place. At the instant of rest rucking the arc, the recovery voltage V, is zero. The voltage across the load capacitance reaches - times the peak value of normal supply voltage. The recovery voltage then starts increasing. If again restriking of arc takes place, a high frequency of oscillation of CL takes place. Such several repetitions of the restriking cycle will increase the voltage across load capacitance to a dangerously high value. In practice this voltage is limited to 4 times the normal peak of the voltage.



Resistance switching

Resistance Switching It can be seen From previous sections that the interruption of low inductivecurrents, interruption of capacitive currents We rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts. This process is known as Resistance Switching. When the resistance is connected across the arc, a part of the arc current flows through the resistance. This will lead to decrease in arc current and increase in rate of deionization of the are path and resistance of arc. This will increase current through shunt resistance . This process continues until the current through the arc is diverted through the resistance either External 4.--- resistance completely or in major part. If C irt the small value of the current remains in the arc then the path . A becomes so unstable that it is Fxed Moved switch easily extinguished. contact contact . The resistance may be automatically switched in and arc current can be transferred. The time required for this action is very small As shown in.. Fig the arc first appears across points A and B which is then transferred across A and C. The shunt resistance also ensures the effective damping of

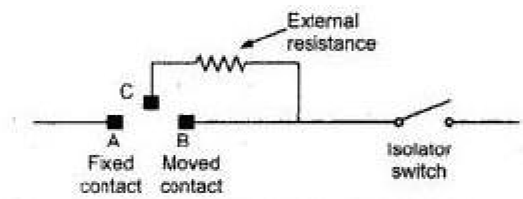
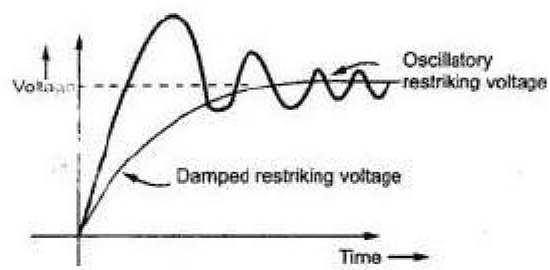
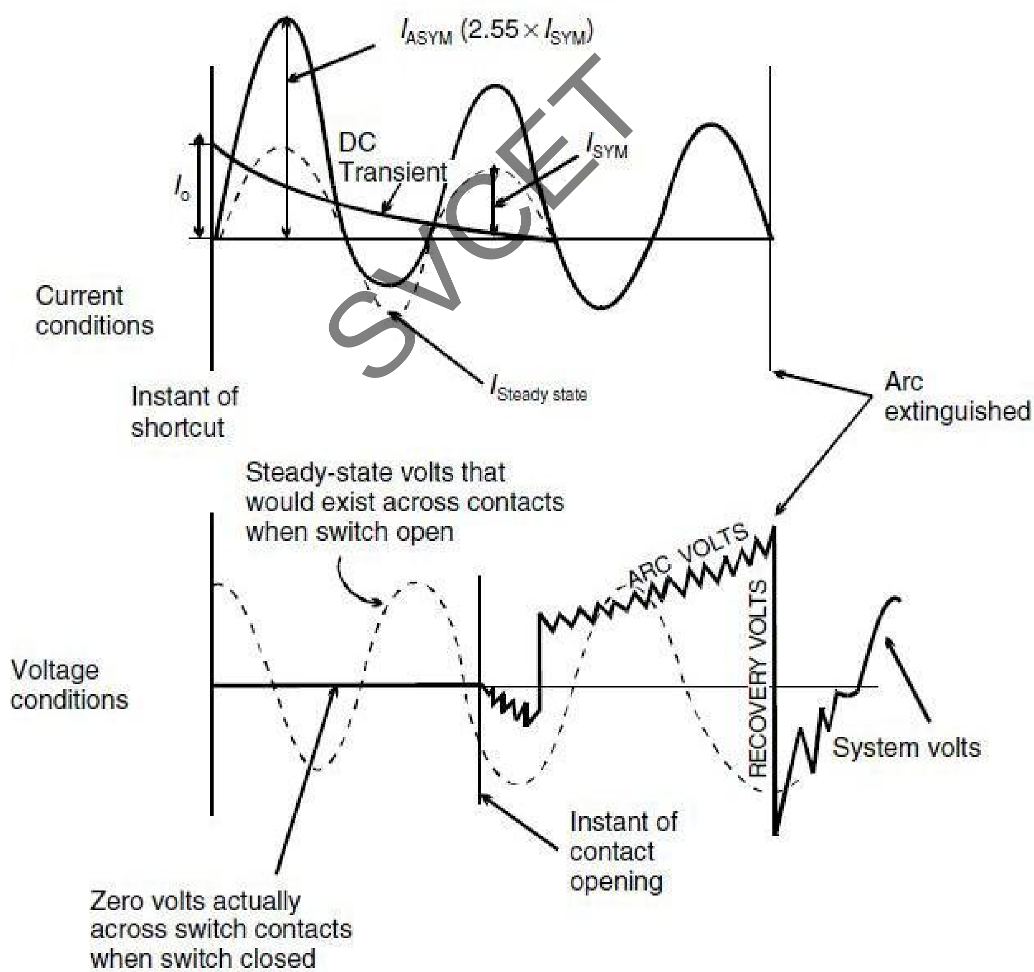


Fig. 9.23 Typical resistor connection



the high frequency re-striking Fig. voltage transients. This is shown in the Fig. **Behavior under fault conditions**



Before the instant of short-circuit, load current will be flowing through the switch and this can be regarded as zero when compared to the level of fault current that would flow

1.Arc

The arc has three parts: 1. **Cathode end (–ve):** There is approximately 30–50 V drop due to emission of electrons.

2. Arc column: Ionized gas, which has a diameter proportional to current. Temperature can be in the range of 6000–25 000 °C.

3. Anode end (+ve): Volt drops 10–20 V.

When short-circuit occurs, fault current flows, corresponding to the network parameters. The breaker trips and the current are interrupted at the next natural current zero. The network reacts by transient oscillations, which gives rise to the transient recovery voltage (TRV) across the circuit breaker main contacts.

All breaking principles involve the separation of contacts, which initially are bridged by a hot, highly conductive arcing column. After interruption at current zero, the arcing zone has to be cooled to such an extent that the TRV is overcome and it cannot cause a voltage breakdown across the open gap. Three critical phases are distinguished during arc interruption, each characterized by its own physical processes and interaction between system and breaker.

High current phase

This consists of highly conductive plasma at a very high temperature corresponding to a low mass density and an extremely high flow velocity. Proper contact design prevents the existence of metal vapor in the critical arc region.