UNIT-5

CIRCUIT BREAKERS

Physics of arcing phenomenon and arc interruption - DC and AC circuit breaking – re-striking voltage and recovery voltage - rate of rise of recovery voltage - resistance switching - current chopping - interruption of capacitive current - Types of circuit breakers – air blast, air break, oil, SF6 and vacuum circuit breakers – comparison of different circuit breakers – Rating and selection of Circuit breakers.

5.1. Physics of arcing phenomenon

When a short-circuit occurs, a heavy current flows through the contacts of the *circuit breaker beforethey are opened by the protective system. At the instant when the contacts begin to separate, thecontact area decreases rapidly and large fault current causes increased current density and hence risein temperature. The heat produced in the medium between contacts (usually the medium is oil or air)is sufficient to ionise the air or vaporise and ionise the oil. The ionised air or vapour acts as conductorand an arc is struck between the contacts. The potential difference between the contacts is quite small and is justsufficient to maintain the arc. The arc provides a low resistance path and consequently the current inthe circuit remains uninterrupted so long as the arc persists.During the arcing period, the current flowingbetween the contacts depends upon the arc resistance.The greater the arc resistance, the smaller the current that flows between the contacts. The arcresistance depends upon the following factors:

(i) *Degree of ionisation*— the arc resistance increases with the decrease in the number of ionised particles between the contacts.

(ii) *Length of the arc*— the arc resistance increases with the length of the arc *i.e.*, separation of contacts.

(iii) *Cross-section of arc*— the arc resistance increases with the decrease in area of X-section of the arc.

5.1.1 Initiation of arc

The electric arc is a type of electric discharge between the contacts of the circuit breaker. Arc plays an important role in the behavior of an electric circuit breaker. A circuit breaker should be capable of extinguishing the arc without getting damaged.

As the contacts of a circuit breaker begin to separate, the voltage is appreciable and the distance of separation is very small. Therefore, a large voltage gradient occurs at the contact surface. When the voltage gradient attains a sufficiently high value (10^6 V/cm) electrons are dragged out of the surface causing ionization of the particles between the contacts. The emission of electrons because of the high value of voltage gradient is known as field emission.

Although this high voltage gradient exist only for a fraction of micro-seconds, but a large number of electrons are liberated from the cathode because of this. These electrons move towards the positive contact i.e. anode at a very rapid pace. On their way to anode, these electrons collide with the atoms and molecules of the gases and vapour existing between the contacts. Hence, each liberated electron tends to create other electrons. If the current is high, which is certainly in case of an electric fault, the discharge attains the form of an arc.

The temperature of arc is high enough and causes thermal ionization. The liberation of electrons because of high temperature is calledthermal emission. Thus, in an electric circuit breaker, an arc is initiated because of field emission but is maintained due to thermal ionization.

5.1.2 Maintenance of arc

The factors responsible forthe maintenance of arc between the contacts. These are:

(i) p.d. between the contacts

(ii) Ionised particles between contacts

Taking these in turn,

(i) When the contacts have a small separation, the p.d. between them is sufficient to maintainthe arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d.becomes inadequate to maintain the arc. However, this method is impracticable in highvoltage system where a separation of many metres may be required.

(ii) The ionised particles between the contacts tend to maintain the arc. If the arc path is deionised,the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodilyremoving the ionised particles from the space between the contacts.

5.1.3 Electric arc

An electric arc or arc discharge is an electrical breakdown of a gas that produces an ongoing electrical discharge. The current through a normally nonconductive medium such as air produces a plasma; the plasma may produce visible light. An arc discharge is characterized by a lower voltage than a glow discharge, and it relies on thermionic emissionof electrons from the electrodes supporting the arc. An archaic term is voltaic arc, as used in the phrase "voltaic arc lamp".

An electric arc is the form of electric discharge with the highest current density. The maximum current through an arc is limited only by the external circuit, not by the arc itself.

An arc between two electrodes can be initiated by ionization and glow discharge, as the current through the electrodes is increased. The breakdown voltage of the electrode gap is a function of the pressure, distance between electrodes and type of gas surrounding the electrodes. When an arc starts, its terminal voltage is much less than a glow discharge, and current is higher. An arc in gases near atmospheric pressure is characterized by visible light emission, high current density, and high temperature. An arc is distinguished from a glow discharge partly by the approximately equal effective temperatures of both electrons and positive ions; in a glow discharge, ions have much less thermal energy than the electrons.

A drawn arc can be initiated by two electrodes initially in contact and drawn apart; this can initiate an arc without the high-voltage glow discharge. This is the way a welder starts to weld a joint, momentarily touching the welding electrode against the workpiece then withdrawing it till a stable arc is formed. Another example is separation of electrical contacts in switches, relays and circuit breakers; in high-energy circuits arc suppression may be required to prevent damage to contacts

Electrical resistance along the continuous electric arc creates heat, which ionizes more gas molecules (where degree of ionization is determined by temperature), and as per this sequence: solid-liquid-gas-plasma; the gas is gradually turned into thermal plasma. A thermalplasma is in thermal equilibrium; the temperature is relatively homogeneous throughout the atoms, molecules, ions and electrons. The energy given to electrons is dispersed rapidly to the heavier particles by elastic collisions, due to their great mobility and large numbers.

Current in the arc is sustained by thermionic emission and field emission of electrons at the cathode. The current may be concentrated in a very small hot spot on the cathode; current densities on the order of one million amperes per square centimetre can be found. Unlike a glow discharge, an arc has little discernible structure, since the positive column is quite bright and extends nearly to the electrodes on both ends. The cathode fall and anode fallof a few volts occurs within a fraction of a millimetre of each electrode. The positive column has a lower voltage gradient and may be absent in very short arcs.[9]

A low-frequency (less than 100 Hz) alternating current arc resembles a direct current arc; on each cycle, the arc is initiated by breakdown, and the electrodes interchange roles as anode and cathode as current reverses. As the frequency of the current increases, there is not enough time for all ionization to disperse on each half cycle and the breakdown is no longer needed to sustain the arc; the voltage vs. current characteristic becomes more nearly ohmic

5.2.Arc interruption

The insulating material (may be fluid or air) used in circuit breaker should serve two important functions. They are written as follows:

- It should provide sufficient insulation between the contacts when circuit breaker opens.
- It should extinguish the arc occurring between the contacts when circuit breaker opens.

The second point needs more explanation. To understand this point let us consider a situation if there is some fault or short circuit in the system, the relay provides desired signals to the circuit breaker so as to prevent system from ongoing fault. Now when circuit breaker opens its contacts, due to this an arc is drawn. The arc is interrupted by suitable insulator and technique.

5.2.1 Theroies of arc interruption

There are two theories which explains the phenomenon of arc extinction:

1. Energy balance theory,
2. Voltage race theory.

Energy Balance Theory

When the contact of circuit breaker are about to open, restriking voltage is zero, hence generated heat would be zero and when the contacts are fully open there is infinite resistance this again make no production of heat. We can conclude from this that the maximum generated heat is lying between these two cases and can be approximated, now thistheory is based on the fact that the rate of generation of heat between the contacts of circuit breaker is lower than the rate at which heat between the contact is dissipated. Thus if it is possible to remove the generated heat by cooling, lengthening and splitting the arc at a high rate the generation, arc can be extinguished.

Voltage Race Theory

The arc is due to the ionization of the gap between the contact of the circuit breaker. Thus the resistance at the initial stage is very small i.e. when the contacts are closed and as the contact separates the resistance starts increasing. If we remove ions at the initial stage either by recombining them into neutral molecules or inserting insulation at a rate faster than the rate of ionization, the arc can be interrupted. The ionization at zero current depends on thevoltage known as restriking voltage.

Let us define an expression for restriking voltage. For loss-less or ideal system we have,

$$v = V\left[1 - \cos\left(\frac{t}{\sqrt{LC}}\right)\right]$$

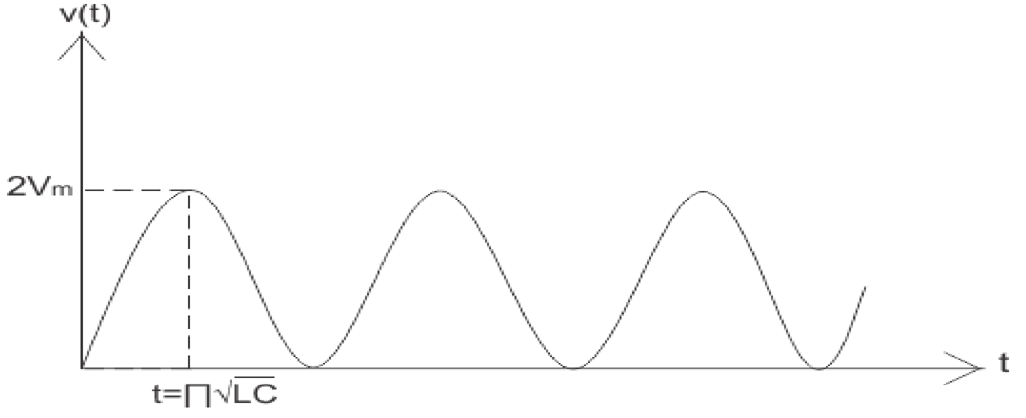
Here v = restriking voltage.

V = value of voltage at the instant of interruption.

L and C are series inductor and shunt capacitance up to fault point.

Thus from above equation we can see that lower the value of product of L and C, higher the value of restriking voltage.

The variation of v versus time is plotted below:



5.2.2 Modes of arc interruption

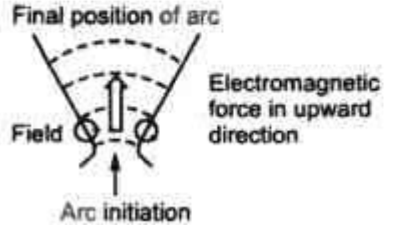
There are two methods of extinguishing the arc in circuit breakers

1. High resistance method. **2.** Low resistance or current zero method

1. High resistance method. In this method, arc resistance is made to increase with time sothat current is reduced to a value insufficient to maintain the arc. Consequently, the current is interruptedor the arc is extinguished. The principal disadvantage of this method is that enormous energyis 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:

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

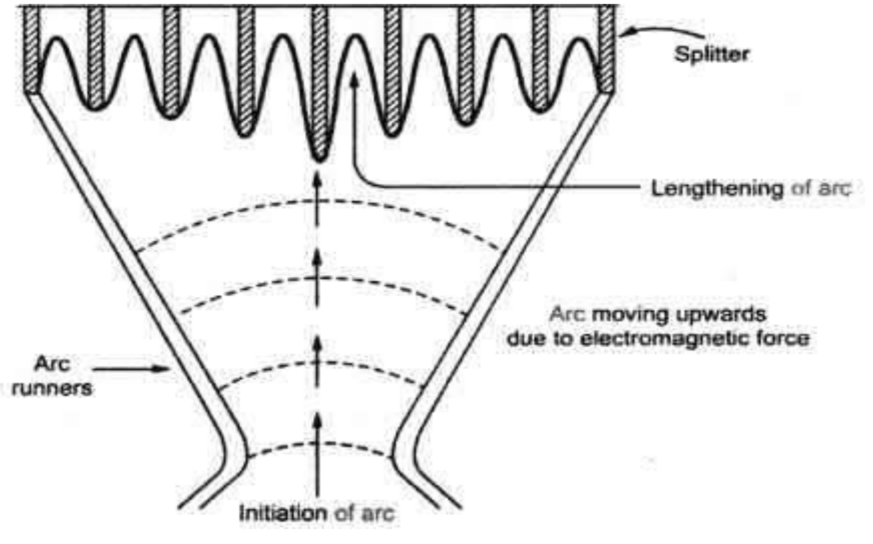


(ii) Cooling the arc. Cooling helps in the deionisation of the medium between the contacts.

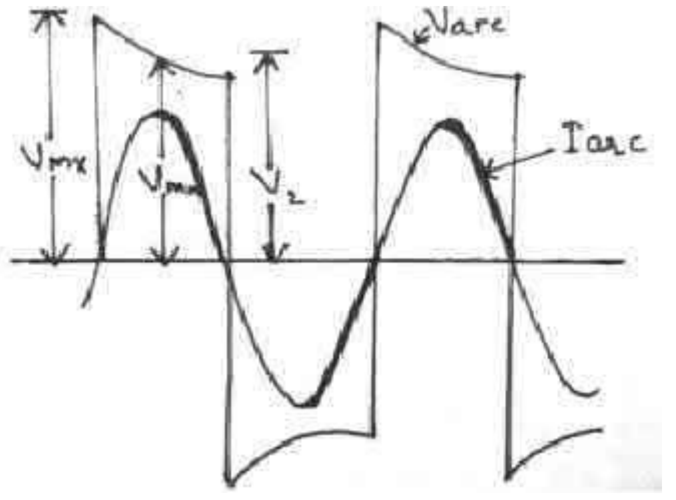
This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

(iii) Reducing X-section of the arc. If the area of X-section of the arc is reduced, the voltagenecessary to maintain the arc is increased. In other words, the resistance of the arc path isincreased. The cross-section of the arc can be reduced by letting the arc pass through anarrow opening or by having smaller area of contacts.

(iv) Splitting the arc. The resistance of the arc can be increased by splitting the arc into anumber of smaller arcs in series. Each one of these arcs experiences the effect of lengtheningand cooling. The arc may be split by introducing some conducting plates between the contacts.



2. Low resistance or Current zero method. This method is employed for arc extinctionin 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 restrikinginspite 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 arcextinguishes for a brief moment. Now the medium between the contacts contains ions and electronsso that it has small dielectric strength and can be easily broken down by the rising contact voltageknown 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 isbuilt up more rapidly than the voltage across the contacts, the arc fails to restrike and the current willbe interrupted. The rapid increase of dielectric strength of the medium near current zero can beachieved by :

(a) Causing the ionised particles in the space between contacts to recombine into neutralmolecules.

(b) Sweeping the ionised particles away and replacing them by un-ionised particlesTherefore, the real problem in a.c. arc interruption is to rapidly deionise the medium betweencontacts as soon as the current becomes zero so that the rising contact voltage or restriking voltagecannot breakdown the space between contacts.

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

(i) Lengthening of the gap. The dielectric strength of the medium is proportional to the lengthof the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectricstrength of the medium can be achieved.

(ii) High pressure. If the pressure in the vicinity of the arc is increased, the density of theparticles constituting the discharge also increases. The increased density of particles causeshigher rate of de-ionisation and consequently the dielectric strength of the medium betweencontacts is increased.

(iii) Cooling. Natural combination of ionised particles takes place more rapidly if they are allowedto cool. Therefore, dielectric strength of the medium between the contacts can beincreased by cooling the arc.

(iv) Blast effect. If the ionised particles between the contacts are swept away and replaced by unionisedparticles, the dielectric strength of the medium can be increased considerably. Thismay be achieved by a gas blast directed along the discharge or by forcing oil into the contactspace.