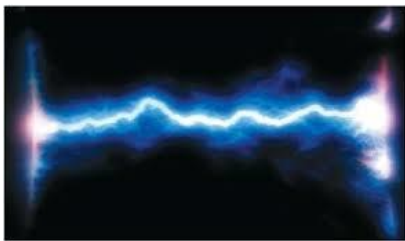


# Theory of Arc

## What is Arc ?

During opening of current carrying contacts in a circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows. This is called arc.



## Arc in Circuit Breaker

Whenever, on load current contacts of circuit breaker open there is an arc in circuit breaker, established between the separating contacts. As long as this arc is sustained in between the contacts the current through the circuit breaker will not be interrupted finally as because arc is itself a conductive path of electricity. For total interruption of current the circuit breaker it is essential to quench the arc as quick as possible. The main designing criteria of a circuit breaker is to provide appropriate technology of arc quenching in circuit breaker to fulfill quick and safe current interruption.

## Thermal Ionization of Gas

There are numbers of free electrons and ions present in a gas at room temperature due to ultraviolet rays, cosmic rays and radioactivity of the earth. These free electrons and ions are so few in number that they are insufficient to sustain conduction of electricity. The gas molecules move randomly at room temperature. It is found an air molecule at a temperature of 300°K (Room temperature) moves randomly with an approximate average velocity of 500 meters/second and collides other molecules at a rate of 1010 times/second. These randomly moving molecules collide each other in very frequent manner but the kinetic energy of the molecules is not sufficient to extract an electron from atoms of the molecules. If the temperature is increased the air will be heated up and consequently the velocity on the molecules increased. Higher velocity means higher impact during inter molecular collision. During this situation some of the molecules are disassociated in to atoms. If temperature of the air is further increased many atoms are deprived of valence electrons and make the gas ionized. Then this ionized gas can conduct electricity because of sufficient free electrons.

This condition of any gas or air is called plasma. This phenomenon is called thermal ionization of gas.

### **Electron Collision Ionization**

As we discussed that there are always some free electrons and ions presents in the air or gas but they are insufficient to conduct electricity. Whenever these free electrons come across a strong electric field, these are directed towards higher potential points in the field and acquire sufficiently high velocity. In other words, the electrons are accelerated along the direction of the electric field due to high potential gradient. During their travel these electrons collide with other atoms and molecules of the air or gas and extract valance electrons from their orbits. After extracted from parent atoms, the electrons will also run along the direction of the same electric field due to potential gradient. These electrons will similarly collide with other atoms and create more free electrons which will also be directed along the electric field. Due to this conjugative action the numbers of free electrons in the gas will become so high that the gas stars conducting electricity. This phenomenon is known as ionization of gas due to electron collision.

### **Deionization of Gas**

If all the cause of ionization of gas is removed from an ionized gas it rapidly comes back to its neutral state by recombination of the positive and negative charges. The process of recombination of positive and negative charges is known as deionization process. In deionization by diffusion, the negative ions or electrons and positive ions move to the walls under the influence of concentration gradients and thus completing the process of recombination.

### **Role of Arc in Circuit Breaker**

When two current contacts just open, an arc bridges the contact gap through which the current gets a low resistive path to flow so there will not be any sudden interruption of current. As there is no sudden and abrupt change in current during opening of the contacts, there will not be any abnormal switching over voltage in the system. If  $i$  is the current flows through the contacts just before they open,  $L$  is the system inductance, switching over voltage during opening of contacts, may be expressed as  $V = L.(di/dt)$  where  $di/dt$  rate of change of current with respect to time during opening of the contacts. In the case of alternating current arc is monetarily extinguished at every current zero. After crossing every current zero the media between separated contacts gets ionized again during next cycle of current and the arc in circuit breaker is reestablished. To make the interruption complete and successful, this re-ionization in between separated contacts to be prevented after a current zero.

If arc in circuit breaker is absence during opening of current carrying contacts, there would be sudden and abrupt interruption of current which will cause a huge switching over voltage sufficient to severely stress the insulation of the system. On the other hand, the arc provides a gradual but quick, transition from the current carrying to the current breaking states of the contacts.

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

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

### **Methods of Arc Interruption**

There are two methods by which interruption is done.

1. High resistance method,
2. Low resistance method or zero interruption method.

In high interruption method we can increase the electrical resistance many times to such a high value that it forces the current to reach to zero and thus restricting the possibility of arc being re-struck. This method is applied in dc power circuit breaker, low and medium ac power circuit breaker.

Low resistance method is applicable only for ac circuit and it is possible there because of presence of natural zero of current. The arc gets extinguished at the natural zero of the ac wave and is prevented from restricting again by rapid building of dielectric strength of the contact space.

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

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

Before going in details about these theories, we should know the following terms.

**Re-striking voltage:** It may be defined as the voltage that appears across the breaking contact at the instant of arc extinction.

**Recovery voltage:** It may be defined as the voltage that appears across the breaker contact after the complete removal of transient oscillations and final extinction of arc has resulted in all the poles.

**Active recovery voltage:** It may be defined as the instantaneous recovery voltage at the instant of arc extinction.

**Arc voltage:** It may be defined as the voltage that appears across the contact during the arcing period, when the current flow is maintained in the form of an arc. It assumes low value except for the point at which the voltage rise rapidly to a peak value and current reaches to zero.

### Energy Balance Theory:

When the contact of circuit breaker are about to open, re-striking 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 this theory 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 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 contacts of the circuit breaker. Thus the resistance at the initial stage is very small (i.e. when the contact 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 the voltage known as re-striking voltage.


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

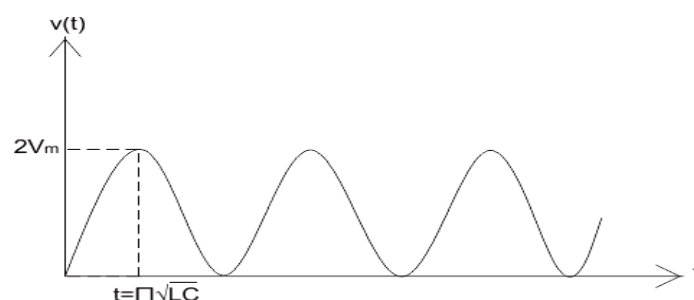
$$v = V \left[ 1 - \cos \left( \frac{t}{\sqrt{LC}} \right) \right]$$

Here  $v$  = re-striking voltage.  $V$  = value of voltage at the instant of interruption.

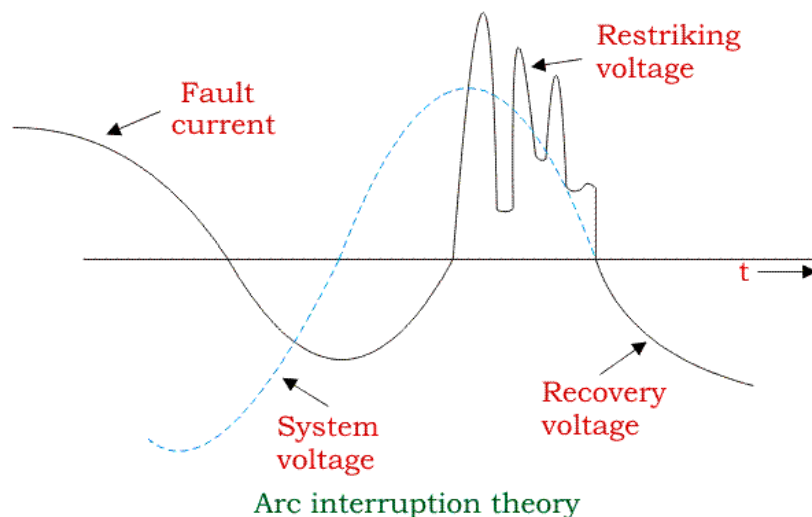
$L$  and  $C$  are series inductor and shunt capacitance up to fault point.

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

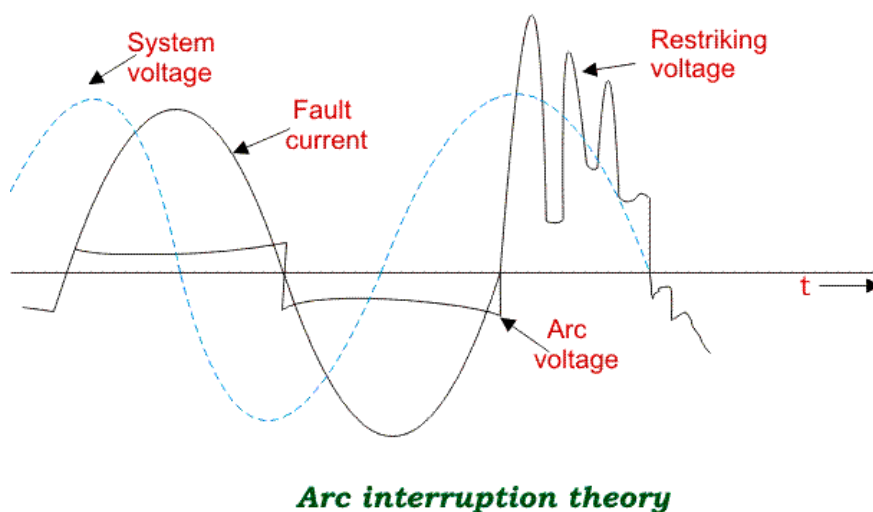
The variation of  $v$  versus time is plotted below: 



Now let us consider a practical system, or assume there finite loss in the system. As fig. shown below in this case the re-striking voltage is damped out due to the presence of some finite resistance. Here it is assumed that the current lags behind the voltage by an angle (measured in degrees) of 90. However in practical situation angle may varies depending upon time in cycle at which the fault is occurred.



Let us consider the effect of arc voltage, if arc voltage is included in the system, there is an increment in the re-striking voltage. However this is offset by another effect of an arc voltage which opposes the current flow and making change in the phase of current, thus bringing it more into phase with the applied voltage. Hence the current is not at its peak value when voltage passes through zero value.



**Rate of Rise of Re-striking Voltage (RRRV):** It is defined as the ratio of peak value of re-striking voltage to time taken to reach to peak value. It is one of the most important parameter as if the rate at which the dielectric strength developed between the contacts is greater than RRRV, then the arc will be extinguishes.