UNIT IV

THEORY OF CIRCUIT INTERRUPTION

4.1 Formation of arc during circuit breaking

The phenomena of 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 after the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows in the form of an arc.

Arc in circuit breaker

Whenever, the contacts of circuit breaker open while carrying load there is an arc in the medium between the separating contacts of the circuit breaker. As long as this arc is sustained in between the contacts, the current through the circuit breaker will not be interrupted totally. For total interruption of current, the arc needs to be quenched as quickly 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. So before going through different arc quenching techniques employed in circuit breaker, it is first necessary to understand the phenomena of arc in circuit breaker.

Role of arc in circuit breaker

When two current carrying contacts 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. Let i is the current flowing through the contacts just before they open and 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 momentarily extinguished at every current zero. After crossing every current zero the medium 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 overvoltage 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.

Arc Interruption or Arc Quenching or Arc Extinction Theory

At high temperature the charged particles in a gas move rapidly and randomly, but in absence of electric field, no net motion occurs. Whenever an electric field is applied in the gas, the charged particles gain drift velocity superimposed on their random thermal motion. The drift velocity is proportional to the voltage gradient of the field and particle mobility. The particle mobility depends upon the mass of the particle, heavier particles, lower the mobility. The mobility also depends upon mean free paths available in the gas for random movement of the particles. Since every time a particle collides, it loses its directed velocity and has to be reaccelerated in the direction of electric field again. Hence net mobility of the particles is reduced. If the medium has high pressure, it becomes denser and hence, the gas molecules come closer to each other, therefore collision occurs more frequently which lowers the mobility particles. The total current by charged particles is directly proportional to their mobility. Therefore the mobility of charged particles depends upon the temperature, pressure of the gas and as well as nature of the gas. Again the mobility of gas particles determines the degree ionization of gas.

So from above explanation we can say that ionization process of gas depends upon nature of gas (heavier or lighter gas particles), pressure of gas and temperature of gas. As we said earlier the intensity of arc column depend up on the presence of ionized media between separated electrical contacts, hence, special attention should be given in reducing ionization or increasing deionization of media between contacts. That is why the main designing feature of circuit breaker is to provide different pressure control methods, cooling methods for different arc media in between circuit breaker contacts.

HEAT LOSS FROM ARC

Heat loss from an arc in circuit breaker takes place through conduction, convection as well as radiation. In circuit breaker with plain break arc in oil, arc in chutes or narrow slots nearly all the heat loss due to conduction. In air blast circuit breaker or in breaker where a gas flow is present between the electrical contacts, the heat loss of arc plasma occurs due to convection process. At normal pressure the radiation is not a significant factor but at higher pressure the radiation may become a very important factor of heat dissipation from arc plasma. During opening of electrical contacts, the arc in circuit breaker is produced and it is extinguished at every zero crossing, getting established again during the next cycle. The final arc extinction or arc quenching in circuit breaker can be achieved by rapid increase of the dielectric strength in the medium between the contacts so that the arc gets quenched after the first zero crossing. This rapid increase of dielectric strength in between circuit breaker contacts is achieved either by deionization of gas in the arc media or by replacing ionized gas by cool and fresh gas. There are various deionization processes applied for arc extinction in circuit breaker, let us discussed in brief.

DEIONIZATION OF GAS DUE TO INCREASING PRESSURE

If pressure of the arc path increases, the density of the ionized gas is increased which means, the particles in the gas come closer to each other and as a result the mean free path of the particles is reduced. This increases the collision rate and as we discussed earlier at every collision the charged particles loss their directed velocity along electric field and again they are re-accelerated towards field. It can be said that over all mobility of the charged particles is reduced so the voltage required to maintain the arc is increased. Another effect of the increased density of particles is a higher rate of deionization of gas due to the recombination of oppositely charged particles.

The rate of ionization of gas depends upon the intensity of impact during collision of gas particles. The intensity of impact during collision of particles again depends upon velocity of random motions of the particles. This random motion of a particle and its velocity increases with increase of temperature of the gas. Hence it can be concluded like that if temperature of a gas is increased; its ionization process is increased and opposite statement is also true that is if the temperature is decreased the rate of ionization of gas is decreased means deionization of gas is increased. Therefore more voltage required to maintain arc plasma with a decreased temperature. Finally it can be said that the cooling effectively increases the resistance of the arc.

The insulating material (may be fluid or air) used in circuit breaker should serve two important functions 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 to be struck again. Proper steps must be taken in order to ensure that the rate at which the resistance is increased or decreased is not abnormal because it may lead to generation of harmful induced voltages in the system. The arc resistance can be increased by various methods like lengthening or cooling of the arc etc.

Limitations of high resistance method: Arc discharge has a resistive nature due to this most of the energy is received by circuit breaker itself hence proper care should be taken during the manufacturing of circuit breaker like mechanical strength etc. Therefore 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.

Restriking 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.

4.2 AC and DC circuit breaking

DC circuit breakers and AC breaker main difference is the ability to arc. Because the exchange of each cycle, have had zero, zero easy to extinction in the past, but has not been zero DC switching, arc extinguishing ability is poor, so to add additional interrupter device. DC arc is generally difficult, but the exchange has zero, breaking easily. Exchange can be derived for the DC circuit breaker protection, attention to three changes: 1, overload and short circuit protection.

1. long delay overload protection.

By thermal-action (double metal components) for long delay overload protection, the source of its action as I2R, AC RMS and DC current equal to the average, there is no need to use any restructuring. However, the large current size, to the current transformer secondary current heat who can not be used due to transformer can not be used on DC circuits. Release long delay if the overload is the use of electromagnetic type (hydraulic type, that is, oil cup), then the delayed release characteristics to change, the minimum operating current to 110% -140% bigger,

so the whole electromagnetic Release not be used for DC circuits (such as the use will have to redesign).

2.short circuit protection.

Thermal - Magnetic AC circuit breaker short-circuit protection is the use of magnetic system, which is used by the filtering of the rectifier circuit (DC), need to exchange the original setting current value multiplied by a factor of

1.Electromagnetic type of short circuit protection and thermal dynamic electromagnetic same.

2.circuit breaker accessories, such as shunt release, under voltage release, electrically operated institutions; shunt, under voltage are voltage coil, as long as the line voltage, is used for systems, need not be Any change can be used for DC system. Auxiliary and alarm contacts, AC and DC common. Electric operating mechanism for the DC Time to re-design.

3. unlike the exchanges as DC current zero-crossing characteristics, dc short circuit current (or even multiple small fault current) is breaking; arc out all the difficulties, so wiring should be two extreme ways or three poles in series increase the fracture, so that the fracture energy to bear part of the arc.

• DC arcs are to be interrupted by increasing the resistance interruption method in which resistance of the arc is increased so that the arc voltage can no longer maintain the current and the arc is extinguished.

• Size of DC circuit breaker increases as the voltage level increases.

• AC arcs current reduces to zero in each cycle (2 times)

• If the circuit breaker contacts are opened at time when the current passed through zero and dielectric strength of the medium is build up rapidly so that arc cannot strike again then arc can be extinguished successfully.

• Size of AC circuit breaker can be small compared to same voltage DC circuit breaker.

4.3 Restriking voltage and recovery voltage

It is the transient voltage that appears across the contacts at or near current zero during arcing period. If dielectric strength rise is greater than the rise of restriking voltage then the arc will not restrike.



RestrikingVoltage :

it is the transient voltage that exists during the arcing time. (natural frequency kHz). **Recovery Voltage** :

it is the rms voltage after final arc extinction. (normal frequency 50 or 60 Hz). both voltages appear between circuit breaker poles.

- 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 condition
- Make a circuit either manually or by remote under fault condition
- Circuit Breaker consists of fixed and moving contacts called electrodes
- Under normal operating condition these contacts remain closed and will not open automatically unless the system becomes faulty .These contacts can be opened manually or by remote control.
- When a fault occurs in a circuit the trip coils of the circuit breaker get energized and the moving contacts are pulled apart by some mechanism ,thus opening the circuit.

4.4 Rate of rise of recovery voltage

It is the rate of increase of restriking voltage and is abbreviated by R.R.R.V. its unit is kV/m sec.Consider the fig2 below showing the opening of circuit breaker under fault conditions. 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

The short circuit current will lag the voltage by 90° where i represents the short circuit current and *ea* represents the arc voltage. Under short circuit condition the entire generator voltage appears across inductance L. 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. This L-C combination forms an oscillatory circuit produces a transient

of frequency; $fn = 1/[2\pi(LC)1/2]$, which appears across the capacitor and hence across the contacts of the circuit breaker. This transient voltage is known as restriking voltage and may reach an instantaneous peak value twice the peak phase neutral voltage i.e. 2 *Em*.

It is R.R.R.V, which decides whether the arc will re-strike. If R.R.R.V is greater than the rate of rise of dielectric strength between the contacts, the arc will re-strike. 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 on:

- Recovery voltage
- Natural frequency of oscillations

4.5 Resistance switching

To reduce the restriking voltage, RRRV and severity of the transient oscillations, a resistance is connected across the contacts of the circuit breaker.

This is known as resistance switching. The resistance is in parallel with the arc. A part of the arc current flows through this resistance resulting in a decrease in the arc current and increase in the deionization of the arc path and resistance of the arc.

This process continues and the current through the shunt resistance increases and arc current decreases. Due to the decrease in the arc current, restriking voltage and RRRV are reduced. The resistance may be automatically switched in with the help of a sphere gap as shown in Fig. The resistance switching is of great help in switching out capacitive current or low inductive current.





The analysis of resistance switching can be made to find out the critical value of the shunt resistance to obtain complete damping of transient oscillations. Figure 5.8 shows the equivalent electrical circuit for such an analysis.

Unipolar switching

Unipolar systems usually have a dielectric that is a simple TMO. Examples are NiO [12], CuO, CoO, Fe2O3, HfO, TiO2Ta2O5, Nb2O5 [10,11]. These systems are good insulators with a large resistivity. They would normally not show any RS effect. To get the systems into the switching regime it is usually required to perform and initial _electroforming' step. In this process, a strong electric field is applied, which brings the system close to the dielectric break down. A full break down is prevented by a current limitation or compliance. After this _SET' procedure, the resistance of the device shows a significant decrease, reaching a _low resistance' state, *R*LO, which is stable, i.e., non-volatile. This state has an ohmic *I-V* characteristic at low bias. To switch the system to the _high resistance' state, *R*HI, a voltage has to be applied to the device, with either the same or opposite polarity than the previously applied _forming' voltage. In this _RESET' step, the resistance of the system suddenly increases, back to a _high resistance' value close to the original one.

No current compliance should be used in the RESET step. In fact, the resistance change occurs when the current through the device becomes larger than the value of the compliance. To SET the system again in the low resistance state, a voltage with current compliance has to be once again applied, similarly to the forming step. The system's resistance suddenly decreases down to a value close to *R*LO at a threshold voltage *Vth* , which is smaller that the forming one. The SET and RESET switching process can be repeated may times. The magnitude of resistance change typically remains within well-defined values, however some dispersion is often observed. An example of a typical electroforming and successive RESET and SET steps are shown in Fig



Bipolar switching

Bipolar resistive switching has been observed in a variety of ternary oxides with perovskite structure such as SrTiO3(STO), SrZrO3, and also in more complex systems such as the _colossal' magnetoresistive manganites LSMO, LCMO, PCMO, PLCMO, and even in cuprate superconductors YBCO and BSCCO. Some reports indicate that better performance may be obtained by small chemical substitution, such as Bi:SrTiO3 and Cr:SrTiO3. These bipolar systems may be either insulators or poor metals. Strong hysteresis in the two-terminal resistance is often observed without the need of an initial forming step. Nevertheless, electro-forming usually done, as it may improve the reproducibility of resistive switching, but this initial forming step remains not well understood [13].

The choice of a proper electrode material for each dielectric is an important issue for bipolar devices. Sawa and collaborators have performed a systematic study, concluding that a key feature for RS is the formation of Shottky barriers [10]. In fact, the observed scaling of *R*HI and *R*LO with the geometry of the devices indicate that the phenomenon should take place at the electrode/oxide interfaces.

4.6 current chopping

Current chopping is a term that came to our vocabulary with the advent of vacuum switching which was commercially started back in the 1950's. Earlier switching means in air or oil are in terms of dielectric recovery rate relatively slow and as the main contacts would part the arc would go through several zero crossings before it would finally go out and the dielectric strength across the now open gap be strong to prevent a restrike, and thus continuation of current for a further half cycle. With the introduction of vacuum as a dielectric medium that has a completely different characteristic to that of air or oil dielectrics in so much that it has a very

rapid dielectric recovery rate. Upon opening the main contacts of a vacuum interrupter whether is be a circuit breaker or a contactor, high velocity movements are easily obtained because of the low mass and small movements required to obtain arc isolation up to limited high voltages. As such, the arc will be extinguished at the first current zero and within half a cycle. Because of the rapid recovery rate of the dielectric, the arc, in vacuum interrupter will tend to go out before current zero which will result in an instantaneous current drop to zero and lead to an induced voltage or voltage transient being generated to down-stream equipment.



This can be seen by calculating the formula. Vt = IC xZ0 Vt - Voltage Transient IC - Current Chop Z0 - Surge Impedance Therefore if the current chop is .9 of an amp and the surge impedance is 3,000 ohm's, the voltage transient will equal 2700 volts on top of the RMS system voltage whether it be 4160 or 5KV. However if the current chop is 5 amps times surge impedance of 3,000 ohms, then the voltage transient can equal 15KV on top of the RMS supply voltage. You will notice from the above that some assumptions are made with regards to surge impedance values which are difficult to obtain and vary per circuit. In addition, the voltage transient value that a motor or dry type transformer will withstand is difficult to obtain from motor and transformer manufacturers. Therefore Joslyn Clark has taken the approach in their designs by the contact material mix gives an interrupt characteristic more than capable of handling the maximum horsepower rating lock rotor currents in terms of interrupt level and keeping the chopping current to an absolute minimum.

Over the years this philosophy has proven itself as unlike other manufacturers we have yet to see motor insulation problems created by our contactor. The motors manufactured to NEMA design standards which we consider high class or on motors produced to IEC standards which we consider to be of a lower class, cheaper version.

