4.10. ARC EXTINCTION IN VACUUM

When the contact of vacuum interrupter are separated the arc is drawn between them. The current leaves the electrodes from small, intensely hot spot (or spots). The metal vaporizes from the spots. The vapour stream constitutes the plasma in vacuum arc. The vapour formed is proportional to rate of vapour emission, which is proportional to the current in arc. Therefore, at current zero the plasma may vanish. Therefore the arc is interrupted at current zero. The vacuum has high dielectric strength, hence the arc may not restrike. The contact material shape are very important. Arc time constant of vacuum is lowest.

4.11. ARC EXTINCTION IN AIR-BLAST

In air-blast circuit, breakers the air flows from high pressure reservoir to the low atmospheric pressure during the arc extinction process. The flow rate is governed by the throat diameter of the nozzle, the pressure difference and the nozzle profile. The design is such that almost supersonic speeds of flows are achieved. The axial flow of air at high velocity causes rapid reduction in the diameter of the arc and the arc does not reappear after the final current zero.

4.12. ARC EXTINCTION IN SF_6 GAS*

In plasma, most of the current is carried by electrons. In certain gases like SF_6 the atoms and molecules have the property of attracting electrons to form negative ions. Negative ions are heavier than electrons and move slowly, thereby the resistance of plasma increases rapidly. Therefore electronegative gas like SF_6 is excellent arc extinction medium.

The arc extinction process in SF_6 gas is based on axial heat dissipation. The gas flows from high pressure to the low pressure through a well designed nozzle over the arc. The flowing gases take away the heat of the arc causing reduction in the diameter of arc. After current zero, the medium regains its dielectric strength very rapidly. This property of rapid recovery of the dielectric strength is due to the electronegativity of the gas.

4.13. ARC TIME CONSTANT

The time required by the quenching medium to gain original dielectric strength after final current zero. It is expressed in microseconds.

QUESTIONS

1. Explain the arc extinction process is alternating current circuit breaker.
2. State the theories postulated to explain the arc extinctions phenonmenon. What is the significance of restriking voltage in the arc extinction process?
3. An electric arc of 5 cm has a current of 1000 amperes and voltage across the arc is 25 volts. Calculate the energy consumed by the arc in one second.

* *Puffer type SF_6 circuit-breakers are becoming popular for HV & EHV systems Whole Breaker is filled with gas at 5 kgf/cm^2.*

Puffer type single pressure SF_6 circuit-breaker uses Puffer principle for arc exinction. A cylinder called Puffer cylinder is attached to the moving contact. Puffer cylinder moves against fixed piston during opening stroke. The SF_6 gas trapped in the Puffer cylinder is compressed due to relative movement between the puffer cylinder and the piston. The gas pressure in puffer cylinder depends upon the speed of Puffer cylinder. Higher opening speeds (6 to 7 metres/sec) are used. The compressed gas in Puffer cylinder is released through convergent-divergent nozzles. The gas flows with almost supersonic velocity over the arc. Arc diameter is reduced to zero. Arc is quenched at first or second current zero. Dielectric strength is regained due to electronegativity of SF_6 gas.

Self-Extinguishing Principle : The heat of arc generates pressure which forces the arc in hollow moving contact. The arc gets lengthened and cooled. The arc is exinguished at current zero. For smaller current the puffer principle is used.

5

Air-Break Circuit-Breaker

Introduction—Design features—Heavy duty air-break circuit-breaker—Low voltage air breaker circuit-breaker—Arc extinction by means of magnetic field—D.C. air breaker circuit-breaker —Summary

5.1. INTRODUCTION

The air at atmosphere pressure is used as an arc extinguishing medium in Air-Break Circuit-Breakers. These circuit-breakers employ the high resistance interruption principle. The arc is rapidly lengthened by means of the arc runners and arc chutes and the resistance of the arc is increased by cooling lengthening and spliting the arc. The arc resistance increases to such an extent that the voltage drop across the arc becomes more than the supply voltage and the arc extinguished.

Air-breaker circuit-breakers are used in d.c. circuits and a.c. circuits upto 12 kV.

The air-break circuit-breakers are generally indoor type and installed on vertical panels or indoor draw-out type switchgear.

A.C. air-break circuit-breakers are widely used in indoor medium voltage and low voltage switchgear. Typical reference values of ratings of air-break circuit-breakers are:

460 V, 400—3500 A,	40—75 kA.
3.3 kV, 400—3500A,	13.1—31.5 kA.
6.6 kV, 400—2400 A,	13.1—20 kA.

Magnetic field is utilised for lengthening the arc in high voltage air-break circuit-breakers.

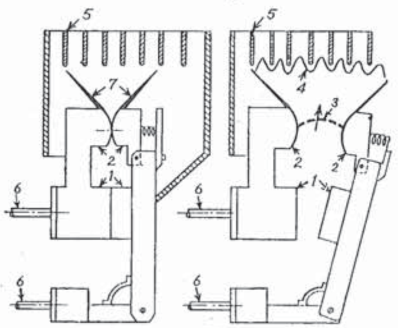
5.2. CONSTRUCTION OF AIR-BREAK CIRCUIT-BREAKER

In the air-break circuit-breaker the contact separation and arc extinction takes place in air at atmospheric pressure. Fig. 5.1 (a) shows the closed current carrying contacts. As the contacts are opened arc is drawn between them. The arc core is a conducting path of plasma. The surrounding medium contains ionized air. By cooling the arc, the diameter of arc core is reduced. The arc is extinguished by lengthening the arc, cooling the arc and splitting the arc. The arc resistance is increased to such an extent that the system voltage cannot maintain the arc and the arc gets extinguished at current zero of AC wave.

Fig. 5.1 (c) illustrates the normal arrangement of an air-break circuit-breaker. This type of breaker is used for medium and low voltages.

There are two sets of contacts: Main contacts and Arcing contacts. Main contacts conduct the current in closed position of the breaker. They have low contact resistance and are silver plated. The arcing contacts (2) are hard, heat resistant and are usually of copper alloy. While opening the contact, the main contacts dislodge first. The current is shifted to the arcing contacts. The arcing contacts dislodge later and arc is drawn between them (3). This arc is forced upwards by the electromagnetic forces and thermal action. The arc ends travel along the Arc Runner (Arcing horns.) The arc moves upwards and is split by arc splitter plates (5) as shown by the arrow (4). The arc is extinguished by lengthening, cooling splitting etc. In some breakers the arc is drawn in the direction of the splitter by magnetic field.

(*a*) Contacts in closed position (*b*) Contacts Separated in air at atmospheric pressure



1. Main contacts
2. Arcing contacts
3. Arc rising in the direction of the arrow
4. Arc getting split
5. Arc splitter plates
6. Current carrying terminals
7. Arc runners

(I) Contacts Closed (II) Contacts Open
Principle of air-break circuit-breaker

Fig. 5.1. Arc extinction is air-break circuit-breaker.

Furthermore, air-break circuit-breakers have been developed with current limiting feature, magneting blow-up of arc, etc. Air break a.c. circuit breakers are widely used for industrial switchgear auxiliary switchgear in generating stations.

Air-break principle of lengthening of arc, arc runners, magnetic blow-up is used for d.c. circuit-breakers upto 15 kV.

5.3. ARC EXTINCTION IN A.C. AIR-BREAK C.B. (Ref. Sec. 4.7.1)

In a.c. air-break circuit-breakers the arc is lengthened cooled and splitted so as to increase the resistance of the arc. The rapid increase in the arc-resistance causes the reduction in the fault current and the fault current does not reach the prospective high value. The arc extinction process is assisted by the current zeros in the a.c. wave. The voltage drop across the arc goes on increasing with the increase in the arc resistance and at a current zero, when the recovery voltage across the contacts is less than the arc-voltage, the arc gets extinguished. The energy in the system inductance at current zero is zero. Hence the arc interruption is easier (Refer. Sec 4.7).

Arc Runners (Arcing Horns). As soon as the arc leaves the vicinity to the contacts it commutes to a pair of run out horns. In doing so the outer blow out system is switched on. These blow out coils provide a magnetic field such that the arc footing is subjected to a strong magnetic field. We know from the electromagnetic theory that force is experienced by current carrying element of length $\overline{dl}$ metres, carrying current I amperes and placed in magnetic field B webers/m^2 is given by the cross product:

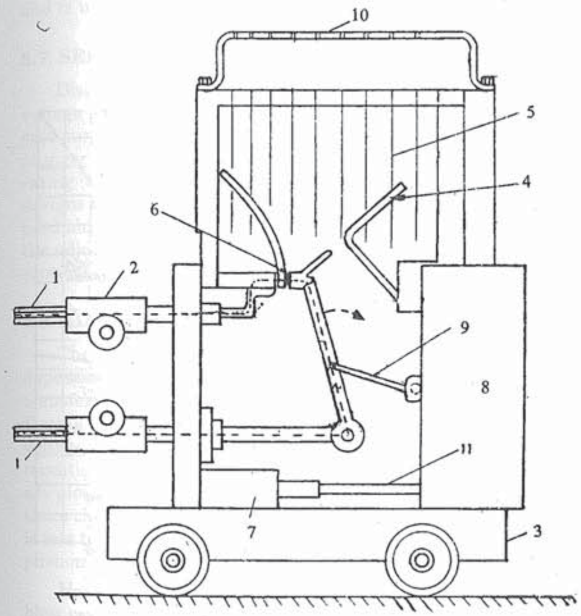
$$dF = I\,(\overline{dl} \times \overline{B}) \text{ Newtons}$$

By the virtue of this force the arc travels upward and its length increases. The tips of the arc run along the arc runners and come to extremity. As the length of arc increases. At a particular length the system voltage is unable to maintain the arc and the arc is extinguished. For systems having low inductance the energy $\frac{1}{2}LI^2$ joules is small and arc gets extinguished before reaching the extremity of runners. For high inductance circuits special techniques such as magnetic blow-out, additional larger arcing horns etc. are used.

5.4. LENGTHENING OF ARC BY MEANS OF MAGNETIC FIELDS

The arc is directed into arc splitters by application of magnetic field provided by current in blow out coils. These blow out coils are usually not connected permanently but come in the circuit completed by the arc. The blow out coil is energized during the breaking process automatically as the roots of the arc move over to the arc runners. It is important to connect the coils at correct polarity so that the arc is directed upwards.

The magnetic field itself does not extinguish the arc. It moves the arc rapidly into the arc splitters. As the arc moves in the cooler still air, it deionizes partly. It is brought in contact with cool arc splitters, the partitions remove heat from the arc and affect deionization. The plates are of a material which can with stand high temperatures.



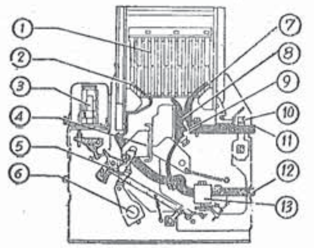
1. Isolating contacts
2. Insulating bushing
3. Carriage
4. Arc runner
5. Arc splitters
6. Contacts
7. Operating solenoid
8. Operating mechanism
9. Operating Lever
10. Cover with vents .... current path.
11. Link

Fig. 5.2 Truck-mounted air-break circuit-breaker shown in closed position.

5.5. DESCRIPTION OF A LOW VOLTAGE AIR-BREAKER CIRCUIT-BREAKER

The air-break circuit-breakers have current limiting feature. Because of current limiting property, there is considerable saving in other equipment such as bus bars, cables, insulating supports, etc. by reducing the heating effect as well as the electrodynamic forces. This novel property is illustrated in Figs. 5.4 and 5.5. In Fig. 5.4 we observe that the prospective short circuit current, (*i.e.* the current that would flow in the circuit if the circuit-breaker is replaced by conductor), would be as indicated by thin line. But the circuit-breaker modifies the current waveform and has a limiting effect so as to obtain the waveform shown by thick line of let through current. The contacts open rapidly and the increased arc length gives the current limiting property.

The peak values of current attained corresponding to prospective value of current are given in Fig. 5.5.



1. Arc chutes having deionization plates coated with plastic paint on the top half.
2. Arc runner for extending the arc for effective and quick extinction.
3. Magneto thermal release with inverse time current characteristic on overload and instantaneous tripping on heavy fault currents.
4. Moving contact carrier.
5. Main trip rocker arm on which the super rapid tripping device acts.
6. Main operating shaft.
7. Arcing horn.
8. Arcing contacts.
9. Main contacts.
10. Current transformer for feeding releases.
11. Line terminal.
12. Load terminal.
13. Super rapid tripping device a built-in protection device which trips the breaker from the function point.

[*Courtesy* : Larsen and Toubro Ltd. India]

Fig. 5.3 Sectional view of a low voltage circuit-breaker.

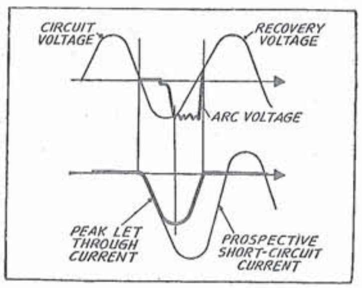


Fig. 5.4. Characteristic of voltage and current.

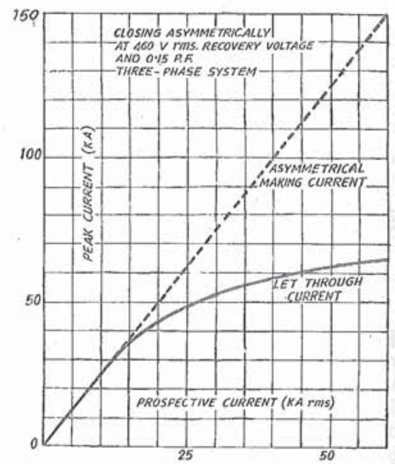


Fig. 5.5. Current limiting feature.

These circuit-breakers can be supplied with the following type of protective releases.

(1) **Thermal Tripping Releases.** It consists of an adjustable bimetallic thermal release having inverse time current characteristic for protection against overloads.

(2) **Super Rapid Trip.** A non-adjustable super rapid magnetic release is provided in each phase. The tripping time is of the order of 13-15 milliseconds. This has been achieved by collapsing from the fulcrum point instead of actuating the trip bar.

(3) Under voltage release suitable for d.c. or a.c. supply.

(4) **Shunt Trip.** Suitable for a.c. or d.c. supply with remote control.

Typical Ratings of low voltage air-break a.c. circuit-breakers

Nominal current rating	640 A r.m.s.
Rated voltage	460V r.m.s.
Breaking current at 50 Hz, p.f. = 0.15	75 k.A r.m.s. (Refer Sec. 15.9)

5.6. OPERATING MECHANISMS FOR AIR-BREAK CIRCUIT-BREAKERS

The operating mechanisms of Air-Break Circuit-Breakers are generally with operating spring. The closing force is obtained from one of the following means:

— solenoid
— spring charged manually or by motor
— pneumatic

The solenoid mechanisms drive power from battery supply or rectifiers. The solenoid energised by the direct current gives the necessary force for closing the circuit-breaker.

The springs used for closing operation can be charged manually or by motor driven gears. At the time of closing operation the energy stored in the spring is released by unlatching of the spring and is utilised in closing of the circuit-breaker.

5.7. SERIES CONNECTED OVER LOAD TRIP COIL ARRANGEMENT

Direct acting overload trip coils can be incorporated with the circuit-breaker. In some medium voltage and low voltage circuit-breakers, the coils are connected in series and are rated for the circuit current. The tripping is based on electromagnetic attraction by the field of solenoid. The plunger, when lifted, initiates the trip-mechanism of the switching device. Upto a certain current rating (*e.g.* 800 amperes in one design), such coils have been developed. However the direct acting designs for 5 amps. or 1 amp. are developed to be used in conjunction with CTs. Oil dashpots, are used along with the plunger which facilitates time-lag. Certain time lag adjustment is possible with the adjustment of the initial position of the plunger. Design is developed to give accurate time current characteristic for wide range of ambient temperature.

5.8. AIR-BREAK D.C. CIRCUIT-BREAKERS FOR MEDIUM VOLTAGES

The d.c. circuit-breakers should limit and interrupt any short circuit currents in the circuit dependably and rapidly. Accordingly, as soon as the fault occurs, the contacts separate, the arc is transferred from contacts to the arc runners where it rises upwards and extinguishes of its own. During this process the arc resistance is increased and the voltage across the arc exceeds the supply voltage. Every length of the free arc corresponds to a definite arc characteristic. Assuming that the conditions of the free burning arc can be applied to the arc under consideration, the characteristics are plotted for three different lengths of the arc as in Fig. 5.6. In the region of length , the resistance characteristics shown by straight line intersects arc characteristic at point A. The arc voltage is less than supply voltage and therefore, arc continues to burn till the contacts are destroyed. The phenomenon is known as *Standing Arc*.

However, the arc is extended by means of magnetic blow out system thereby increasing the arc voltage above the supply voltage, to cause arc extinction. There is no intersection with the characteristic of supply system. The energy stores in the system inductance is dissipated and the arc is extinguished. During the time of burning of the arc the supply source continues to give up the energy, the longer the arc burns, the greater the energy, in other words larger the system of inductance and lower arc voltages. Hence the entire interrupting operation is a question of energy. The arc moves from the contact zone at a speed of sound. Its uniform extension poses special problems influenced by thermal electro-dynamic stress.

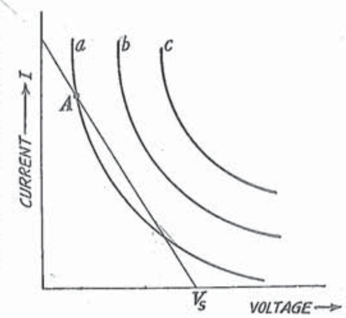


Fig. 5.6. D.C. arc characteristics for different arc lengths.

Typical rating of d.c. circuit breaker

1500 V., 10 kA continuous, 80 kA breaking

5.9. MINIATURE CIRCUIT-BREAKER, MOULDED CASE CIRCUIT-BREAKERS

These are used extensively in low voltage domestic, commercial and industrial applications. They replace conventional fuses and combine the features of a good HRC fuse and a good switch. For normal operation it is used as switch. During overloads or faults, it automatically trips off. The tripping mechanism is actuated by magnetic and thermal sensing devices provided within the MCB.

Tripping mechanism and the terminal contacts are assembled in a moulded case, moulded out of thermosetting powders. They ensures high mechanical strength, high dielectric strength and virtually no ageing. The current carrying parts are made out of electrolytic copper or silver alloy depending upon the rating of the breaker. All other metal parts are of non-ferrous non-rusting type. Sufficient cross-section for the current carrying parts is provided to ensure low temperature rise even under high ambient temperature environment. The arc chute has a special construction which increases the length of the arc by the magnetic field created by the arc itself and the arc chute is so placed in the breaker that the hot gases may not come in contact with any of the important parts of the breaker.

The breaker has unit construction whereby multiple pole breakers can be made by assembly of single pole breakers.

Typical Ratings of MCB

Current Rating : 5, 10, 15, 20, 30, 40, 50, 60, Amp. also 0.5, 1, 2, 2.5, 3, 3.5, 6, 7.5, 8, 10, 12, 35, 45, 55 Amp.

Voltage Rating : 240 V/415 V AC; 50 V/110 VDC

Rupting Capacity: AC : 3 kA at 50 V (non-inductive)

1 kA at 110 V (non-inductive).

QUESTIONS

1. Describe with neat sketches the principle of medium voltage-air-break circuit-breakers.
2. Explain the arc interruption process in air-break circuit-breakers incorporating arcing horns, arc splitters, magnetic blow-out coils.
3. Describe current limiting feature of Air-break circuit-breakers.

6

Air Blast Circuit-Breaker

Introduction—Principle of ABCB—Circuit-Breaker with External Extinguishing Energy—Design Features—Multi-Unit Design—Resistance Switching—Voltage Distribution—Cross-jet Design —Technical Data—Merits—Maintenance—Compressed Air System—Generator C.B.—Summary.

6.1. INTRODUCTION

Air blast circuit-breakers were used before 1980s for 11 to 1100 kV. A compressor plant is necessary to maintain high air pressure in the air receiver.

During the period 1950-1970, Air-blast circuit-breakers were preferred for 220 kV and above. However today, SF_6 circuit-breakers are preferred for this range. For 11 kV and 33 kV applications. VCBs are preferred Air-blast Circuit Breakers have become obsolete. (1995)

6.2. CONSTRUCTION OF AN AIR BLAST CIRCUIT-BREAKER

In air blast circuit-breaker (also called compressed air circuit-breaker) high pressure air is forced on the arc through a nozzle at the instant of contact separation. The ionized medium between the contacts is blown away by the blast of the air. After the arc extinction the chamber is filled with high pressure air, which prevents restrike. In some low capacity circuit-breakers the isolator is an integral part of the circuit-breaker. The circuit-breaker opens and immediately after that the isolator opens, to provide additional gap.

In EHV switch-yards of today, isolators are generally independently mounted.

Fig. 6.1 shows one pole of the EHV air blast circuit-breaker. In the complete assembly there are three identical poles.

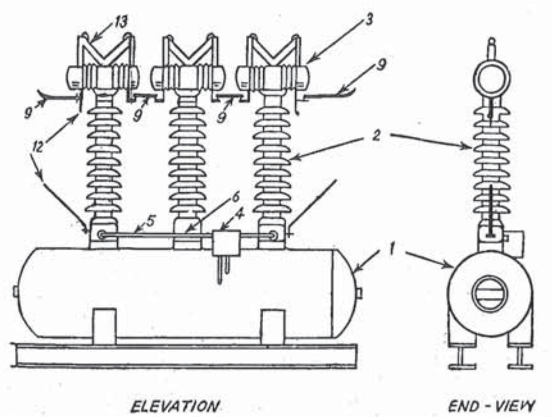


Fig. 6.1. (*a*) One pole of an extra-high voltage air blast circuit-breaker.