High-voltage A.C. Circuit-Breakers

The fault clearing process—Types of circuit breakers—Circuit-breaker assembly—Operating mechanism—Materials—Summary

2.1. INTRODUCTION

In this chapter, the constructional aspects of circuit-breakers have been briefly discussed. Th theoretical aspects regarding transient variation of current and voltage, arc extinction process an the various of circuit-breakers have been described in detail in subsequent chapters.

The circuit-breakers are automatic switches which can interrupt fault currents. In some ap plications like single phase traction system, *Single pole* circuit-breakers are used. The part of th circuit-breakers connected in one phase is called the *pole*. A circuit-breaker suitable for three phas system is called a *'triple-pole* circuit-breakers'.

Each pole of the circuit-breaker comprises one or more *interrupters* or *arc-extinguishing cham bers*. The interrupters are mounted on support insulators. The interrupter encloses a set of *fixe and moving contact*. The moving contacts can be drawn apart by means of the operating links the operating mechanism. The operating mechanism of the circuit-breaker gives the necessary ene gy for opening and closing of contacts of the circuit-breakers.

The arc produced by the separation of current carrying contacts is interrupted by a suitabl medium and by adopting suitable techniques for arc extinction. The circuit-breaker can be classifie on the basis of the arc extinction medium.

2.2. THE FAULT CLEARING PROCESS

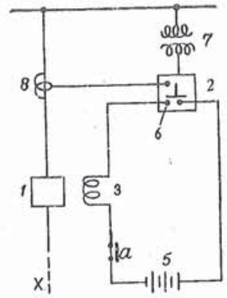
During the normal operating condition the circuit-breaker can be opened or closed by a statio operator for the purpose of switching and maintenance. During the abnormal or faulty condition the relays sense the fault and close the trip circuit of the circuit-breaker. Thereafter the circuit breaker opens. The circuit-breaker has two working positions, *open and closed*. These correspon to open circuit-breaker contacts and closed circuit-breaker contacts respectively. The operation o automatic opening and closing the contacts is achieved by means of the *operating mechanism* o the circuit-breaker. As the relay contacts close, the trip circuit is closed and the *operatin mechanism* of the circuit-breaker starts the opening operation. The contacts of the circuit-breake open and an arc is drawn between them. The arc is extinguished at some natural current zero o a.c. wave. The process of current interruption is completed when the arc is extinguished and th current reaches final zero value. The fault when the arc is extinguished and the current reache final zero value. The fault is said to be cleared. The process of fault-clearing has the following se quence:

- Fault occurs. As the fault occurs the fault impedance being low, the currents increase and the relay gets actuated. The moving part of the relay move because of the increase in th operating torque. The relay takes some time to close its contacts.
- Relay contacts close, the trip circuit of the circuit-breaker closes and trip coil is energized
- The operating mechanism starts operating for the opening operations. The circuit-breake contacts separate.

- Arc is drawn between the beaker contacts. The arc is extinguished in the circuit-breaker by suitable techniques. The current reaches final zero as the arc is extinguished.

2.3. THE TRIP-CIRCUIT

Fig. 2.1 illustrates the basic connections of the circuit-breaker control for the opening operation.



1. Circuit-breaker
2. Relay
3. Trip coil of c.b. (Shunt Release)
4. Trip circuit
5. Battery
6. Relay Contacts
7. Potential transformer
8. Current transformer

a Auxiliary switch contacts
x Protected element.

Fig. 2.1. Simplified diagram of circuit-breaker control for the opening operation.

The Protected circuit *x* is shown by dashed line. When a fault occurs in the protected circuit, the relay (2) connected to the CT. and PT actuates and closes its contacts (6) Current flows from the battery (5) in the trip circuit (4). As the trip coil of the circuit breaker (3) is energized, the circuit-breaker operating mechanism is actuated and it operates for the opening operation. Auxiliary switch is an important item in the circuit.

2.4. RECENT ADVANCES

Before 1970s in medium voltage range and high voltage range, air-break, bulk-oil; minimum oil, air blast circuit breakers ruled the world market. During 1970s vacuum circuit-breakers were introduced for applications up to rated voltages of 36 kV. Single pressure puffer type SF_6 breakers were introduced for rated voltages from 3.3 kV to 760 kV. SF_6 Gas Insulated Substations (GIS) were introduced for 12 kV to 760 kV. Fault levels * and rated voltages in the system have increased. ** The bulk-oil breakers, minimum oil breakers, air-blast breakers have become obsolete. However you will find them in the existing installations during 1990s.

The vacuum breakers and SF_6 breakers are maintenance-free and of superior switching performance. They are now preferred for various switching duties in new installations. In low voltage range Air-break circuit-breakers and contactors rule the market.

During 1970s and 1980s, the research and development was focussed on in various switching phenomena, switching overvoltages, short-circuit testing, development of Vacuum/SF_6 and HVDC CBs, SF_6, GIS.

The Standards on circuit breakers were totally revised with the introduction of TRV concept and rigorous testing. Short circuit testing laboratories with synthetic testing facilities were built in various countries. Reliable, maintenance-free, simpler circuit breakers and compact indoor SF_6 Gas Insulated Substations (GIS) are now manufactured and installed in India for various rated voltages from 3.6 kV to 420 kV.

* Fault MVA = $\frac{\sqrt{3} \times V \times I}{10^6}$, where V is the service voltage in volts and I is the fault current in amperes.

In low voltage range air-break circuit breakers/contactors ; miniature circuit breakers, moulde case circuit breakers and solid state switching devices, HRC fuses have been developed to meet th requirements of control gear.

The Circuit Breaker technology has matured and circuit-breakers are available for every faul level*, rated voltage** and switching duty in power system.

2.5. CLASSIFICATION BASED ON ARC QUENCHING MEDIUM

The a.c circuit-breakers can be classified on the basis of rated voltages. Circuit-breakers belo rated voltage of 1000 V are called low voltage circuit-breakers and above 1000 V are called hig voltage a.c. circuit-breakers.

The type of the circuit-breaker is usually identified according to the medium of arc extinctio The classification of the circuit breakers based on the medium of arc extinction is as follows:

(1) Air break circuit-breaker/Miniature circuit-breaker.

(2) Oil circuit-breaker (tank type of bulk oil)

(3) Minimum oil circuit-breaker.

(4) Air blast circuit-breaker.

(5) Sulphur hexafluoride circuit-breaker. (Single pressure or Double Pressure).

(6) Vacuum circuit-breaker.

Each circuit-breaker will be studied thoroughly in the subsequent chapters. These circuit breakers employ various techniques to extinguish the arc resulting from separation of the curren carrying contacts. The mode of arc extinction is either 'high resistance interruption' or 'zero-poin interruption'.

High Resistance Interruption. In this process the resistance of the arc is increased b lengthening and cooling it to such and extent that the system voltage is no longer able to maintai the arc and the arc gets extinguished. The technique is employed in airbreak circuit-breakers an d.c. circuit-breakers.

Low Resistance or Zero Point Interruption. In this process, the arc gets extinguished a natural current zero of the alternating current wave and is prevented from restriking again b rapid build up of dielectric strength of the contact space. This process is employed in almost all a.c circuit-breakers. HVDC circuit-breakers employ *'artificial current zero method'*.

Each leading manufacturer of circuit-breaker develops two or more types of circuit-breaker for every voltage class. (Ref. Table 2.1). The construction of the circuit-breakers depends upon it type (arc-quenching medium), voltage rating and structural form.

Air-break Circuit-breakers. Utilize air at atmospheric pressure for arc-extinction (Ref. Ch. 5).

Air-blast Circuit-breakers. Utilize high pressure compressed air for arc extinction (Ref. Ch. 6). They need compressed air plant.

Bulk-oil and Minimum-oil Circuit-breakers. Utilize Dielectric oil (Transformer oil) for arc extinction. In Bulk-oil circuit breakers, the contacts are separated inside a steel tank filled with dielectric oil. In minimum oil circuit-breakers the contacts are separated in an insulating housing (interrupter) filled with dielectric oil.

SF_6 Circuit-breakers. Sulphur-hexa-fluoride gas is used for arc extinction. There are two types :

— **Single Pressure puffer type SF_6 Circuit-breakers,** in which the entire circuit-breaker is filled with SF_6 gas at single pressure (4 to 6 kgf/cm^2). The pressure and gas flow required for arc extinction is obtained by piston action.

— **Double pressure type SF_6 Circuit-breaker,** in which the gas from high-pressure system is released into low pressure system over the arc during the arc quenching process.

* Fault MVA = $\frac{\sqrt{3} \times V \times I}{10^6}$, where V is the service voltage in volts and I is the fault current in amperes.

** Rated Voltages of circuit-breakers refer to higher system voltage *e.g. 3.6 kV, 12 kV, 36 kV, 145 kV, 245 kV, 420 kV, 800 kV, rms ph. to ph.*

Table 2.1 Comparison of Circuit-breakers

	Type	*Medium*	*Voltage-Breaking Capacity*	*Design Features*	*Remarks*
1.	Air-break-circuit-beaker	Air at atmospheric pressure	430-600V, 5-15-35 MVA recently 3.6-12 kV, 500 MVA	**Incorporates :** Arc runners arc splitters magnetic coils	Used for medium low voltages A.C. D.C. Industrial circuit-breakers. Have current limiting features.
	Miniature C.B.	Air at atmospheric pressure	430-600 V	Small size, current limiting feature	Used for Low and Medium Voltages.
2.	Bulk-Oil circuit-breaker	Dielectric oil	12 kV, 3.6 kV	One tank upto 36 kV, 3 tanks above 36 kV, fitted with arc control devices	Getting obsolete used upto 12 kV, 500 MVA.
3.	Minimum oil circuit-breaker	Dielectric oil	Preferred for 3.6 kV to 145 kV	The circuit breaking chamber is separate from supporting chamber. Small size, Arc control device used.	Used for metal enclosed switchgear upto 36 kV, Outdoors type between 36 and 245 kV. Now superseded by SF_6 CB.
4.	Air-blast circuit-breaker	Compressed air (20-30) kg/cm^2	245 kV, 35,000 MVA upto 1100 kV, 50,000 MVA	Unit type construction several units per pole, auxiliary compressed air system required.	Suitable for all EHV applications, fast opening closing. Also for Arc Furnace Duty. Now Superseded by SF_6 CB for 145 kV, and above
5.	SF_6 circuit-breaker Single pressure puffer type SF_6 GIS	SF_6 gas (5 kg/cm^2)	145 kV, 7500 MVA 245 kV, 10,000 MVA 12 kV, 1000 MVA 36 kV, 2000 MVA 420 kV, 40 kA	One interrupter pole upto 245 kV	Suitable for SF_6 switchgear and Medium voltage swgr. EHV circuit breaker. Maintenance free.
6.	Vacuum circuit-breaker	Vacuum	Preferred for indoor switchgear rated upto 36 kV, 750 MVA	Variety of designs, long life, modest maintenance.	Suitable for a variety of application from 3.6 kV to 36 kV
7.	H.V.D.C. Circuit-breaker	Oil or Air-Blast	33 kV, 2kA	Artificial current zero by switching in capacitors.	Used for Metallic Return Transfer Breaker.

This type has been superseded by single pressure puffer type.

In Vacuum circuit-breakers, the fixed and moving contacts are housed inside a permanently sealed Vacuum interrupter. The arc is quenched as the contacts are separated in high vacuum. (Ref. Ch. 9)

2.6. TECHNICAL PARTICULARS OF A CIRCUIT-BREAKER

A circuit-breaker is identified by the following particulars :

(1) Type of medium for arc-extinction.

(2) Rated voltage. This corresponds to highest power-frequency voltage between phase to phase, e.g. 3.6 kV, 7.2 kV, 12 kV, 36 kV, 72.5 kV, 145 kV, 245 kV.

(3) Rated breaking current

(4) Other rated characteristics, (Ref. Ch. 3)

(5) Type of construction :

— Indoor metal-clad type, draw-out type

— outdoor type

— Metal-clad SF_6 gas insulated type.

(6) Type of operating mechanism.

(7) Total break-time e.g. 2 cycle, 3 cycle, 5 cycle.

(8) Structural form

(9) Additional feature for overvoltage limiting.

— Surge suppressor — Switching resistor.

2.7. ASSEMBLY OF OUTDOOR CIRCUIT-BREAKERS

The design features of an individual circuit-breaker depends upon its voltage, other ratings and the type. The circuit-breakers manufactured by different companies may have quite different design patterns. However, a general description of an EHV circuit breaker can be given to cover the various types. The low voltage circuit-breakers, have different design features as the voltage, capacity and frequency of operation is different from that of the EHV circuit-breakers. The part of the circuit-breaker connected in one phase is called 'Pole of the circuit-breaker'. A circuit-breaker for power systems is called 'Triple pole circuit breaker'. In single phase traction systems, single pole circuit breakers are employed.

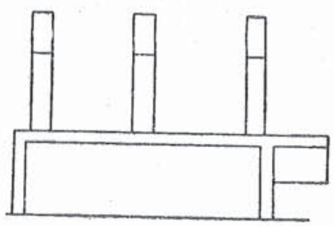


Fig. 2.2. Structural form of a triple outdoor circuit-breaker with one iterrupter per pole.

TABLE 2.2. Present Trends in Choice of Circuit-Breakers

Rated Voltage	*Preferred type*	*Remarks*
Below 1 kV (low voltage)	— Air break Circuit-breaker	— Metal-enclosed switchgear — Metal-enclosed control gear
3.6 kV to 12 kV	— Vacuum Circuit-breakers — SF_6 C.B.	— Metal-enclosed Switchgear, Indoor use with : — Vacuum Switchgear preferred — Single Pressure SF_6 preferred
36 kV	— Minimum Oil Circuit-Breaker — Vacuum C.B. SF_6 Circuit Breaker	Outdoor Type or in Kiosk MOCB becoming obsolete.
145 kV and 245 kV*	— Minimum Oil Circuit-Breaker out door — SF_6 Outdoor Puffer type	— SF_6 Circuit Breaker Preferred — MOCB becoming obsolete.
420 kV*	— SF_6 Outdoor Puffer type	— SF_6 Circuit-Breaker Preferred.

* Puffer type out-door SF_6 C.B. installed in India 1980-1981.
** Vacuum Switchgear introduced in India 1980-81.
* Vacuum contactors introduced in India 1980.

† Capacitor Switching VCB or SF_6 Motor Switching SF_6 or VCB with RC Suppressors Arc Furnace Duty. VCB/SF_6/ABCB Repeated operations VCB/SF_6

Motor Switching SF_6 or VCB with RC Suppressors

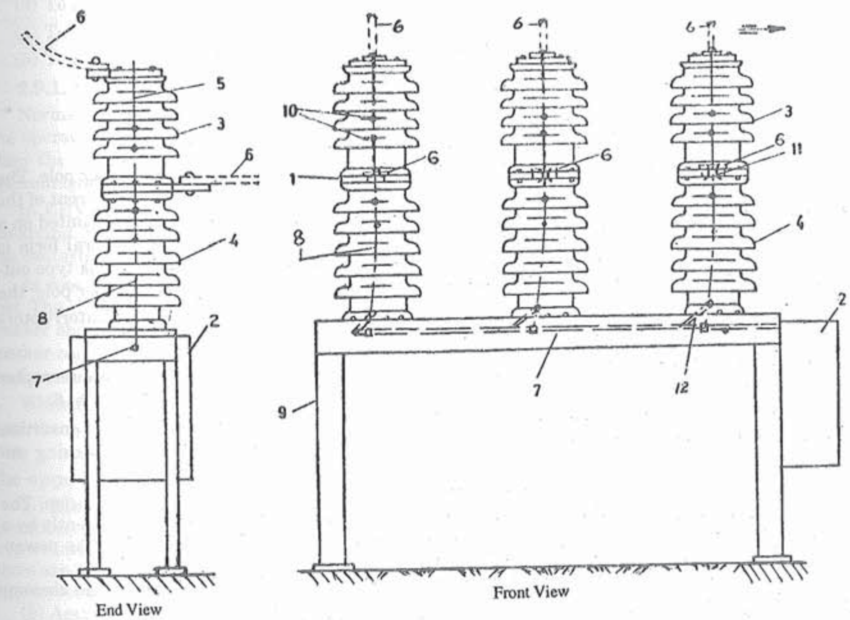
In Fig. 2.3 we see three identical poles of a circuit breaker assembled on a common frame. The distance between the poles is determined by the voltage between their conducting parts. The current carrying parts are supported by dielectric materials. The current is interrupted in closed chamber known as arc extinction chamber (Fig. 2.3, item 3) or interrupter.

The contacts (10) are generally in pairs of fixed contact and moving contact. The moving contact is moved mechanically. To achieve this operation of closing and opening, an *Operating Mechanism* is necessary. The function of operating mechanism is to open and close the contact when desired.

The operating mechanism may be common for the three poles or may be separate one for each pole. In addition to the operating mechanism, there is *Control Cabinet* or what is known as *Switch Cubicle*. The various control interlocking, indicating connections are through this control cabinet placed near the breaker.

Thus a complete three-phase circuit-phase circuit breaker consists of the following sub-assemblies.

— Three poles
— control cabinet
— operating mechanism support structure
— auxiliaries



1. Circuit-breaker pole
4. Support porcelain
7. Operating rod
10. Contacts
12. Linkage
2. Operating mechanism
5. Conductor
8. Insulating operating rod
11. Transfer contacts between moving contacts and terminal.
3. Interrupter
6. Terminals
9. Frame

Fig. 2.3. Diagram illustrating the assembly of an outdoor circuit-breaker.

2.8. STRUCTURAL FORM OF CIRCUIT-BREAKERS

The structural form of a circuit-breaker depends on its type, rated voltage type of design, type of operating mechanism etc.

In indoor, metal clad switchgear, the three poles of the circuit-breaker are mounted on a withdrawable truck. Such configuration is commonly used for rated voltages unto 24 kV (Ref. Ch. 15).

For 36 kV and above, outdoor circuit-breaker are preferred. The structural form of outdoor circuit-breaker depends of rated voltage, number of interrupters of per pole and type of operating mechanism. Circuit-breakers of rated voltages upto and 145 kV generally have a single interrupter per pole (Ref. Fig. 2.3) In such a structural form, the interrupter porcelain and support porcelain should withstand the power-frequency and impulse test voltages internally and externally (Ref. Ch. 12).

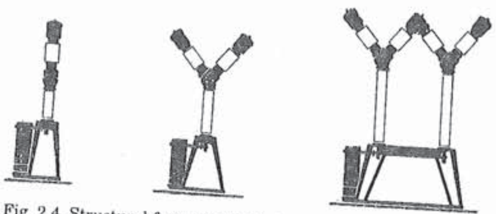


Fig. 2.4. Structural from of 145 kV, 245 kV and 420 kV C.B. Pole.

245 kV circuit-breakers have two or more identical interrupter units (elements) per pole. The number of interrupters per pole depends upon the rated voltage and rated breaking current of the circuit-breaker. Such circuit-breaker pole comprises identical twintinterrupter units mounted on a single support porcelain column in T or Y formation (Ref. Fig. 2.4). Such a structural form is preferred in outdoor minimum oil circuit breakers, air blast circuit-breaker and live tank type outdoor SF_6 circuit-breakers. While MOCBs and ABCDs require two to six interrupters per pole; the SF_6 circuit-breakers are with one or two interrupters per pole for 245 kV and with two interrupters per pole for 420 kV. The SF_6 breakers are therefore more economical.

In multi-break type construction *voltage-grading capacitor* is connected across each interrupter for equalizing the voltage shared by the interrupter during interruption process (Ref. Ch. 6).

Pre-closing resistors are also connected in parallel whenever necessary. The pre-insertion resistors (Preclosing resistors) are necessary to limit over-voltages occurring during closing unloaded transmission lines (Ref. Ch. 18).

Circuit-breakers for rated voltage above 245 kV generally have *independent pole operation.* The operating mechanism of each pole is independent and each pole can be tripped independently by a separate relay. Independent pole operation is desirable for improving the stability of the power-system (Ref. Sec 44.8).

Structural form of EHV metal-clad SF_6 insulated switchgear is quite different than conventional equipment discussed above (Ref. Ch. 7).

2.9. OPERATING MECHANISMS

Circuit-breakers have two working positions-open and close. During the closing operation, the circuit-breaker contacts close against opposing forces. During the opening operation, the closed contacts are separated as early as possible. Operating mechanisms are provided to achieve the opening and closing operations. Operating mechanisms are also necessary for isolator. The circuit breaker operating mechanisms must be capable of dealing with large forces at high speeds with complete reliability even if the circuit breaker has remained idle for a prolonged duration.

The operating should be fast, in order to reduce circuit-breaker time. The operating time between instant of receiving trip signal and final contact separation is of the order of 0.03 second, *i.e.* 1.5 cycles in modern EHV circuits-breakers. In slow circuit-breakers used in distribution system time can be about 3 cycles.

While closing, the contact closure should be fast, sure without hesitation, with adequate contact pressure at the end of contact travel. If these conditions are not satisfied, contact welding can result.

The operating mechanisms should be capable of giving the specified duty of the breaker (sequence of opening and closing as specified in standard specification). The breaker should also pass the operational tests which ascertain the capability of the operating mechanism. The interlocks are provided between breaker, isolator and earthing switch, so as to avoid wrong operation and to assure operation in a correct sequence. The functions of the operating mechanisms can be summarised as follows:

(1) To provide means whereby the circuit-breaker can be closed rapidly without hesitation at all currents from zero to rated making current capacity.

(2) To hold the circuit-breaker in closed position by toggles or latches till tripping signal is received.

(3) To allow the circuit-breaker to open without delay immediately on receiving tripping signal.

(4) To perform the auto reclosure cycle.

(5) To perform the related functions such as indication control.

2.9.1. Closing Operation (C)

Normally, closing the circuit-breaker contacts during normal load does not cause any difficulty. The operating Mechanism has to overcome friction and accelerate the moving masses. However, when the circuit-breaker has to close against a short circuit, additional thermal stresses and electromagnetic stresses are involved.

In EHV circuit-breakers, the arc is established prior to final contact touch. This is known as pre-arcing. Pre-arcing causes higher temperature stresses and pressure due to vaporisation of oil. The contacts should close with sufficient speed to minimise the prearcing.

As soon as the contacts close on an existing short-circuit, breaker is subjected to making current. The electromagnetic forces set-up by the making current tend to repel the contacts. The circuit breaker should have rated making capacity, *i.e.* the highest peak current against which the circuit breaker can be closed at a given voltage. The making capacity of the circuit-breaker depends upon the force and speed with which the closing operation is carried out.

While closing the circuit-breaker, the operating mechanism should have enough power to overcome the opposing forces and accelerate the moving contact assembly rapidly within specified short time.

The opposing forces during closing operation

(*a*) **Electromagnetic forces between contacts.** When the contacts touch during the closing operation, electromagnetic forces appear at the instant of contact touch, their magnitude being proportional to square of the current and the direction being opposite to the direction closing. These forces are large if the breaker is closing on existing short circuit. Breaker should be capable of closing on short circuit.

(*b*) **Action of operating spring.** The moving contacts of circuit-breakers are opened by spring pressure. While closing these spring oppose the closure.

(*c*) **Inertia of movable subassembly.** The movable parts are contacts their holders tension rods, operating links of operating mechanisms, etc. The mass of these sub-assemblies is quite large in EHV circuit-breakers. And their inertia tries to oppose rapid acceleration. In modern EHV circuit-breakers, these parts are made as light as possible.

(*d*) **Opposing forces due to medium such as oil, SF_6 gas.** The movable sub-assembly has to move in dielectric medium which is, in some cases, compressed air/gas/oil at high pressure and density.

The total forces of the operating mechanism should be more than the sum of the above men tioned opposing forces.

(e) **Friction.** Static and dynamic.

2.9.2. Opening Operation (O)

The opening operation is significant in the fault-clearing process. As the trip coil is energized the opening operation is initiated. The energy required for the opening operation is obtained from one of the following methods :

— Opening springs charged during the closing operation
— High pressure hydraulic oil stored in accumulators
— High pressure compressed air stored in auxiliary air receivers.

The functional requirements of the opening mechanism are as follows:

(1) To accelerate the moving masses including contacts and linkages rapidly to achieve desired opening characteristic (Fig. 2.6).

(2) To achieve desired speed of contact at contact separation and during the opening stroke (3 to 7 m/s).

(3) To damp the speed at the end of the travel by dampers.

The forces and energy should be adequate to overcome the following:

Opposing forces during opening operating

(a) **Electromagnetic forces due to contact-grip.** The current transfer from fixed finger-contacts to movable contact is illustrated in Sec. 8.9. The finger contacts are spring-loaded and their grip oppose the movement of moving contact. During the short-circuit condition, the electromagnetic forces tend to increase the grip of the finger-contact assembly. The forces of contact grip increases in proportion to square of current. Hence it is significant during higher short-circuit currents.

(b) **Friction.** The various operating links, bearing surfaces mating surfaces between movable and fixed parts, etc. offer static friction. The frictional component depends upon the coefficient of friction, smoothness of mating surfaces, configuration of moving parts etc. High friction can reduce the initial speed of moving contact which may result in disastrous consequence of failure of the circuit-breaker to quench the arc.

(c) Inertia of movable parts. Energy in the operating mechanism is utilised in accelerating the movable sub-assemblies to required speed.

(d) **Opposing forces due to quenching medium.** The quenching medium (compressed air, dielectric oil SF_6 gas) itself may offer substantial opposing forces to the movement.

The operating mechanisms should be capable of overcoming these opposing forces and should achieve desired opening characteristic of contact travel during normal and short-circuit opening operations. (Refer Note at the end of this Chapter)

2.9.3. Closing followed by Opening Operating (CO)

The rated operating sequence of the circuit-breaker (Sec. 3.19.8) demands the operation 'CO'. The operating mechanism should have enough stored energy and capability to perform CO operation and rated operating sequence under short-circuit condition.

2.9.4. Types of Mechanisms

The operating mechanisms in circuit-breakers are either 'dependable' or 'stored energy type'. Dependent operating mechanisms depend on continuity of power supply or manual forces during closing. They are accordingly called as :

— dependable manual operating mechanisms
— dependable power mechanisms.

The stored energy type operating mechanisms are called independent operating mechanisms as they are independent of continuity of power supply or the skill of the operator. In such mechanisms the energy required for closing in stored in a charged spring or in compressed gas-hydraulic oil.

Stored energy type independent automatic operating mechanisms are used in all high voltage circuit-breakers above 200 MVA. These can be classified as follows :

— Spring opened, spring closed Mechanism.
— Solenoid closed, spring opened Mechanism
— Hydraulic Mechanisms
— Pneumatic Mechanisms etc.

(a) **Spring Opened Spring closed Mechanism.** In such a mechanism the opening and closing operations are achieved by means of separate springs.

The closing spring is of higher energy level and is charged by motor driven gear. When closing signals is given to the closing coil, the closing spring energy is utilized in closing the moving contacts and also for charging the opening springs. During the opening operation, the opening signal is given to trip-coil. The movable system is unlatched and the energy of the opening spring is released to obtain the opening. The closing spring is automatically charged after each closing operation. Hence energy is always available for reclosing the breaker. The oil-dashpots are provided for damping the forces at the beginning of opening and closing strokes. Springs have maximum force at the beginning of travel and the force reduces at the end of the travel. This is disadvantageous in closing operation. Both opening and closing operations are initiated by high speed, electromagnetic operated latches.

(b) **Pneumatically-closed spring-opened Mechanism.** Pneumatically closed spring-tripped mechanism are used for extra-high voltage minimum oil circuit breakers and SF_6 circuit-breakers. In such mechanisms, the circuit breakers is closed by means of pneumatic cylinder and piston. The compressed air required for the closing operation is obtained from a local air-receiver mounted inside the mechanism cubicle. During the closing stroke, the tripping springs are charged. The tripping spring is released by a latch operated by high speed electromagnetic energized by the trip coil. The closing operation is initiated by operation of a solenoid operated pneumatic value, which admits the compressed air into pneumatic cylinder. Damping is provided in pneumatic cylinder.

(c) **Solenoid-closed Spring-opened Mechanism.** In such mechanism the closing operation is obtained by energising a solenoid by direct current. When direct current is passed through the solenoid, the plunger is attracted. The plunger sets into motion the link mechanism resulting in closing of the breaker. The opening springs are charged during the closing operation. Solenoid has maximum force of attraction when plunger is fully inserted and the air-gap is minimum. This is advantageous in closing operation.

The solenoid requires d.c., supply which it takes from battery or rectifier. The solenoid is supplied at 110 or 220 V d.c. The current taken by solenoid is relatively high. Solenoid mechanism can be suitable for auto-reclosing.

Solenoid operating mechanism is a separate unit mounted on the front of the circuit-breaker. When current is passed through the solenoid it attracts the plunger which in turn sets into motion the link mechanisms resulting in closing of breaker.

When the breaker is closed, it is held in latched or toggled position, When the tripping signal is received, the latch is released and the breaker opens by spring action. Generally the links have three positions—tripped, reset, closed.

Solenoid closing mechanisms are used with low voltage and medium voltage circuit-breakers. On EHV circuit-breakers, the power requirement of solenoid mechanism tends to be too large (above 50 kW in some cases). Hence they are not preferable.

(d) **Pneumatic Operating Mechanism.** Pneumatic operating mechanisms are preferred in stations where compressed air supply is available *i.e.* where air blast circuit-breakers are installed.

Air blast circuit-breakers are invariably provided with pneumatic operating mechanisms. The operating rod is linked with the piston in pneumatic cylinder in the control cubicle of the operating mechanisms.

Compressed air at thigh pressure is used for closing. High pressure air is stored in the air receiver of the breaker. The air comes in the reservoir from the compressed air system. While closing the air at high pressure (18-30 kgf/cm^2) is admitted in the pneumatic cylinder. The closing piston is pushed by compressed air. Thereby the levers move the closing operation is obtained. The automatic operations are achieved by means of solenoid operated pneumatic valves.

In SF_6 circuit-breakers spring assisted pneumatic mechanisms are preferred for opening and closing.

In air blast circuit-breakers the high pressure air is admitted in arc extinction chambers. The moving contacts are pushed against spring pressure (Details in Ch. 6).

Pneumatic operating mechanisms require the auxiliary set up for the supply of high pressure air.

In some hybrid-operating mechanisms, the pneumatic pressure is utilized to charge the closing spring. Then the stored energy of the spring is utilized for closing the breaker. Such operating mechanisms are called pneumo-spring mechanisms.

(*e*) **Hydraulic mechanisms.** The hydraulic system comprises the following essential components:

— motor driven hydraulic pump, accumulators
— Hydraulic valves and piping
— Oil tank
— Hydraulic cylinder, piston, etc.

The oil is maintained high pressure in the accumulators (300 to 350 kgf/cm^2). The piston can be moved with high pressure by opening of hydraulic valves and letting in the hydraulic oil from the accumulator into the cylinder. This movement is utilized to operate the links so as to close the circuit-breaker contacts.

During opening, the high pressure oil acts on upper area of piston and opening stroke is obtained.

2.10. INTERLOCKS, INDICATION AND AUXILIARY SWITCH. (Ref. Sec. 26.3)

Interlocking devices are those which make to operation of the switching device dependent upon the position or operation of other equipment. Interlocks are provided as a safety measure against erroneous operation of a switching device. The interlocks are of the following forms: Electrical Interlock, Mechanical Interlock.

Electrical interlock can be used between remote equipment, mechanical interlock can be provided for the operating mechanisms of the two adjacent equipments. The electrical interlock comprises coil and bolt. When the coil is energized, the bolt is drawn by magnetic attraction and the interlocking is achieved. Interlocks are provided between circuit-breaker, isolator and earthing switch to ensure the following sequence :

While opening :
— First to open: Circuit-breaker — Next to open: Isolator
— Then the earthing switch (if any) to close
While closing :
— Open earthing switch — Close isolator
— Then close circuit-breaker.

This sequence must be followed because Isolators are no load disconnecting devices. They do not have breaking capacity, nor do they have making capacity. Hence breaker performs the opening and closing duty.

Indicator or indicating device indicates whether the switching device is in 'open' or 'closed' position. Such indication is available on the glass-window on the control cabinet near the breaker, in form of a flag marked open close. One breaker panel, the indication is obtained by means of lamps. Thus, from the control room, the operator can know the position of circuit-breakers and isolators. (Breaker Panel in installed in control room).

Auxiliary switches have standard number of pairs of contacts (6, 8, 12). Auxiliary switch has two positions 'open' and 'close' corresponding to the position of the circuit-breaker. In each position, some auxiliary circuits are opened and some are closed. The auxiliary circuits serve several purposes such as:

(1) **Indication.** Breaker open or closed by lamps, near circuit-breaker and at a remote place.
(2) **Electrical Interlocks.** The breaker is interlocked electrically with isolators. The connections to solenoids in operating mechanisms are made through the auxiliary switch.
(3) Connections for relaying, auxiliary circuits of operating mechanisms.

The various terminals are connected in a terminal blocks in the operating cubical.

2.11. CIRCUIT-BREAKER TIME (TOTAL BREAK TIME) (Ref. Sec. 3.19.23)

Fault clearing time is the sum of relay time and circuit-breaker time. Circuit-breaker time is also called total break time.

The rapid fault clearing of extra-high-voltages transmission lines improves the power system stability. Hence faster relaying and fast circuit-breakers are preferred for extra-high-voltage transmission lines, the circuit-breaker time being of the order of 2.5 cycles, 2 cycles.

For distribution system such a fast clearing is not necessary. Discrimination is obtained by graded time-lag. Hence Slower Circuit breakers, 3 to 5 cycles are used.

Remember the Time Events :

[Fault clearing Time]	=	[Relay Time]	+	[Circuit-breaker Time]
[Relay Time]	=	[Instant to fault]	to	[Closure of Trip Circuit]
[Circuit-Breaker Time]	=	[Closure of Trip Circuit]	to	[Final Arc Extinction]
	=	[Opening Time +		Arcing Time]

Relay time is the time elapsed between the instant of occurrence of fault and instant of closure of relay contacts *i.e.* closure of trip circuit.

Circuit-breaker time is the time elapsed between the instant of closure ot trip circuit and the instant of final current zero. Circuit-breaker time is the sum of time required for operating mechanism to open the contacts and the arcing time. Total break time is equal to the sum of opening time and the arcing time.

Thus the fault clearing time is elapsed time between the instant of occurrence of fault and the instant of final arc interruption.

The circuit-breaker time is of the order of a few cycles. One cycle equals 1/50 seconds in 50 cycles per second system. Circuit-breaker time of EHV circuit-breaker of the order of 2.5 cycles. Circuit-breakers of time more than 5 cycles can be considered as slow.

2.12. AUTO RECLOSURE (Ref. Sec. 44.5 and 44.132)

Many faults on overhead transmission lines are transient in nature. Statistical evidence shows that about 90% of faults are used by lightning, birds, vines, tree branches etc. These conditions result in arcing faults and the arc in the fault can be extinguished by de-energizing the line by simultaneous opening of circuit-breakers on both ends of the line or on one end of the line. Since the cause of transient faults mentioned above disappears after a short time the circuit-breakers can be reclosed as soon as the arc in fault has been extinguished and the path has regained its dielectric strength. Reclosing of lines restores the supply continuity of service is the major advantage of Auto-enclosure. If the fault is transient one the normal condition is restored by auto reclosure.

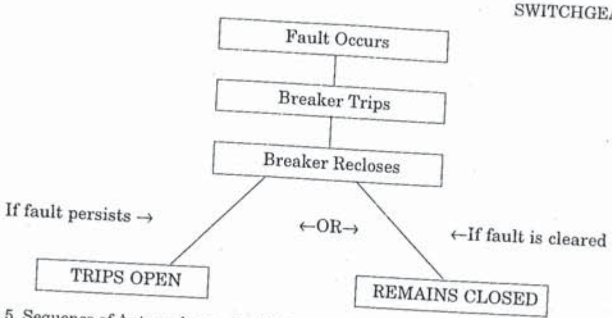


Fig. 2.5. Sequence of Auto reclosure for EHV, bulk of power transmission lines. Single Shot Scheme.

High speed tripping and high speed reclosing improves the stability of power system*. Henc the circuit-breakers and relaying on EHV lines are provided with auto reclosing feature. Tests o high voltage systems have shown that a reclosure in 12 cycles (0.24 sec) is practical the perio depending upon the time necessary to dissipate the ionised air of arc path.

The Auto-reclosing of EHV lines is high speed and single shot, *i.e,*. only one reclosing is at tempted.

2.13. AUTO RECLOSURE OF EHV CIRCUIT BREAKERS FOR TRANSMISSION LINES

The timing of EHV Auto-reclosure is based on the following requirements.........(Ref. Sec. 44.12

— It is a single-shot Reclosure.

— the arc in the fault should de-ionise before allowing reclosure. Hence certain 'Dead Time' of the order of 0.2 seconds is provided between opening and reclosing of C.B.

— the operating mechanisms of c.b. to open and to close as per desired operating sequence.

Looking Fig. 2.6 the following sequence can be observed:

Table 2.2

(Refers to Fig. 2.6) (Ref. Sec. 3.19.23)

Sequence	*Time in 1/100 Second*	*Operation*	*Remarks*
1	0	Fault occurs	Circuit-breaker closed. Protective gear starts operating.
2	0-4	Relay time	Fast relaying
3	4	Trip circuit closed	Operating mechanism starts to open.
4	4-9	Opening time of breaker	
5	9-12	Total break time	Breaker is of 4 cycles
6	12-36	Dead time	12 cycles for deionization. CB remains open.
7	27	Contacts start closing	
8	36	Contact touch for reclose	
9	40	Circuit-breaker reclosed	Will be opened again if fault persists and will lock-open.
10	Single shot is complete, the circuit-breaker will remain closed, if fault has vanished CB will open again if fault persists and will remain locked-open.		

* Rapid Auto-reclosing: For weakly interconnected systems, Delayed Auto-reclosing: a for strongly interconnected systems. (Ref. Sec. 44.12)

— C.B.'s at both ends of the line should reclose simultaneously.

— Deionization time for arc space in fault on overs-head line depends on several aspects such as magnitude of fault current, service voltage, length of line wind condition, spacing of conductors etc. Generally the time allowed is based on rated voltage of line and is as follows:

— The circuit-breakers should be capable of withstanding the electrodynamic stress in case they are reclosing on an existing short circuit. The pressure in the reservoir generally reduces after the first opening, thereby there is a reduction in breaking capacity for the subsequent opening. This aspect should be taken care of while designing the circuit-breakers suitable for auto-reclosure.

Voltage of Transmission line (kV)	*Rated voltage of C.B. (kV)*	*Minimum Deionization time necessary, Cycles*
66	72.5	5
132	145	9
220	245	14
400	420	18

2.14. AUTO RECLOSURE FOR DISTRIBUTION LINES (upto 33kV)

In rural distribution overhead lines are used. The spacing between conductors is relatively close. The disturbance on such lines are generally trasient, as described earlier. Auto reclosure is therefore, suitable in improving the continuity of service. The usual procedure was to reclose circuit-breaker three times between 15 to 120 seconds.

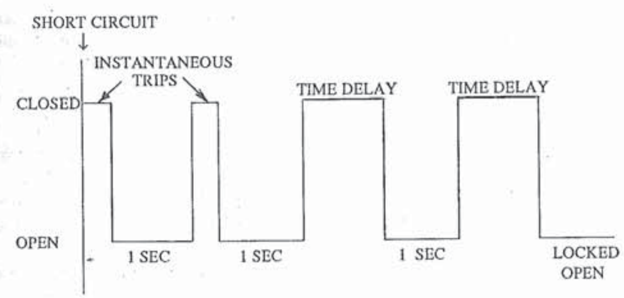


Fig. 2.7. Auto reclosure cycle of a 12 kV c.b. for rural distribution.

If the breaker trips after the third reclosure, it opens and remains open. The attendant thereby knows that the fault is permanent and sends electricians to locate and correct the fault. The auto reclosure cycle is illustrated in Fig. 2.7, but the sequence may vary in other cases. This practice is no more favoured in modern distribution systems.

2.15. WEIGHT OPERATED RECLOSING, POLE MOUNTED CIRCUIT-BREAKERS

Such circuit-breakers were used in rural distribution. An endless chain passes over a pulley on the end of an operating shaft. The operating shaft is brought out through the side of the breaker top plane. A weight is attached to the chain. The energy required to reclose the breaker is derived from the weight falling due to gravity. The timing mechanism controls the open-circuit time (about 30 sec.)

2.16. TRIP-FREE FEATURE

Suppose the breaker has been instructed to close by manual instruction by pushing of push button. The operating mechanism will start operating for closing operation. Meanwhile a fault has taken place and a relay close the trip circuit of the breaker. The Trip-Free mechanisms, permits the circuit-breaker to be tripped by the protective relay even if it is under the process of closing. This feature is called *Trip Free* feature. Another feature of operating mechanisms is to prevent 'Pumping', *i.e.* alternate tripping and closing if the closing button is held closed during a fault.

In oil circuit-breakers and puffer type SF_6 circuit-breakers, the contacts should be allowed to touch during the end of the closing stroke before the start of the opening operation.

2.17. MATERIALS

The materials are important in switchgear manufacturing. Normally all the incoming materials are tested in the factory before acceptance. The manufacturer maintains with him all the necessary standards of material specifications.

Currents Carrying Parts

These include contacts, contact stems, flanges bus-bars, bushing-conductors connectors etc. The design of conducting parts is based on the following requirements:

— temperature rise during normal continuous current.
— temperature stresses during short-time current. (rated duration of short-circuits)
— mechanical stress during opening and closing operation.
— mechanical stresses due to electromagnetic forces under short-circuit conditions.

Insulating Parts

These include interrupter-enclosures, insulating supports for interrupters, supports to bus-bars insulating pull-rods connecting the operating mechanism to the moving contacts, insulating tubes enclosing the arc-control devices etc.

2.18. DESIGN AND DEVELOPMENT

The development of a new circuit-breaker comprises the following major activities (Ref. Sec. 12.3).

(1) **Research.** The research on arc quenching techniques, various thermal, electrical, mechanical stresses under various switching conditions, design principle for arc quenching etc. This is carried out in research laboratories.

Table 2.3 Material Used in Circuit-Breakers and Metal Enclosed Switchgear, Controlgear

	Material	*Applications*	*Remarks*
1.	Porcelain	Enclosures for Interrupter support Procelain, support for bus-bars insulating tubes solid rods etc.	Compression strength 6000 kg/cm^2. Tensile Strength 3000 kg/cm^2. Ceramic material made by firing clay, glazing and firing again. Suitable for outdoor use.
2.	Epoxy Resin	Support Insulators for indoor applications, enclosures covers encapsulation etc.	Used in solid form. Obtained by maxing with suitable hardener and curing a suitable temperature, suitable fillers used. Not suitable for outdoor use.
3.	Glass fibre reinforced synthetic resin	Insulating drive rods, insulating tubes for interrupted	High tensile strength, withstand pressure, dielectric strength.
4.	Polytetra fluroethelene PTFE	Nozzles for SF_6 Breakers, bearings, Piston rings etc.	Low friction; arc resistant; can be moulded/machined. Pure PTFE is insulating used with various filters.

	Material	*Applications*	*Remarks*
5.	Electrolytic Copper (99.9% purity)	Bus-bars Main contacts conducting parts, terminals	Ref. Sec. 17.16
6.	Eletrical grade aluminium	Busbar, conducting parts, casting, terminals Enclosures of SF_6 GIS, Enclosures of busbars Eclosures of busducts	Ref. Sec. 17.16
7.	Tungsten Copper	Arcing contacts	80% Tungsten, 20% copper, sintered material
8.	Stainless Steel	Enclosures of SF_6 GIS parts enclosed circuits	
9.	Copper-bismuth, Copper-Chromium, Copper-berrylium	Main Contacts of vacuum interrupters, Contactors	High conductivity, low welding-tendency. Ref. Sec. 9.9.5

(2) **Design and development of Prototypes.** The structural configuration (Sec. 2.8) is decided first. Then the various sub-assemblies are designed and finally the complete breaker is designed. Full scale prototypes are manufactured.

(3) **Development Testing.** Various development tests (Sec. 10.1) are carried-out on sub-assemblies poles, mechanism and complete breaker.

(4) **Type Tests for Certifications** (Sec 10.1) These are exhaustive test as per standards.

(5) **Actual Installation** in system for observing performance.

Summary

Circuit breakers are classified on the basis of the arc quenching medium as: Air break; bulk-oil; Minimum oil; Air blast; vacuum ; SF_6. While various types are in service; the trends in new installation is in favour of;

Low voltage (upto 1000 V): Air-Break CB and Contractors

Medium Voltage (upto 33 kV): VCB and SF_6 CB

High Voltage (33 kV and above): SF_6 and SF_6 insulated GIS.

QUESTIONS

1. With the help of a neat sketch, describe the configuration of an outdoor, triple pole circuit beaker for 36 kV application. Name the parts and explain the operation of the circuit breaker during fault clearing.
2. Explain the functions of operating mechanism of a circuit breaker and describe the motor Charged Spring Mechanism.
3. Describe a trip circuit and the fault clearing process.
4. Explain the purpose of Auto Reclosing of an EHV Circuit Breaker controlling an over head transmission line. State the sequential events in a single shot auto reclosing scheme.
5. Explain the functions of isolator, earthing switch and circuit breaker. State the sequence during opening and closing of circuits. State the interlocks necessary to prevent accidents.