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Circuit Breakers and Substations

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Chapter (1)

1.1 Electrical Substations

Electrical Network comprises the following regions:

1 - Generating Stations.
2 - Transmission Systems.
3 - Distribution Systems.
4 - Load Points.

Functions of a Substation

1. Supply of required electrical power.
2. Maximum possible coverage of the supply network.
3. Maximum security of supply.
4. Shortest possible fault-duration.
5. Optimum efficiency of plants and the network.
6. Supply of electrical power within targeted frequency limits, (49.5 Hz and 50.5 Hz).
7. Supply of electrical power within specified voltage limits.
8. Supply of electrical energy to the consumers at the lowest cost.
9. Switching requirements for normal operation.
10. Switching requirements during abnormal operations, such as short circuits and overloads.
11. Flexibility in operations, simplicity.
12. Freedom from total shutdown and permissible period of shutdown.
13. Maintenance requirements, space for approaching various
14. Safety of personnel.
15. Protective zones, main protection, back-up protection
16. Bypass facilities.
17. Technical requirements such as ratings, clearances, Earthing lightning protection, Noise, radio interference, etc.

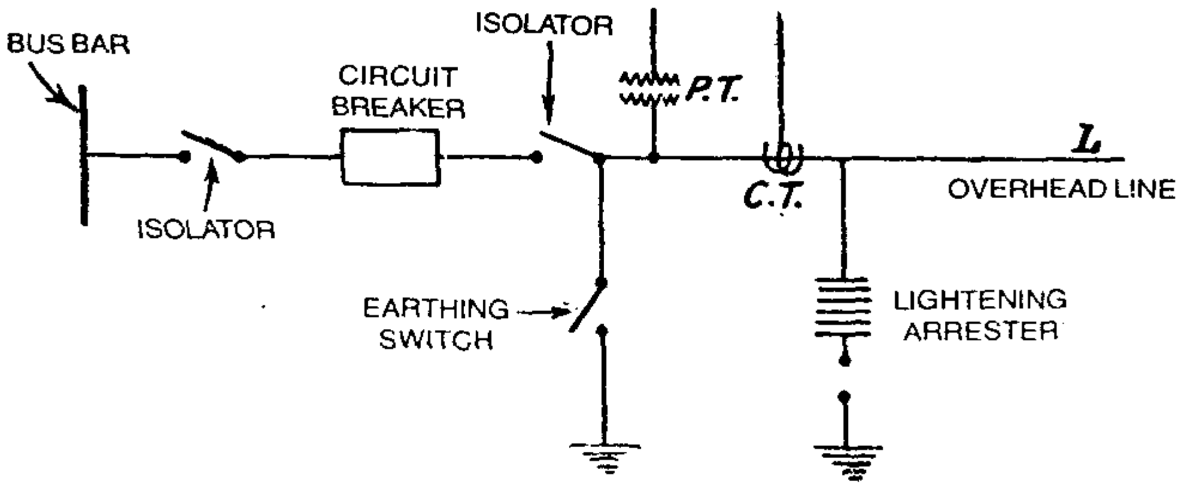


Fig.1.1 Single Line Schematic Diagram of one bay in Switchyard

	Equipment	Function
1.	Bus-bar	Incoming and outgoing circuits connected to bus-bars.
2	Circuit-breakers	Automatic switching during normal or abnormal conditions.
3	Isolators (Disconnectors)	Disconnection under no-load condition for safety, isolation and maintenance.
4	Earthing Switch	To discharge the voltage on deadlines to earth.
5	Current Transformer	To step-down currents for measurement, control, and protection.
6	Voltage Transformer	To step-down currents for measurement, control and protection.
7	Lightning Arrester (Surge Arrester)	To discharge lightning over voltages and switching over voltages to earth.
8	Shunt Reactor in EHV substation	To provide reactive power compensation during low loads.
9	Series Reactors	To reduce the short-circuit current or starting currents.
10	Neutral-Grounding Resistor	To limit the earth fault current.
11	Coupling capacitor	To provide connection between high voltage line and power line carrier current equipment.
12	Line-trap	To prevent high frequency signals from entering other zones.
13	Shunt capacitors	To provide compensations to reactive loads of lagging power factors.
14	Power Transformer	To step-up or step-down the voltage and transfer power from one a.c. voltage to another a.c. voltage at the same frequency.
15	Series Capacitors	Compensation of series reactance of long lines.

The term **switchgear**, used in association with the electric power system, or grid, refers to the combination of electrical disconnects, fuses and/or circuit breakers used to isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream.

One of the main basic functions of switchgear is protection: discrimination between circuit breakers enhances availability, that is to say continuity of service. The overall approach is termed coordination: the standards provide a framework for discrimination and cascading that protects the integrity of the power system and minimizes the scope of downstream outages.

Fig.1.2 A section of a large switchgear panel, in this case, used to control on-board casino boat power generation.

Several different classifications of switchgear can be made:

- By size of current that they may safely switch:
  - Circuit breakers can open and close on fault currents
  - Load-break/Load-make switches can switch normal system load currents
  - Isolators may only be operated while the circuit is dead, or the load current is very small.
- By voltage class:
  - Low voltage (less than 1000 volts AC)
  - Medium voltage (1000-35,000 volts AC)
  - High voltage (more than 35,000 volts AC)
- By insulating medium:
  - Air
  - Gas (SF6 or mixtures)
  - Oil
  - Vacuum
- By construction type:
  - Indoor
  - Outdoor
  - Industrial
  - Utility
- By interrupting device:
  - Fuses
  - Air Blast Circuit Breaker

- Minimum Oil Circuit Breaker
- Oil Circuit Breaker
- Vacuum Circuit Breaker
- Gas (SF6) Circuit breaker

- By operating method:
  - Manually-operated
  - Motor-operated
  - Solenoid/stored energy operated
- By type of current:
  - Alternating current
  - Direct current
- By interrupting rating (maximum short circuit current that the device can safely interrupt)
- By application:
  - Transmission system
  - Distribution.

A piece of switchgear may be a simple open air isolator switch or it may be insulated by some other substance. An effective although more costly form of switchgear is "gas insulated switchgear" (GIS), where the conductors and contacts are insulated by pressurized (SF6) sulfur hexafluoride gas. Another common type is oil insulated switchgear.

1.2 Circuit breakers

Circuit breakers are a special type of switchgear that is able to interrupt fault currents. Of many hundreds or thousands of amps. Circuit breakers are usually able to terminate all current flow very quickly: typically between 30mS and 150mS depending upon the age and construction of the device.

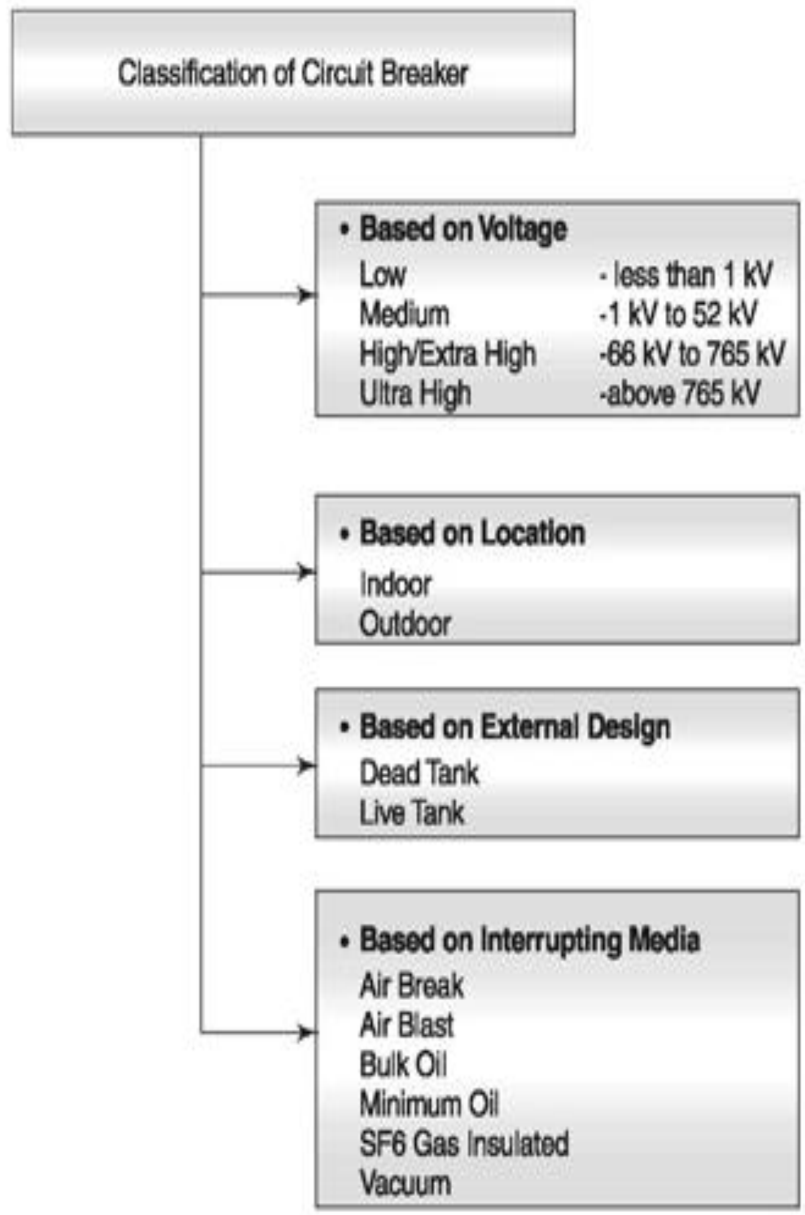
Circuit breakers keep electrical circuits from being damaged by short circuits or overloads. They work automatically and have an electrical switch. a fuse operates in the same way, but is different in that once is blows, it must be replaced.A fuse is a thin wire inside a casing which connects to the circuit. If the circuit is closed, the charge flows through the fuse wire. The purpose of the fuse is to burn up when it overheats. A circuit breaker, on the other hand, can be reset to continue operating. When the breaker detects a bad condition such as an overload, it disrupts electrical flow by halting it.

Because different kinds of devices need circuit breakers, they come in different builds and sizes. Some are used to provide protection for a small appliance, while others keep an entire city functioning. One of the first circuit breakers on record was imagined by Thomas Edison in an 1879 application for a patent.

We need circuit breakers these days to guard against hazards that can happen when electrical wires have too much current flowing through them. If there wasn't a device to monitor electrical flow, the risk of fire would dramatically increase and some of our electrical items would be destroyed.

The Circuit Breakers are automatic Switches which can interrupt fault currents. The part of the Circuit Breakers connected in one phase is called the pole. A Circuit Breaker suitable for three phase system is called a 'triple-pole Circuit Breaker'. Each pole of the Circuit Breaker comprises one or more interrupter or arc-extinguishing chambers. The interrupters are mounted on support insulators. The interrupter encloses a set of fixed and moving contacts. The moving contacts can be drawn apart by means of the operating links of the operating mechanism. The operating mechanism of the Circuit Breaker gives the necessary energy for opening and closing of contacts of the Circuit Breakers. The arc produced by the separation of current carrying contacts is interrupted by a suitable medium and by adopting suitable techniques for arc extinction. The Circuit Breaker can be classified on the basis of the arc extinction medium.

<u>The different types of C.Bs:</u>



- Oil circuit breakers rely upon vaporization of some of the oil to blast a jet of oil through the arc.
- Gas (SF6) circuit breakers sometimes stretch the arc using a magnetic field, and then rely upon the dielectric strength of the SF6 to quench the stretched arc.
- Vacuum circuit breakers have minimal arcing (as there is nothing to ionise other than the contact material), so the arc quenches when it is stretched a very small amount (<2-3 mm). Vacuum circuit breakers are frequently used in modern medium-voltage switchgear to 35,000 volts.
- Air circuit breakers may use compressed air to blow out the arc, or alternatively, the contacts are rapidly swung into a small sealed chamber, the escaping of the displaced air thus blowing out the arc.

The type of the Circuit Breaker is usually identified according to the medium of arc extinction. 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) Vacuum Circuit Breaker.
(6) Sulphur hexafluoride Circuit Breaker. (Single pressure or Double Pressure).

Type	Medium	Voltage, Breaking Capacity
1 – Air break Circuit Breaker	Air at atmospheric pressure	(430 – 600) V– (5-35)MVA (3.6-12) KV - 500 MVA
2 – Miniature CB.	Air at atmospheric pressure	(430-600) V
3 – Tank Type oil CB.	Dielectric oil	(3.6 – 12) KV
4 – Minimum Oil CB.	Dielectric oil	(3.6 - 145)KV
5 – Air Blast CB.	Compressed Air (20 – 40) bar	245 KV, 35000 MVA up to 1100 KV, 50000 MVA
6 – SF6 CB.	SF6 Gas	12 KV, 1000 MVA 36 KV , 2000 MVA 145 KV, 7500 MVA 245 KV , 10000 MVA
7 – Vacuum CB.	Vacuum	36 KV, 750 MVA
8 – H.V.DC CB.	Vacuum , SF6 Gas	500 KV DC

Low voltage C.B (less than 1000 V_{AC}) are common in domestic, commercial and industrial application, Low voltage power circuit breakers can be mounted in multi-tiers in low-voltage switchboards or switchgear cabinets. This type of breaker is more common in homes and certain industries. and includes:

- **MCB (Miniature Circuit Breaker)** — rated current not more than 100 A (carries a current no more than 100 A). Trip characteristics normally not adjustable. It is operated thermally or thermally and magnetically.
- **MCCB (Molded Case Circuit Breaker)** — rated current up to 2500 A. This type of breaker is operated either thermally or thermally and magnetically as well. Trip current may be adjustable in larger ratings. Large low-voltage molded case and power circuit breakers may have electric motor operators so they can trip (open) and close under remote control. These may form part of an automatic transfer switch system for standby power.

The Three Types of Circuit Breakers

- **Magnetic Circuit Breakers**
  These types of circuit breakers use electromagnetism to break a circuit. On this circuit breaker, the electromagnet will get stronger with the flow of electricity. If the electrical load goes over the expected amount, the electromagnet forces the circuit lever down, moving the contact plate which in turn, flips the switch.
- **Thermal Circuit Breakers**
  This type of circuit breaker employs heat to break a circuit. A bimetallic strip in the circuit breaker responds to the heat of an electrical current. Like its name states, the strip is made of two types of metal, and each metal expands differently to help bend the strip. If an electrical current gets too strong, the strip bends to angle that turns over the conductive plate, breaking the circuit.
- **Thermal and Magnetic Circuit Breakers**
  Another type of circuit breaker is one which uses heat and electromagnetism. The electromagnet keeps the circuit from sudden surges in electrical load, while the bimetallic strip guards against prolonged overload and overheating.

Medium-voltage circuit breakers (rated between 1 and 66 kV) may be assembled into metal-enclosed switchgear line for indoor use, or may be individual components installed outdoors in outdoors substation.

Like the high voltage circuit breakers, these are also operated by current sensing protective relays operated through current transformers. Medium-voltage circuit breakers always use separate current sensors and protective relays, instead of relying on built-in thermal or magnetic overcurrent sensors.
In the past, they have oil-filled units for even indoor use, but they are mainly being replaced by vacuum circuit breakers. They interrupt currents by creating and putting out an arc in a vacuum container. An air circuit breaker typically uses compressed air to blow out an arc, but these do not last as long as vacuum breakers. Finally there is the SF6

circuit breaker uses sulfur hexafluoride gas (SF6) to put out the circuit. These types of breakers are used in industrial, commercial and utility situations, where a generator, transmission line or motor is operated.

Medium-voltage circuit breakers can be classified by the medium used to extinguish the arc into:

- Vacuum circuit breakers— with rated current up to 3000A, these breakers interrupt the current by creating and extinguishing the arc in a vacuum container. These are generally applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life than do air circuit breakers.
- Air circuit breakers— rated current up to 10,000A. Trip characteristics are often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled via an integral electronic trip unit. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.
- SF_6 circuit breakers extinguish the arc in a chamber filled with sulfur hexafluoride SF_6 gas.

High-voltage circuit breakers (rated between 66 and 765kV) Electrical power transmission networks are protected and controlled by high-voltage breakers. High-voltage breakers are always solenoid-operated, with current sensing protective relays operated through current transformers. In substations the protective relay scheme can be complex, protecting equipment and buses from various types of overload or ground/earth fault.

Fig.1.3- 110 kV oil circuit breaker

115 kV bulk oil circuit breaker

400 kV SF_6 live tank circuit breakers

These types of circuit breakers are also known as oil breakers, as their contacts are submerged in a tank of oil. The way this works is that the oil or SF6 quenches the electrical arc and cools them so that circuits don't overheat. The downside is that oil is flammable and it's difficult to keep the oil in good condition. They have to be maintained in a ways that standard circuit breakers do not. These types of circuit breakers are used for power transmission, as with power lines.

Oil Circuit Breaker

Oil has better insulating property than air. In **oil circuit breaker** the fixed contact and moving contact are immerged inside the insulating oil. Whenever there is a separation of current carrying contacts in the oil, the arc is initialized at the moment of separation of contacts, and due to this arc the oil is vaporized and decomposed in mostly hydrogen gas and ultimately creates a hydrogen bubble around the arc. This highly compressed gas bubble around the arc prevents re-striking of the arc after current reaches zero crossing of the cycle.

There are mainly two **types of oil circuit breakers** available**:**

Bulk Oil Circuit Breaker or **BOCB** is such **types of circuit breakers** where oil is used as arc quenching media as well as insulating media between current carrying contacts and earthed parts of the breaker. The oil used here is same as transformer insulating oil.

Minimum Oil Circuit Breaker or MOCB These types of circuit breakers utilize oil as the interrupting media. However, unlike **bulk oil circuit breaker**, a **minimum oil circuit breaker** places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing **MOCB** are to reduce requirement of oil, and hence these breaker are called **minimum oil circuit breaker**.

Other breakers

The following types are described in separate articles.

- Breakers for protections against earth faults too small to trip an over-current device:
  - Residual-current device (RCD, formerly known as a *residual current circuit breaker*) — detects current imbalance, but does not provide over-current protection.
  - Residual current breaker with over-current protection (RCBO) — combines the functions of an RCD and an MCB in one package. In the United States and Canada, panel-mounted devices that combine ground (earth) fault detection and over-current protection are called Ground Fault Interrupter (GFI) breakers; a wall mounted outlet device or separately enclosed plug-in device providing ground fault detection and interruption only (no overload protection) is called a Ground Fault Circuit Interrupter (GFCI).
  - Earth leakage circuit breaker (ELCB)—This detects earth current directly rather than detecting imbalance. They are no longer seen in new installations for various reasons.
- Autorecloser—A type of circuit breaker that closes automatically after a delay. These are used on overhead power distribution systems, to prevent short duration faults from causing sustained outages.

Each circuit breaker will be studied thoroughly in the subsequent sections. This circuit breaker employs various techniques to extinguish the arc resulting from separation of the current carrying contacts. The mode of arc extinction is either 'high resistance interruption' or 'zero-point interruption'.

High Resistance Interruption: In this process the resistance of the arc is increased by lengthening and cooling it to such an extent that the system voltage is no longer able to maintain the arc and the arc gets extinguished. This technique is employed in air break circuit breakers and d.c. circuit breakers.

Low Resistance or Zero Point Interruption: In this process, the arc gets extinguished at natural current zero of the alternating current wave and is prevented from restriking again by rapid build-up of dielectric strength of the contacts space. The process is employed in almost all a.c. circuit breakers.

Air-break circuit breaker: Utilize air at atmospheric pressure for arc extinction.

Air-blast circuit breakers: Utilize high pressure-compressed air for arc extinction. They need compressed air plant.

Bulk-oil and Minimum-oil circuit breaker: 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.

SF6 circuit breakers: sulphur-Hexa-Fluoride gas is used for arc extinction. There are two types:

- Single pressure puffer type SF6 circuit breaker, in which the entire circuit breaker is filled with SF6 gas at single pressure (4 to 6 kg/cm^2). The pressure and gas flow required for arc extinction is obtained by piston action.
- Double pressure type SF6 circuit breaker in which the gas from high-pressure system is released into low pressure system over the arc during the arc quenching process. This type has been superseded by puffer type.

Vacuum circuit breaker: In vacuum circuit breaker 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.

In Your Home's Electric Panel

Circuit breakers were introduced into homes during the 19th century as electrical power was introduced. Essentially, in a home electrical panel, there are five types of breakers found, although most homes just use two types.

Single-pole Circuit Breaker--This type of breaker is very common and it delivers 120 volts to an appliance. They also deliver electricity to one circuit that branches off to a designated area of the home. Many homes have combos of 15 and 20 amp single-pole breakers. You'll notice them if you open the breaker panel in your basement.

Double-pole Circuit Breaker--This is the second-most-common breaker in a home. This breaker starts at 30 amps and delivers one circuit to an area as well, but typically to an outlet that powers a dryer or other large appliance.

Quad Breaker--Just as you might imagine, this type of breaker is made of two double-pole breakers. The purpose is for use in a small electrical panel box. They can be configured so that one double-pole breaker has 30 amps, and the other 20 amp.

GFCI Breaker--This type of breaker is for areas of the home which can be wet, like a kitchen or bath. These breakers trip immediately when there's an imbalance in electrical flow. This keeps people who might be in those areas form being electrocuted, should an electrical current be exposed to water.

Table 2: Comparison between Circuit Breakers

Type	Medium	Voltage. Breaking capacity	Design Feature	Remarks
1- Air-break circuit breaker	Air at atmospheric pressure	430-600 V, 5-15-35 MVA Recently 3.6-12 KV, 500 MVA	Incorporates: Arc runners, arc splitters, magnetic coils	Used for medium and low voltage, A.C., D.C., Industrial circuit breakers. Have current limiting
Miniature C.B.	Air at atmospheric pressure	430-600 KV	Small size, current limiting feature	Used for low and medium voltage
2- Tank type oil circuit breaker	Dielectric oil	12-36 KV	One tank up to 36 KV, 3 tank above 36 KV, fitted with arc control devices	Getting obsolete, used up to 12 KV, 500 MVA
3- Minimum oil circuit breaker	Dielectric oil	3.6-245 KV	The circuit breaking chamber is separate from supporting chamber. Small size, arc control device used	Used for metal enclosed switchgear up to 36 KV. Outdoor type between 36 and 245 KV
4- Air blast circuit breaker	Compressed air (20-30 kg/cm^2)	245 KV, 35.000 MVA up to 1100 KV, 50.000 MVA, also 36 KV, 500 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
5- SF6 circuit breaker –single	SF6 gas (5 kg/cm^2)	145 KV, 7500 MVA 245 KV, 10.000 MVA 12 KV, 500 MVA 36 KV, 2000 MVA	Live tank/Dead tank design, single pressure type preferred	Suitable for SF6 switchgear, and medium voltage switchgear. EHV circuit breaker. Maintenance free
6- Vacuum circuit breaker	Vacuum	Preferred for indoor switchgear rated up to 36 KV, 750 MVA	Variety of designs, long life, modest maintenance	Suitable for a variety of applications from 3.6 KV up to 36 KV
7- H.V.D.C circuit breaker	Vacuum or SF6	500 KV DC, 15 KA/20 KA	Artificial current zero by switching in capacitors	Recently developed, used in HVDC systems. Installed in USA

The Fault Clearing Process

During the normal operating condition the Circuit Breaker can be opened or closed by a station operator for the purpose of Switching and maintenance. During the abnormal or faulty conditions 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 correspond to open Circuit Breaker contacts and closed Circuit Breaker contacts respectively.

The operation of automatic opening and closing the contacts is achieved by means of the operating mechanism of the Circuit Breaker. As the relay contacts close, the trip circuit is closed and the operating mechanism of the Circuit Breaker starts the opening operation.

The contacts of the Circuit Breaker open and an arc is draw between them. The arc is extinguished at some natural current zero of a.c. wave. The process of current interruption is completed when the arc is extinguished and the current reaches final zero value. The fault is said to be cleared.

Trip circuit of circuit breakers

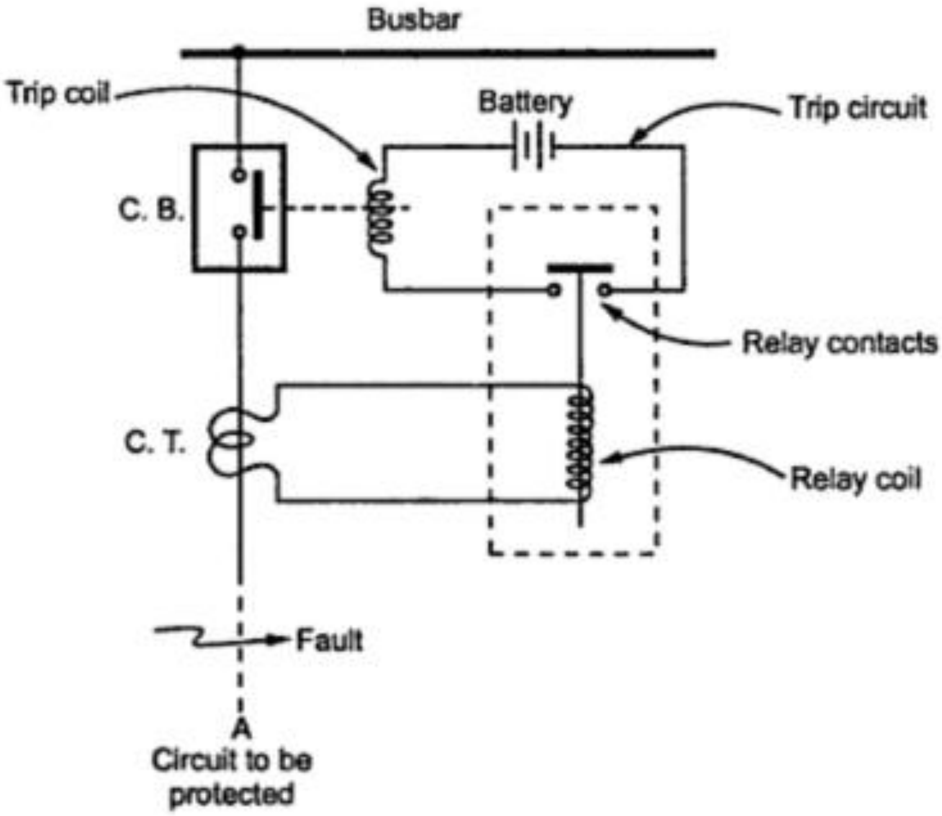
Consider a simplified circuit of a typical relay as shown in the Fig. 1.4 usually the relay circuit is a three phase circuit and the contact circuit of relays is very much complicated. The Fig. 1.4 shows a single phase simplified circuit to explain the basic action of a relay. Let part A is the circuit to be protected. The current transformer C.T. is connected with its primary in series with the line to be protected. The secondary of C.T. is connected in series with the relay coil. The relay contacts are the part of a trip circuit of a circuit breaker. The trip circuit consists of a trip coil and a battery, in addition to relay contacts. The trip circuit can operate on a.c. or d.c.

If the fault occurs as shown in the Fig. 1.4, then current through the line connected to an increases to a very high value. The current transformer senses this current. Accordingly its secondary current increases which are nothing but the current through a relay coil. Thus the relay contacts get closed mechanically under the influence of such a high fault current. Thus the trip circuit of a circuit breaker gets closed and current starts flowing from battery, through trip coil, in a trip circuit. Thus the trip coil of a circuit breaker gets energized. This activates the circuit breaker opening mechanism, making the circuit breaker open. This isolates the faulty part from rest of the healthy system.

<u>The process of fault clearing has the following sequence:</u>

1- 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 the operating torque. The relay takes some time to close its contacts.
2- Relay contacts close the trip circuit of the Circuit Breaker closes and trip coil is energized.
3- The operating mechanism starts operating for the opening operation. The Circuit Breaker contacts separate.

4- Arc is drawn between the breaker contacts. The arc is extinguished in the Circuit Breaker by suitable techniques. The current reaches final zero as the arc is extinguished and does not restrict again.



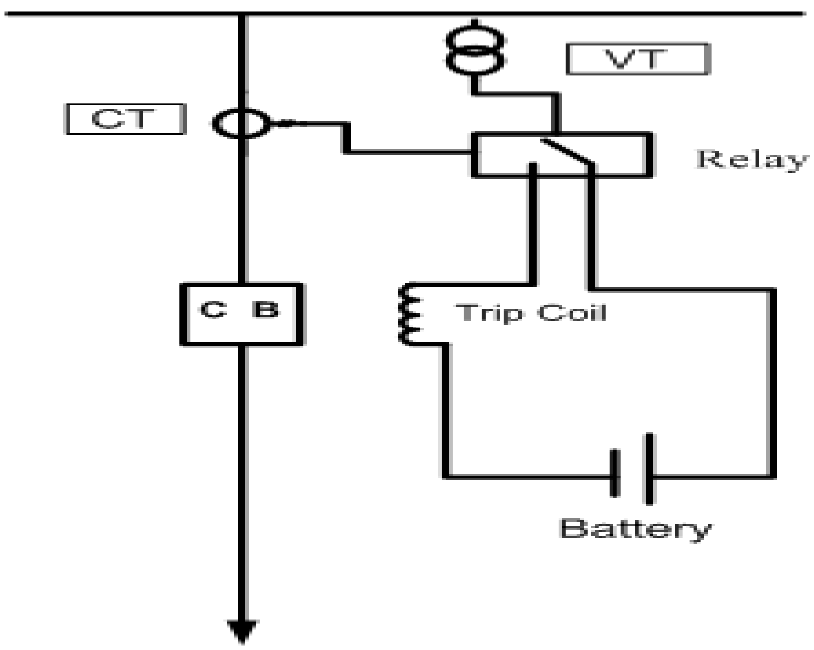


Fig.1.4 Typical Trip-Circuit

Tripping Schemes in Circuit Breaker

Two schemes are very popularly used for tripping in circuit breakers which are:

1. Relay with make type contact
2. Relay with break time contact

The relay with make type contact requires auxiliary D.C supply with its operation. While the relay with break type contact uses the energy from the main supply source for its operation. Let us see the details of these two types of schemes.

1- Relays with Make Type Contact

The schematic diagram representing the arrangement of various elements in a relay with make type contact is shown in the Fig.1.5. A separate supply is necessary for the relay operation. The relays are connected in star while the relay contacts are connected in parallel. The entire relay contact unit is connected in series with the auxiliary switch, trip coil and the battery. Relay contacts are open in normal position.

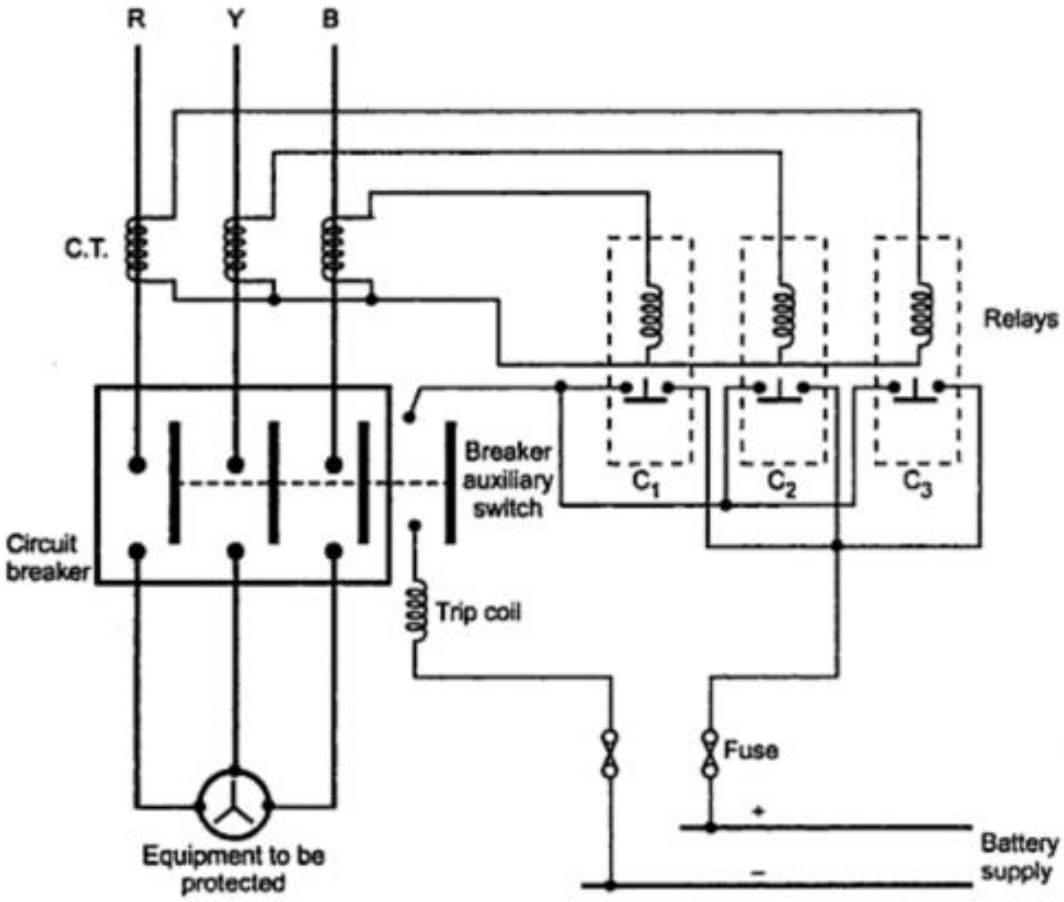


Fig. 1.5 Relay with make type contact

Operation: When the fault occurs, the current through relay coils increases to a very high value. Due to this, the normally open relay contacts C_1, C_2 and C_3 get closed. This activates the trip coil of a circuit breaker. The auxiliary switch is initially closed along with the circuit breaker. So when contacts C_1, C_2 and C_3 are closed, the current flows through trip coil of circuit breaker. This activates the trip coil which opens the circuit breaker. As auxiliary switch is mechanically coupled with the circuit breaker, it also gets opened. This interrupts the current through trip coil. Thus supply to fault part gets interrupted and trip coil also gets de-energized. This brings the relay contacts back to normal position.

Due to auxiliary switch, arcing across relay contacts gets avoided. As relay contacts are normally open and they 'make' the circuit to open the circuit breaker hence called make type contact relay.

2- Relay With Break Type Contact

The schematic arrangement of various elements in a relay with break type contact is shown in the Fig. 1.6. This type of relay does not require external battery supply for the tripping. The current transformers (C.T.s) or potential transformers (P.T.s) are used to derive the energy required for the relay from the main supply source. The relay using C.T.s to derive operating energy from the supply is shown in the Fig. 1.6.

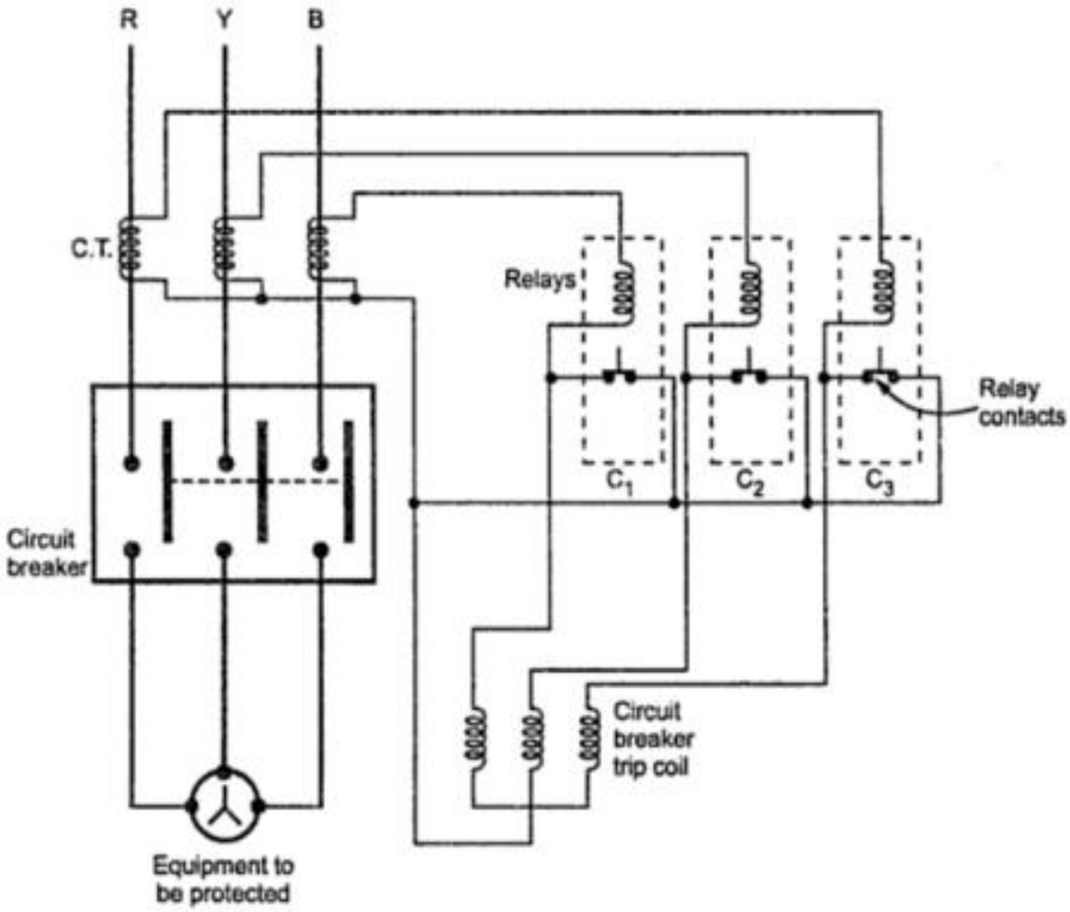


Fig.1.6 Relay with break type contact (using C.T.s)

Operation: In this scheme, the relay coil and trip coil of each are connected in series. The three phases are then connected in star. Under normal working, the relay contacts C_1, C_2 and C_3 are closed. The energy for relay coils is derived from supply using C.T.s. The trip coils of circuit breaker are de-energized under normal condition. When the fault occurs, heavy current flows through relay coils which causes the relay contacts C_1, C_2 and C_3 break. Thus current flows through trip coils of circuit breaker causes the circuit breaker gets open.

The Fig. 1.7 shows the break type contact relay using P.T. to derive energy to keep relay coils energized.

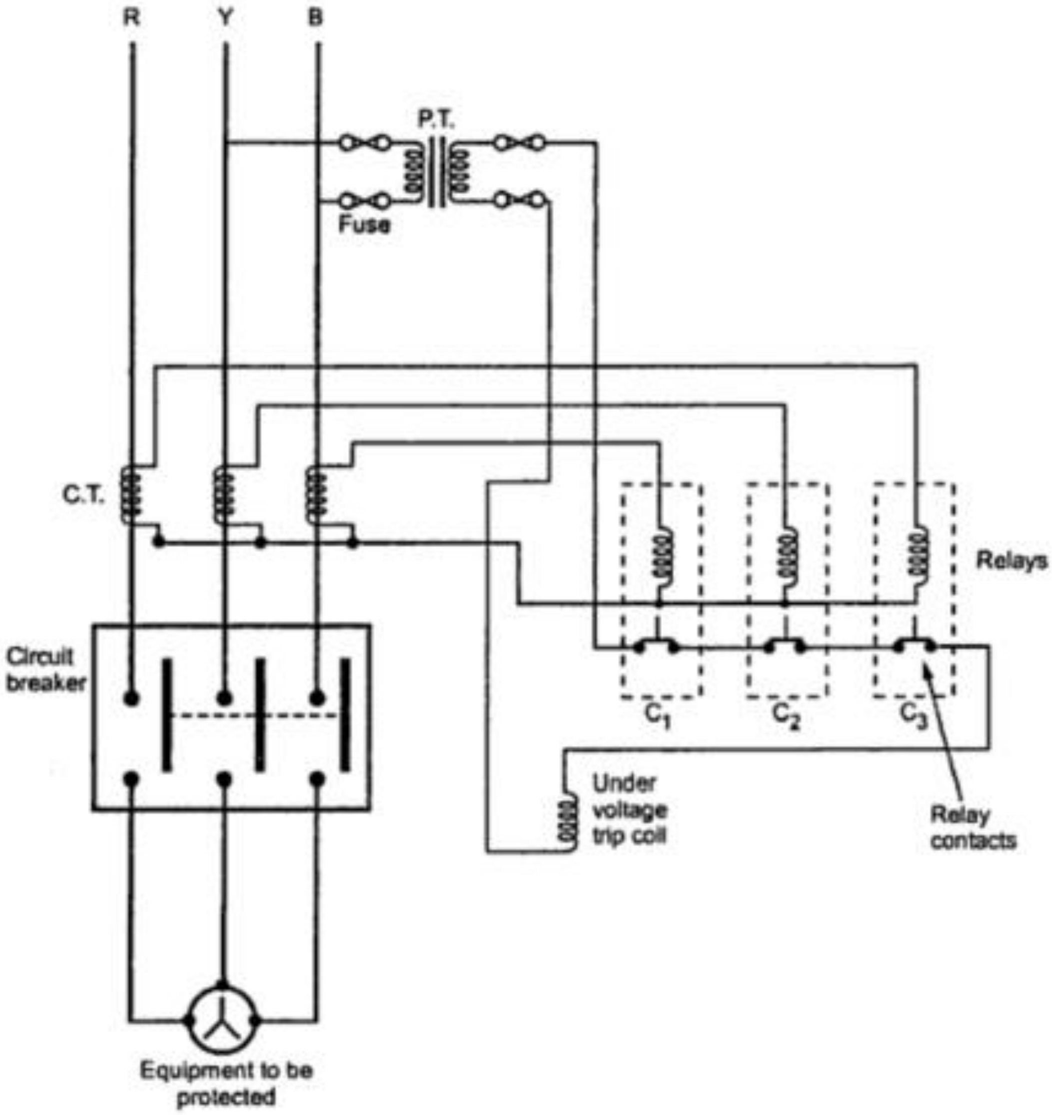


Fig.1.7 Relay with break type contact (using P.T.)

Operation: In this type, in addition to normal trip coils of circuit breaker, an additional under voltage trip coil is used. All the relay contacts are in series with the under voltage trip coil. Through potential transformer, for normal voltage, the under voltage trip coil is kept energized. When the voltage becomes less than the normal value, the magnetic effect produced by under voltage trip coil reduced which is responsible for the opening of the circuit breaker. When fault occurs, the normal trip coils of circuit breaker come into the picture and are responsible for the opening of the circuit breaker.

In both the above types of tripping circuit (using C.T. Or P.T.), relay contacts 'break' to cause the circuit breaker operation hence the relay is called break type contact relay.

STANDARD RATINGS OF CIRCUIT BREAKERS AND THEIR SELECTION

The ratings of a circuit breaker denote its capabilities under specified condition of use and behavior. The following paragraphs are generally based on the recommendation of IEC-56: "High Voltage Alternating Current Circuit-Breakers" and IS-2516: "Specifications of Alternating current circuit-breaker".

The capabilities of a circuit breaker of a particular type are proved by conducting type tests as per the recommendations of the standards.

The characteristics of a Circuit Breaker including its operating devices and auxiliary equipment that are used to determine the rating are:

(a) Rated characteristics to be given for all Circuit Breakers.

1. Rated voltage.
2. Rated insulation level.
3. Rated frequency.
4. rated current.
5. Rated short Circuit breaking current.
6. Rated transient recovery voltage for terminal faults.
7. Rated short circuit making current.
8. Rated operating sequence.
9. Rated short time current.

1. <u>Rated Voltage</u>

The rated voltage of a circuit-breaker corresponds to the higher system voltage for which the circuit breaker is intended. The standards values of rated voltages are given in table 3. The rated voltage is expressed in KV_{rms} and refers to phase to phase voltage for three-phase circuit. The earlier practice of specifying the rated voltage of a circuit breaker as nominal system voltage is no more followed.

Table 3: Rated Voltage of Circuit Breaker

Nominal System Voltage (KV_{rms})	Rated Voltage of Circuit Breaker (KV_{rms})
0.240	0.246
0.415	0.440
3.300	3.600
6.600	7.200
11.000	12.000
22.000	24.000
33.000	36.000
66.000	72.000
132.000	145.000
220.000	245.000
400.000	420.000
500.000	525.000
750.000	765.000

2. **Rated Insulation Level**

The rated insulation level of a circuit breaker refers to the power frequency withstand voltage and impulse voltage withstand values which characterize the insulation of the circuit breaker.

Power-frequency over voltages are due to regulation, ferranti effect, higher tap-setting, etc. The circuit breaker should be capable of withstanding the power frequency over-voltages which are likely to occur. These capabilities are verified by conducting power frequency voltage withstand tests and impulse voltage withstand tests. The circuit breaker is subjected to impulse over-voltage due causes like lighting surge and switching surge.

During single-line to ground faults, the voltage of healthy lines to earth increases to $\sqrt{3}$ time the normal value in the system with insulated neutral. Hence higher values of insulation are recommended for circuit breaker connected in noneffectively earthed systems. The following insulations are provided in the circuit breaker:

- Insulation between live parts and earth for each pole external and internal.
- Insulation between poles.
- Insulation between terminals of the same pole-external and internal

The design of these insulations depends upon the structural form of the circuit breaker and the rated insulation level desired.

3. **Rated Frequency**

The standard frequency for a three pole circuit breaker is the frequency of the power system (50/60 HZ). The characteristics like normal current breaking capacity etc. are based on the rated frequency.

The frequency of the current influences the circuit breaker behavior as follows:

- The temperature rise of current carrying parts and neighboring metallic parts is influenced by eddy-current heating . The increase in frequency results in increased eddy currents. Hence, with specified limits of the temperature rise the rated current of a circuit breaker needs de-rating for application on higher frequency.
- The frequency corresponds to the number of current-zeros per second. Since the breaking time of the circuit breaker is associated with the time for half cycles during the arc extinguishing process, the breaking time is influenced by the frequency of current. The breaking time increases with reducing in frequency.
- The increase in frequency influences the TRV and rate-of-rise TRV. Hence a circuit breaker designed and rated for a certain frequency cannot be recommended for other frequencies unless capabilities are proved for those frequencies.
- The d.c. circuit breakers generally adopt a different principle of arc extinction and have different construction than a.c. circuit breaker

4. **Rated Normal Current (Rated Current)**

The rated normal current of a circuit breaker is the r.m.s value of the current which the circuit breaker can carry continuously and with temperature rise of the various parts within specified limits. Preferred values of rated current in A_{rms} are 400, 630, 800, 1250, 1600, 2000, 2500, 3150, and 4000.

The design of contacts and other current carrying parts in the interrupter of the circuit breaker are generally based on the limits of the temperature rise. For a given cross-section of the conductor and a certain value of current, the temperature rise depends upon the conductivity of the material. Hence, high conductivity material is preferred for current carrying parts. The cross-section of the conductors should be increased for materials with lower conductivity. The use of magnetic materials in close circuits should be avoided to prevent heating due to hysteresis loss and eddy currents. The rated current of a circuit breaker is verified by conducting temperature rise tests.

The rated short circuit breaking current of a circuit breaker is the highest rms value of short circuit current which the circuit breaker is capable of breaking under specified conditions of transient recovery voltage and power frequency voltage. It is expressed in KArms at contact separation.

5. <u>Rated Short Circuit Breaker Current</u>

Referring to Fig. below (Oscillogram of Current and Voltage during fault clearing), the short circuit current has a certain value at the instant of contact separation, (t = T_{1}). The breaking current refers to value of current at the instant of the contact separation.

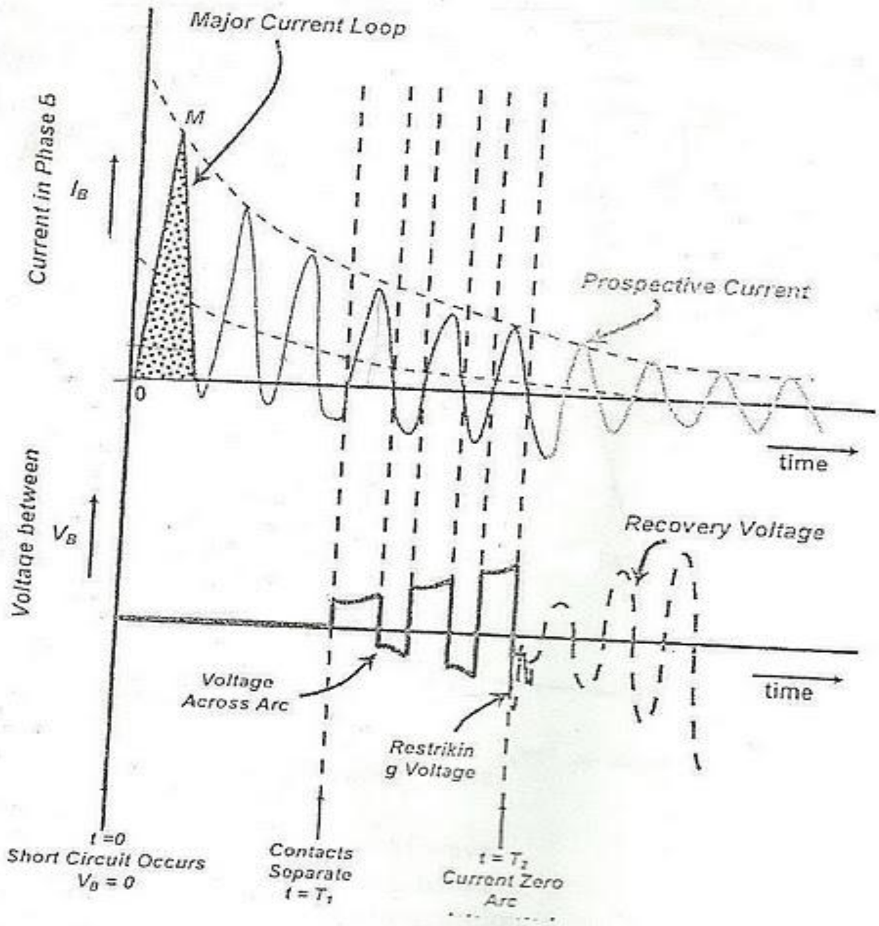


Fig.1.8 Oscillogram of Current and Voltage during fault clearing

The transient recovery voltage refers to the transient voltage appearing across the circuit breaker pole immediately after the arc interruption.
The rated values of transient recovery voltage are specified for various rated voltage of circuit breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit breaker has a certain limit of breaking current. This limit is determined by conducting short circuit type tests on the circuit breaker. The waveforms of short circuit current are obtained during the breaking test.
The evaluation of the breaking current is explained in Fig. below (Dimension of breaking current). The breaking current is expressed by two values:

1. The r.m.s value of a.c. component at the instant of contact separation EE, given by

$$I_{DC}/\sqrt{2}$$

2. The percentage d.c. component at the instant of contact separation given by

$$I_{DC}X100/I_{AC}$$

The r.m.s values of a.c. components are expressed in KA. The standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100KA.
The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows:
MVA = √3 x KV x KA
Where MVA = Breaking capacity of a circuit breaker kV, kV = Rated voltage, kA = Rated breaking current

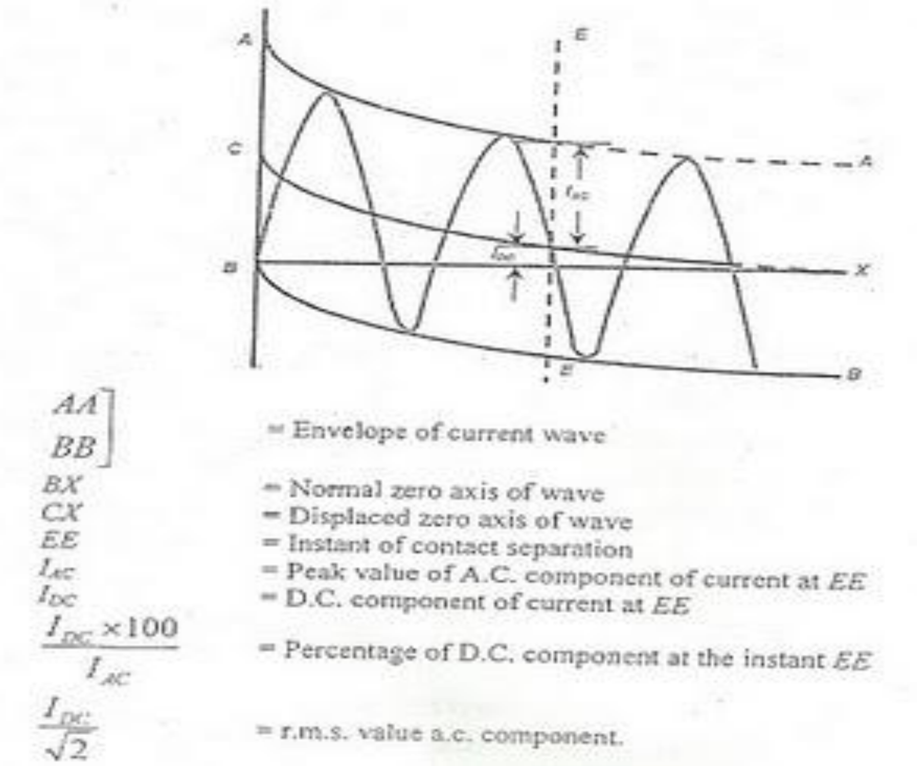


Fig.1.9 Dimension of breaking current

This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards, the breaking capacity is expressed in KA for specified conditions of TRV and this method takes into account both breaking current and TRV.

While selecting the circuit breaker for a particular location in the power system the fault level at that location is determined. The rated breaking current can then be selected from standard range.

6. **Rated Short Circuit Making Current**

It may so happen that circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit breaker should be able to close without hesitation as contact touch. The circuit breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current (I_{max})Which the circuit breaker is capable of making at its rated voltage.

The rated short circuit making current should be at least 2.5 times the r.m.s. value of a.c. component of rated breaking current.

Rated making current = 1.8 x √2 x Rated short circuit breaking current

= 2.5 x Rated short circuit breaking current

In the above equation the factor √2 convert the r.m.s value to peak value. Factor 1.8 takes into account the doubling effect of short circuit current with consideration to slight drop in current during the first quarter cycle.

7. **Circuit Breaker Time (total break time)**

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 voltage transmission lines improves the power system stability. Hence, faster relying and fast circuit breaker are preferred for extra high voltage transmission lines, where the circuit breaker time being in order of 2.5 cycles.

For distribution system, such a fast clearing is not necessary. Discrimination is obtained by "graded time lag. Hence, slower circuit breaker, 3 to 5 cycles, are used. Total breaking time varies between 80-120 ms for circuit breaker up to 12KV and 40-80 ms for circuit breaker above 36KV. It is less than 60 ms for 145KV, less than 50 ms for a 420 kV circuit breaker.

Remember the following time events:

- Fault clearing time = relay time + circuit breaker time
- Relay time = instant of fault **to** closure of trip circuit
- Circuit breaker time = opening time + arcing time

(b) Rated characteristics to be given in the Specific cases given below:

1. Rated characteristics for short line faults for three pole Circuit Breakers rated at 72.5 kV and above, more than 12.5 kA rated short circuit breaking current and designed for direct connection to overhead transmission lines.

2. Rated line charging breaking current, for three pole Circuit Breakers rated at 72.5 kV and above and intended for switching over- head transmission lines.
3. Rated supply voltage of closing and opening devices, where applicable.
4. Rated supply frequency of closing and opening devices, where applicable.
5. Rated pressure of compressed gas supply for operation and Interruption, where applicable.

(c) Optional rated characteristics:

1. Rated out of phase breaking current.
2. Rated line charging breaking current, for three pole Circuit Breakers rated at less than 72.5 kV and for single pole Circuit Breakers.
3. Rated cable charging breaking current.
4. Rated single capacitor bank breaking current.
5. Rated small inductive breaking current.
6. Rated supply voltage of auxiliary circuits.
7. Rated supply frequency of auxiliary circuits